



Paleontological Resource Inventory and Monitoring *Southeast Coast Network*

Natural Resource Technical Report NPS/NRPC/NRTR—2009/197



ON THE COVER

An assortment of photos from the SECN.

Upper Left: Tabby construction, incorporating shells from local shell middens, at Fort Frederica National Monument. National Park Service Photo. Lower Left: Walrus skull from Salvo, Cape Hatteras National Seashore. Photo by Doug Stover (CAHA cultural resource manager). Right: Column composed of Pleistocene-age Anastasia Formation shell coquina at Castillo de San Marcos National Monument. National Park Service Historic Photograph Collection.

For more information, refer to the parks' sections.

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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.

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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 at least 208 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 Southeast Coast 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. Similar summaries have already been prepared for 22 other NPS Inventory and Monitoring Networks. The National Inventory and Monitoring Program provided funding to complete these paleontological resource summaries for each of the remaining networks.

In general, the paleontological resources known from the parks of the Southeast Coast Network are of late Cenozoic age. Canaveral National Seashore (CANA), Cape Hatteras National Seashore (CAHA), and Cape Lookout National Seashore (CALO) have produced a variety of marine invertebrates from the Pleistocene and Holocene, mostly mollusks; CANA and CAHA also have mammal fossils, either from the park itself (CAHA) or the immediate vicinity (CANA). Castillo de San Marcos National Monument (CASA) and Fort Matanzas National Monument (FOMA) include historic forts built from deposits of semi-consolidated Pleistocene shells. Deposits from the last few tens of thousands of years in the floodplain at Congaree National Park (CONG) have been used to detail its past climate. Cumberland Island National Seashore (CUIS) is a well-known location for fossil shark teeth collecting, and has a variety of other fossil resources, including microfossils and marine invertebrates. Tabby construction at CUIS, Fort Frederica, and Timucuan Ecological and Historic Preserve (TIMU) may have incorporated paleontological resources and artifacts from prehistoric shell middens. Microfossils have been recovered from below the surface at Fort Pulaski National Monument (FOPU) and Fort Sumter National Monument (FOSU). Fossiliferous rocks may have been used as building or riprap material at Moores Creek National Battlefield (MOCR). Ocmulgee National Monument (OCMU) has several items of paleontological interest associated with cultural resources. Finally, park museum collections, mostly repositied at the Southeast Archeological Center (SEAC), include fossil resources from CAHA, CANA, CASA, CUIS, FOFR, FOMA, FOSU, OCMU, and Fort Raleigh National Memorial (FORA), the latter not included in the SECN but of interest because of its physical proximity and geological similarity to CAHA. To date, the best known of these finds are skulls of a musk ox and walrus from CAHA, the shell construction at CASA, the paleoclimate indicators of CONG, the shark teeth and marine invertebrates of CUIS, and the specimens associated with the cultural resources at OCMU.

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Dedication

We dedicate the Southeast Coast Network Paleontological Resource Inventory and Monitoring report to David Vela, Southeast Regional Director, for his tremendous support and leadership associated with the management, protection, and interpretation of National Park Service resources.

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 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.

The establishment of baseline paleontological resource data is essential for the appropriate management of fossils found within National Park Service (NPS) areas. Although at least 208 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 Southeast Coast I&M Network (SECN).

The Southeast Coast Network includes twenty National Park Service areas as shown in Figure 1, five in eastern North Carolina, three in central and eastern South Carolina, six in Georgia, one in eastern Alabama, and four in Florida: Canaveral National Seashore (CANA), Cape Hatteras National Seashore (CAHA), Cape Lookout National Seashore (CALO), Castillo de San Marcos National Monument (CASA), Charles Pinckney National Historic Site (CHPI), Chattahoochee River National Recreation Area (CHAT), Congaree National Park (CONG), Cumberland Island National Seashore (CUIS), Fort Caroline National Memorial (FOCA), Fort Frederica National Monument (FOFR), Fort Matanzas National Monument (FOMA), Fort Pulaski National Monument (FOPU), Fort Raleigh National Historic Site (FORA), Fort Sumter National Monument (FOSU), Horseshoe Bend National Military Park (HOBE), Kennesaw Mountain National Battlefield Park (KEMO), Moores Creek National Battlefield (MOCR), Ocmulgee National Monument (OCMU), Timucuan Ecological and Historic Preserve (TIMU), and Wright Brothers National Memorial (WRBR). Seventeen of these are identified as having significant natural resources; the other three (CHPI, FORA, and WRBR) are briefly described in this report due to their proximity and geologic similarity to neighboring parks that are part of the network. Additionally, FOCA and TIMU are managed cooperatively.

The Southeast Coast Network parks covered in this report vary in size from 8 ha (20 acres) (CASA) to nearly 23,500 ha (58,000 acres) (CANA), and protect resources ranging from human prehistory, to military sites dating from the late 16th century to the Civil War, to ecological settings including barrier islands, coastal wetlands, rivers, and bottomland hardwood forests. There are six dominant ecosystem types in the SECN: upland forests; bottomland hardwoods; rivers and streams; salt marshes and coastal wetlands; estuaries and nearshore marine systems; and barrier islands. The Southeast Coast has a diverse biota; among vertebrates, for example, about 485 fish species, 130 amphibian species, 181 reptile species, 232 native and at least 17 introduced bird species, and 96 species of mammals are known from the area.

SECN parks are found across an area that includes two distinct physiographic provinces: the Piedmont in the west, and the Atlantic Coastal Plain in the east. The Piedmont, made up of relatively low, rolling hills, transitions to the Coastal Plain at the Fall Line. The two provinces have distinct geologic compositions. The Piedmont is composed of hard crystalline rocks (metamorphic rocks and igneous rocks) heavily altered by tectonics and associated mountain building events, while the Coastal Plain has at its surface a wedge of sedimentary rocks and unconsolidated deposits dating from the Mesozoic to the present, becoming thicker toward the Atlantic. The Atlantic Ocean borders the SECN on the east. On the southwest, the SECN transitions to a more Gulf Coast-influenced setting represented by the Gulf Coast Network. In Georgia, the SECN borders the Appalachian Mountains, and to the north, in the Carolinas, much of the Piedmont is included in the Cumberland-Piedmont Network. North Carolina represents a

biological transition as well. For example, marine invertebrate faunas north of Cape Hatteras are notably different from those south of this landmark.

The geology of the Southeast Coast Network (discussed in detail in the appropriate park chapters) records a long period of continental assembly and rock deformation, followed by rifting and then relative quiet. Geological investigations in the network have had to overcome limited outcrops, as vegetation covers a great deal of the surface. The shoreline locations of many of the SECN parks means that the period of time best represented is the Quaternary, and these sites are excellent locations for studying the effects of climate change over the last million years (see Figure 2 for a geologic time scale). Parks near the inner edge of the Coastal Plain like CONG and OCMU have much older sedimentary deposits, from the Cretaceous, Paleocene, and Eocene. Finally, the Piedmont parks (CHAT, HOBE, and KEMO) record various periods in the formation of the supercontinent Pangaea during the Paleozoic. Aside from the subsequent breakup of the supercontinent, and sedimentary deposition from the middle Cenozoic, the suite of rocks and deposits found at or just below the surface of SECN parks cover the major events of the last few hundred million years of the SECN.

Much of the SECN was not part of North America before the Paleozoic. Starting before 460 Ma (million years ago), during the Ordovician, landmasses began to collide with the east coast of North America, carried to collision by the progressive destruction of interposed oceanic crust. Under the plate tectonics model, oceanic crust, being denser than continental crust, will go beneath continental crust when the two types of crust collide, in a process called subduction. Microcontinents, island arcs, and seamounts are less dense than the descending oceanic crust and are added to the overriding continental plate, along with slivers of oceanic crust. The southeastern United States, east of the Appalachian Mountains, shows evidence of several such added terranes. The timing of collisions is reflected in mountain-building events, also called orogenies. During orogenies, rocks are folded, faulted, and metamorphosed, and molten material may be emplaced and solidified at or near the surface as igneous rocks.

Three major orogenies occurred in the SECN as Pangaea formed. The first, the Taconic Orogeny, happened during the Ordovician (approximately 460 to 420 Ma), as an island arc collided with the East Coast. Rocks from this time can be seen at CHAT, HOBE, and KEMO. The second, the Acadian Orogeny, occurred during the Late Silurian and Early Devonian as the Carolina Terrane ran into the North American continent, approximately 360 Ma. The western border of the Carolina Terrane is about 24 km (15 miles) northwest of OCMU and runs northeast through the Carolinas. Finally, the Alleghenian Orogeny, of the Pennsylvanian, records the collision of North America and other northern continents with a conglomeration known as Gondwana, which included the modern Southern Hemisphere continents, India, and part of the Middle East. This collision produced the supercontinent Pangaea. In the SECN, this collision was mostly with Africa, with South America to the southwest. When North America separated from Africa and South America during the Late Triassic and Jurassic, the Suwannee Terrane, a small landmass that had been part of Gondwana, had become part of North America. The Suwannee Terrane underlies Florida and parts of Georgia and Alabama.

When Pangaea began to break up, narrow rift valleys were formed, some of which became part of today's Atlantic Ocean. Other valleys are buried deep in the subsurface of the East Coast. Basalt, a type of igneous rock, from the Charleston area near FOSU shows that valley formation was active at least 184 Ma, in the Early Jurassic. By the Middle Jurassic, North America had rifted far enough away from Africa and South America for narrow seas to form. The east coast of North America was transformed into a passive continental margin, without offshore subduction. Because of this, tectonic activity like volcanism and earthquakes has been uncommon in the SECN for over a hundred and fifty million years. Earthquakes and faulting do happen occasionally, as demonstrated by the 1886 Charleston earthquake.

Jurassic and Lower Cretaceous events are not well known in the SECN, due to the relevant rocks being deeply buried. By the Upper Cretaceous, the Coastal Plain had become a long-term environment of deposition, varying in setting from marine to terrestrial depending on sea level. A few large-scale tectonic features developed from the Cretaceous onward, such as the Cape Fear Arch. This upwarped feature has

risen in spurts since the Cretaceous. Because of the way the Coastal Plain slopes to the shoreline, sedimentary rocks go from older to younger away from the Fall Line. Older rocks also appear closer to the surface near tectonic highs like the Cape Fear Arch, which is why Cretaceous rocks are exposed near MOCR, a park relatively near the coast. Cenozoic marine invertebrates are well-represented on the Coastal Plain. Common fossils include sponges, corals, bryozoans ("moss animals"), gastropods (snails), bivalves, ostracodes (tiny shell-dwelling crustaceans), barnacles, echinoids (sand dollars), and trace fossils representing polychaete worm tubes and crustacean burrows. Microfossils such as the hard coverings of single-celled organisms like foraminifera, radiolarians (both amoeba-like), and diatoms (algae), and cysts of dinoflagellates, along with tiny algal plates classified as calcareous nannofossils, are also common. Vertebrate remains are less common, although shark and ray teeth are well-known. Distance from shore can be interpreted in a general way from the makeup of a given coastal deposit: coarse material, like sand, is deposited close to shore, while finer particles like clay are deposited farther out, and settings even farther out are represented by carbonates like limestone, formed from the skeletons of marine microorganisms.

The Upper Cretaceous and Cenozoic sedimentary rocks and deposits of the SECN have had many designations and age assignments over the years, and some periods of time were represented with more deposition than others. Upper Cretaceous deposits, from 100 to 65 Ma, include coastal marine and shallow marine settings, and in the SECN are best known from CONG and OCMU. Paleocene units (65-56 Ma) are less common in SECN parks, exposed only near CONG, and are more terrestrial where found, indicating temporarily lower sea levels. Eocene deposits (56 to 34 Ma) run from thick limestones in Florida, to shallow marine clays and sands in Georgia and South Carolina, to mixed sand/limestone units in North Carolina. These units are also best known at CONG and OCMU. Oligocene sedimentary units (34-23 Ma) are not represented at the surface or in the immediate subsurface of most SECN parks, but FOSU has beneath it the Ashley Formation, a heavily fossiliferous marine sand noted for its fossils of early marine mammals. Miocene deposits (23-5.3 Ma), particularly of the Hawthorn Group and its many included formations, underlie several SECN parks at shallow depths (less than 30 m or 100 ft); parks with such formations under them at shallow depths include CANA, CASA, CUIS, FOCA, FOFR, FOMA, FOPU, FOSU, and TIMU. The most common Hawthorn Group unit under these parks is the Coosawhatchie Formation, a Middle Miocene (approximately 14 to 12 Ma) formation of mixed composition, from shallow marine settings. Pliocene marine deposition (5.3-1.8 Ma) is known from nearly all of the coastal SECN parks, with Pliocene fossils reported from CUIS, FOPU, and CALO.

By and large, though, the bulk of surface deposits at most of the parks derive from marine (CAHA, CALO, CANA, CASA, CUIS, FOCA, FOFR, FOMA, FOPU, FOSU, MOCR, and TIMU) or river (CONG, OCMU) deposition during the Pleistocene and Holocene (1.8 Ma to the present). Naming the units involved has been very complicated, in part because marine terrace names have become mixed with stratigraphic names, and different researchers have had very different definitions for the same names. Marine terraces are a common feature of the Coastal Plain, recording past shorelines from times when sea level was higher than the present. Because of how the terraces are formed, they necessarily become lower and younger toward the coast. At several points in time, sea level was much lower than at present as well, due to great volumes of water becoming trapped in continental ice sheets at the poles during the Ice Age. These sea level fluctuations sculpted the modern coastline and are responsible for forming and reworking the barrier islands. Humans appeared in the SECN by 10,000 years ago, but their earliest activities are not well-represented in SECN parks; they were probably farther east, along coastlines later drowned by rising sea levels. The past few thousand years, however, are well-represented, with numerous archeological sites at CALO, CANA, CHAT, CUIS, FOFR, FOMA, OCMU, and TIMU. One particular type of human trace that is well-known in the SECN is shell middens, piles of shells left by humans. Some shells went on to be incorporated in a second human-resource interaction when Europeans began mining the shell middens for shells to use in tabby, a shell concrete. Humans also used shell limestones known as coquina to build forts in Florida (CASA and FOMA).

Collectively, the paleontological resources of the SECN 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 208 parks have already been identified as containing paleontological resources, much of what is to be known about the history of life on earth remains to be discovered.



Figure 1. Map of SECN network parks. Charles Pinckney National Historic Site, Fort Raleigh National Historic Site, and Wright Brothers National Memorial are briefly described in this report with neighboring parks. Map courtesy SECN staff

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) outlined 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 (in review February 2009), 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. As of February 2009, network-based inventories have been completed for 23 of the 32 I&M Networks including: the Appalachian Highlands, Chihuahuan Desert, Eastern Rivers and Mountains, Great Lakes, Greater Yellowstone, Gulf Coast, Heartland, Mediterranean Coast, Mid-Atlantic, Mojave Desert, National Capital Region, Northeast Coastal and Barrier, Northern Colorado Plateau, Pacific Island, Rocky Mountain, San Francisco Bay Area, Sierra Nevada, Sonoran Desert, Southern Plains, Southeast Coast (this report), Southeastern Alaska, Southwestern Alaska, and Upper Columbia Basin networks. Research for summaries of the Arctic, Klamath, North Coast and Cascades, Northern Great Plains, South Florida/Caribbean, and Southern Colorado Plateau networks is currently underway. NPS I&M Program funding is targeted to complete paleontological resource summaries for the remaining networks by the end of FY2009. 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 2002-2006. 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 (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 (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 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, will 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.

Report Organization

Information from these various sources is compiled in to 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 data sets relative to the park’s paleontological resources is developed. These data sets include museum collections where fossils from the park are repositied 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 Figure 2). 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 200 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 one 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. For example, 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. Another legislative protection for paleontological resources is found in the NPS Omnibus Management Act of 1998. Section 207, with the following statement, “Information concerning the nature and specific location of . . . paleontological objects within the units of the National Park System. . . may be withheld from the public source. . .,” safeguards paleontological locality information from requests under the Freedom of Information Act.

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 & 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 Geologic Society of America is assembling a geologic resource monitoring manual that includes chapters on various geologic resources, including in situ paleontological resources, 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. Publication is expected by late 2009. Contact the Geologic Resources Division for more information or to obtain a copy of the report when it is available.

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 paving the way for future fossil discoveries in NPS areas.

Additional References and Websites of Interest

Website addresses are current as of 9 February 2009.

Elder, W. P., T. Nyborg, J. P. Kenworthy, and V. L. Santucci. 2008. Paleontological Resource Inventory and Monitoring—**San Francisco Bay Area Network**. Natural Resource Technical Report NPS/NRPC/NRTR—2008/078. National Park Service, Fort Collins, Colorado. TIC# D-20.

Hunt, R. K., J. P. Kenworthy, and V. L. Santucci. 2008a. Paleontological Resource Inventory and Monitoring—**Heartland Network**. Natural Resource Technical Report NPS/NRPC/NRTR—2008/132. National Park Service, Fort Collins, Colorado. TIC# D-66.

Hunt, R. K., J. P. Kenworthy, and V. L. Santucci. 2008b. Paleontological Resource Inventory and Monitoring—**Great Lakes Network**. Natural Resource Technical Report NPS/NRPC/NRTR—2008/120. National Park Service, Fort Collins, Colorado. TIC# D-65.

Hunt, R. K., V. L. Santucci and J. P. Kenworthy. 2006. A preliminary inventory of fossil fish from NPS units. Pages 63-69 *in* S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci,

editors.. America's Antiquities (Proceedings of the 7th Federal Fossil Conference). New Mexico Museum of Natural History & Science, Albuquerque, New Mexico. Bulletin 34.

- Hunt, R. K., V. L. Santucci and J. P. Kenworthy. 2007. Paleontological Resource Inventory and Monitoring—**Pacific Islands Network**. National Park Service TIC# D-24.
- Kenworthy, J. P. and V. L. Santucci. 2003. Paleontological Resource Inventory and Monitoring—**Southwestern Alaska Network**. National Park Service TIC# D-93.
- Kenworthy, J. P. and V. L. Santucci. 2003. Paleontological Resource Inventory and Monitoring—**Northeast Coastal and Barrier Network**. National Park Service TIC# D-340.
- Kenworthy, J. P. and V. L. Santucci. 2004. Paleontological Resource Inventory and Monitoring—**National Capital Region**. National Park Service TIC# D-289.
- Kenworthy, J. P. and V. L. Santucci. 2006. A preliminary inventory of NPS paleontological resources found in cultural resource contexts, Part 1: General Overview. Pages 70-76 in S. G. Lucas, J. A. Spielmann, P. M. Hester, J. P. Kenworthy, and V. L. Santucci, editors. America's Antiquities (Proceedings of the 7th Federal Fossil Conference). New Mexico Museum of Natural History & Science, Albuquerque, New Mexico. Bulletin 34.
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- Koch, A. L. and V. L. Santucci. 2003. Paleontological Resource Inventory and Monitoring—**Greater Yellowstone Network**. National Park Service TIC# D-1025.
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- Santucci, V. L. and J. P. Kenworthy. 2007 Paleontological Resource Inventory and Monitoring—**Sierra Nevada Network**. Natural Resource Technical Report NPS/NRPC/NRTR—2007/053. National Park Service, Fort Collins, Colorado. TIC # D-21.
- Santucci, V. L. and J. P. Kenworthy. 2008 Paleontological Resource Inventory and Monitoring—**Southeast Alaska Network**. Natural Resource Technical Report NPS/NRPC/NRTR—2008/108. National Park Service, Fort Collins, Colorado. TIC# D-155.
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General SECN Information

SECN I&M Network: <http://science.nature.nps.gov/im/units/secn/>

Geological Survey Websites

Alabama Geological Survey: <http://www.gsa.state.al.us/>

Florida Geological Survey: <http://www.dep.state.fl.us/geology/>

Georgia Geological Survey (Environmental Protection Division, Georgia Department of Natural Resources): <http://www.gaepd.org/>

North Carolina Geological Survey: <http://www.geology.enr.state.nc.us/>

South Carolina Geological Survey: <http://www.dnr.sc.gov/geology/>

U.S. Geological Survey: <http://www.usgs.gov>

Geological Society of America: <http://www.geosociety.org>

American Geological Institute: <http://www.agiweb.org>

Library catalogs

U.S. Geological Survey Library Catalog: <http://library.usgs.gov/>

Smithsonian Institution Libraries Catalog: <http://www.siris.si.edu/>

Museums

Alabama Museum of Natural History: <http://www.ua.edu/academic/museums/history/index.html>
Florida Museum of Natural History: <http://www.flmnh.ufl.edu/>
Georgia Museum of Natural History: <http://dromus.nhm.uga.edu/>
North Carolina Museum of Natural Sciences: <http://www.naturalsciences.org/index.html>
Smithsonian National Museum of Natural History Dept. of Paleobiology: <http://paleobiology.si.edu/>
Southeast Archeological Center: <http://www.nps.gov/seac/>

Resource Management/Legislation Documents

NPS 2006 Management Policies (§1.4; Park Management):
http://www.nps.gov/policy/mp/policies.html#_Toc157232605
NPS 2006 Management Policies (§4.8.2.1; Paleontological Resources):
http://www.nps.gov/policy/mp/policies.html#_Toc157232741
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 (2000):
<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>
NPS Technical Information Center (Denver, repository for technical (TIC) documents):
<http://etic.nps.gov/>
NPS NatureBib (records of internal park literature):
<https://science1.nature.nps.gov/naturebib/nb/simple/clean>

Other geology/paleontology tools

Bates, R. L. and J. A. Jackson, editors. American Geological Institute dictionary of geological terms (3rd Edition). Bantam Doubleday Dell Publishing Group, New York.
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 Geologic Terms Glossary:
<http://wrgis.wr.usgs.gov/docs/parks/misc/glossarya.html>
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 now available online):
<http://pubs.usgs.gov>

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

Canaveral National Seashore

Canaveral National Seashore (CANA) preserves a 40 km (25 mile) section of undeveloped barrier islands. A variety of ecosystems are protected here, including beaches, dunes, marshes, and lagoons. CANA was established January 3, 1975. It encompasses 23,329.19 ha (57,647.69 acres), all but 6 ha (14 acres) of which are under Federal administration.

Geologic Background

CANA is located along the Atlantic coast of southeastern Volusia County and northeastern Brevard County, in eastern Florida. CANA is elongated north to south, with Mosquito Lagoon between the barrier island on the east and an isthmus of the mainland to the west. It shares its western border with Merritt Island National Wildlife Refuge, and its southern border with the John F. Kennedy Space Center. West of CANA is the Indian River. The Intracoastal Waterway winds through the northern two-thirds of Mosquito Lagoon and then crosses over to the Indian River through the artificial Haulover Canal. Cape Canaveral juts out into the Atlantic about 24 km (15 miles) southeast of CANA. CANA is about 32 km (20 miles) southeast of Daytona Beach. The geology of CANA is described in abstracts (Nelson et al. 2002; Parkinson and Schaub 2007) and a thesis (Vespucci 1974). The geology of nearby Cape Canaveral, Merritt Island, and the John F. Kennedy Space Center have been described in a number of publications (Hess 1964; Osmond et al. 1970; Brooks 1972; May 1972; Pirkle et al. 1972; Chaki 1974; Edward E. Clark Engineers-Scientists, Inc. 1985, 1987a, b, c; Stauble 1985; Grosz et al. 1989; Schmalzer and Hinkle 1990; Allen et al. 1996; Schmalzer et al. 2001) and theses (Martin 1976).

In general, the east coast of the United States, including the Cape Canaveral region, has had relatively little tectonic activity since the events surrounding the formation and subsequent rifting of the supercontinent Pangaea. In the area of the Southeast Coast Network, this activity involved the African and North American continents. The collision of these two continents was the culmination of a long series of events, with multiple deformations recorded in the Appalachian Mountains. North America and Africa rifted apart during the Late Triassic and Jurassic, and are still moving apart today (see Figure 2 for a geologic time scale).

The land beneath the Cape Canaveral area has only been part of North America since Pangaea rifted apart. What is now the east coast of North America was assembled from small landmasses that collided with the continent during the assembly of Pangaea during the Paleozoic (Hatcher 2001). The final portion that was added was the landmass that now underlies Florida and parts of southern Alabama and Georgia. This landmass, called the Suwannee Terrane, had been part of the much larger landmass known as Gondwana, which included most of today's southern continents and India. The Suwannee Terrane had been attached to Gondwana near the northern junction of South America and Africa, but was incorporated into North America during the breakup of Pangaea (Scotese et al. 1979; Horton et al. 1989). Sedimentary rocks of the Suwannee Terrane, deposited in the hundred million years before the North American-African collision, resemble those of similar age in Guinea and Senegal of western Africa (Horton et al. 1989). Rifting occurred from the Late Triassic to the Middle Jurassic, creating basins by faulting (Gottfried et al. 1977; Gohn et al. 1983), and promoting basalt flows (Gottfried et al. 1983). During the time following the rifting, there has been deposition of sedimentary rocks in environments varying from open marine to coastal plain settings in northeastern Florida, depending on sea level. Rocks older than the Cenozoic are deeply buried in the area around CANA; Eocene limestone is present below 457 m (1,500 ft) at Kennedy Space Center (Schmalzer and Hinkle 1990), and the rocks are only as old as the Eocene at 488 m (1,600 ft) below sea level in Volusia County (Rutledge 1985).

The sediments of the Cape Canaveral area were laid down over a structural high known as the Brevard Platform (Lane 1994). The modern, relatively narrow shelf offshore from Georgia and northern Florida was formed during the Eocene. There had been a broader shelf before, including what is now the Blake Plateau, but the plateau submerged after the Middle Cretaceous (Dillon et al. 1978). Florida was generally

under water in the Paleogene, with a shallow-water setting like the present-day Bahama Banks. These conditions led to thick fossiliferous limestone deposits. Rock fragments are uncommon in these deposits because the sources (the Appalachian Mountains) were distant and a powerful current running in the Gulf Trough, in the vicinity of the Florida-Georgia border, swept away what was delivered to the area. Near the end of the Paleogene, the Appalachian Mountains were uplifted and shed enough material to fill in the trough. Combined with falling sea levels beginning in the Late Oligocene, more and more of the state was above sea level for longer and longer periods. Terrestrial exposure and deposition moved from north to south (Lane 1994).

The location of Cape Canaveral is thought to be related to a pre-existing feature. Underneath the area is an Eocene limestone plateau (Schmalzer et al. 2001). Oligocene and lower Miocene formations are not present in the Cape Canaveral region, suggesting that the area may have been a structural high at the time, or that the deposits were eroded. If the area was a structural high, it may be related to structural movements to the west that resulted in the Ocala Uplift and Osceola Low at about that time (Stauble 1985). Long-dormant faults in the area affect the depth to Miocene-age claystone and the Eocene-age Ocala Limestone that forms the area bedrock (Hess 1964). Candidates for structural control on the locations of Cape Canaveral and Merritt Island include a fault trending southwest from False Cape (Hess 1964), the locations of the Sanford High in Volusia County and the Osceola Low to the west (Stauble 1985), and an Eocene limestone ridge of comparable shape to Cape Canaveral (Brown et al. 1962).

Whatever is responsible for controlling the location of Cape Canaveral aside, the area has probably been the setting of a cape for hundreds of thousands of years. To the west of Cape Canaveral, paralleling the shoreline, is a structure called the Orlando Ridge. Orlando Ridge has an extended feature similar to the shape of Cape Canaveral that may be a relict cape (Cape Orlando) from earlier in the Pleistocene (Stauble 1985). Additionally, Merritt Island has been interpreted as an abandoned Pleistocene cape (Schmalzer and Hinkle 1990; Hartl 2006). One interpretation of the history of the present Cape Canaveral is that it formed about 100,000 years ago, in the area of the present False Cape, developing by growth of barrier islands and offshore bars (Stauble 1985). Another is that the cape only formed about 7,000 years ago (Schmalzer et al. 2001), beyond the relict Merritt Island cape (Schmalzer and Hinkle 1990). It is agreed that Merritt Island is significantly older than the cape, at up to about 240,000 years old (Osmond et al. 1970; Stauble 1985; Schmalzer and Hinkle 1990). The Cape Canaveral barrier-lagoon system had two periods of deposition, one at about 110,000 years ago, and a less-extensive period at about 30,000 years ago. These periods of time may have been the only Pleistocene sea level highs in the area (Osmond et al. 1970). The outer barrier islands themselves are only about 8,000 to 7,000 years old (Osmond et al. 1970; Stauble 1985; Schmalzer et al. 2001).

An important feature of Atlantic Coastal Plain geology is the well-developed set of marine terraces, which document ancient shorelines. Over time, terraces formed progressively closer to the modern shore, in distance and elevation. There is a set of named terraces that are used in geologic descriptions. In Florida, from oldest to most recent, these include the Hazelhurst, Cohaire, Sunderland, Wicomico, Penholoway, Talbot, Pamlico, and Silver Bluff terraces (Healy 1975). These terraces were formed between the Pleistocene and the present in response to sea level fluctuations over a long period of marine regression (Colquhoun 1969; Richards et al. 1971). Talbot, Pamlico, and Silver Bluff marine terraces are present in or near CANA, and the Orlando Ridge to the west is a Sunderland feature (Stauble 1985). Terraces typically have a marine layer at the base with a thicker sequence of coastal terrestrial sediments above, such as beach sands, barrier island sands, estuarine or back-barrier sands and clays, and floodplain deposits left behind by receding shorelines (Thornberry-Ehrlich 2006). The terrace deposits are probably similar to those of Georgia's Coastal Plain, which include two major lithologies: linear sand ridges from old barrier islands, and clayey sand plains that represent back-barrier tidal lagoons or marshes (Radkte 1985). The respective heights of marine terraces above sea level near CANA are 0-3.1 m (0-10 ft; Silver Bluff), 1.8-7.6 m (6-25 ft; Pamlico), and 7.6-12.8 m (25-42 ft, Talbot) (Stauble 1985). The youngest of these terraces, the Silver Bluff terrace, is over 40,000 years old (Booth et al. 1999).

Chronologically interspersed with the terraces are marine lowstands, some with sea levels significantly lower than the present as water was taken up into ice sheets during major ice advances in the Pleistocene (“Ice Age”). During the last maximum ice advance, 25,000 years ago, sea level dropped to about 122 m (400 ft) below the modern level. It began to rise again about 11,000 years ago, and rose rapidly until about 5,000 years ago, after which it then slowly rose to its present level (Griffin 1982), with fluctuations. Local sea level reached a lowstand of 3.0 to 4.0 m (9.8 to 13.1 ft) below the present sea level between 3,100 and 2,400 years ago, and then rose rapidly, leading to extensive erosion (Howard and DePratter 1978).

The Cenozoic formations of Florida, particularly those from the Neogene and Quaternary, have complex histories, with different correlations, ages, and names proposed for the rock units. Geologic dating can be problematic for several reasons. For example, the dating of the Pliocene-Pleistocene boundary worldwide is a current topic of dispute. A particular issue is the choice of dating method: aminostratigraphy (using amino acid changes in fossils) may produce significantly different results from radioisotope dating methods (compare Belknap and Wehmiller [1982]’s aminostratigraphic dates to radioisotopes dates from McCartan et al. [1982a, b] for several Pliocene-Pleistocene units of the Atlantic Coastal Plain). The stratigraphy is further complicated by the use of marine terraces in the Atlantic Coastal Plain. Some of the terrace terms have also been used for formations. While this practice is now discouraged (Huddlestun 1988), it is something to watch for in older publications.

The surface geology of CANA is composed of deposits of the Anastasia Formation (Pleistocene), beach ridge and dune sediments (Pleistocene and Holocene), and Holocene sediments (Scott et al. 2001). Depositional settings of the units include beaches, swamps, dunes, and shallow marine (Scott et al. 1986). The general components of the upper subsurface are an upper sandy shell layer of Pleistocene to Holocene age, over Upper Miocene or Pliocene sand, clay, and shells, over Eocene Ocala Limestone. All of these units are known to produce fossils (Wyrick 1960; Brown et al. 1962; Planert and Aucott 1985; Rutledge 1985; Phelps 1990; Schmalzer and Hinkle 1990; Schmalzer et al. 2001). CANA fossil resources include deposits of fossil-rich Anastasia Formation coquina, fossil material now curated as museum specimens, and paleontological resources in association with cultural resources.

Sources of Paleontological Resources

The fossils of CANA present opportunities for education, interpretation, and continued or future scientific research in the park. Aside from the material described in this section, three fossils from CANA are stored at the Southeast Archeological Center (SEAC). These fossils are documented below, as part of the “Park Collections” section following “Potential Sources of Paleontological Resources.” There are also fossils found in cultural resource contexts within the park, as described following the “Park Collections” section.

Surficial Quaternary rocks and sediments (Pleistocene-Holocene)

Of the surficial deposits at CANA, only those deposits pertaining to the Anastasia Formation (see below) have consistently been assigned to a formation. The presence of Pamlico and Silver Bluff marine terraces indicates that the Satilla Formation nomenclature of Huddlestun (1988) would be applicable for at least some of the other sediments. The Satilla Formation is composed of shoreline complex deposits from the Pamlico, Princess Anne, Silver Bluff, and Holocene marine terraces, and includes clay-rich back-barrier deposits, sandy barrier island deposits, and shelly sands and clays from offshore continental coast settings. The four marine terraces formed at different times during the deposition of the Satilla Formation. The Satilla Formation is regarded as Late Pleistocene to Holocene in age (roughly 126,000 thousand years ago to the present). Typical fossils include burrows, foraminifera, bivalves and other mollusks (Huddlestun 1988; Pirkle et al. 2007), and vertebrates including fish, turtles, crocodilians, ground sloths, castorid rodents, tapirids, equids, deer, bovids, and proboscideans (Markewich et al. 1992). The term “Satilla Formation” was only brought into use in 1988, so most references use marine terrace names for identification of deposits, or do not assign the deposits to a formation.

A variety of fossils are known from undifferentiated surficial Quaternary deposits in the vicinity of CANA. There is an organic layer in the subsurface of Cape Canaveral and Merritt Island, about 2.5 m (8 ft) below the surface. This layer represents a Pleistocene salt marsh too old for radiocarbon dating (the limit of radiocarbon dating is about 45,000 years). Unaltered wood is present (Hess 1964). Invertebrate fossils are also present in the undifferentiated deposits of the area (Matson and Clapp 1909; Wyrick 1960; Brown et al. 1962; Planert and Aucott 1985; Rutledge 1985; Phelps 1990; Schmalzer and Hinkle 1990; Schmalzer et al. 2001). Beaches in the vicinity of CANA are known to produce shells ranging in age from the Pleistocene to the modern (Martens 1931, 1935; Scott et al. 1986). Crustacean burrows are known in other Pleistocene and Holocene coastal sediments, particularly those from high-energy littoral and shallow neritic settings (Weimer and Hoyt 1964), so may be present at CANA as well. Regarding vertebrates, fossils of a mastodon have been recovered from Merritt Island National Wildlife Refuge, about 91 m (300 ft) outside of CANA. The specimens include teeth and small bone fragments. These fossils were found before 2008 by a local resident and are kept at CANA because the Refuge does not have the facilities to store them. They are not cataloged because they came from outside the park (J. Stiner, CANA resource manager, pers. comm., September and October 2008).

More extensive fossils have been recovered from the Sams Creek fossil site in the Pine Island Conservation Area on Merritt Island, about 18.5 km (11.5 miles) south of CANA. Vertebrate fossils, including specimens of tortoises, glyptodonts, armadillos, equids, tapirs, peccaries, camelids, mastodons, and mammoths, along with shell tools, are known from this site, and a fossil bone pin has been recovered from an archeological site in the conservation area. Stratigraphic relationships are unknown, as the specimens came from spoil piles thought to have been dredged during the construction of the Sams Creek Canal, about 19 km (12 miles) south of CANA (Indian River Anthropological Society 2008).

The databases of the Florida Museum of Natural History record numerous Pleistocene-age specimens from Volusia and Brevard counties within about 65 km (40 miles) of CANA. Invertebrate finds mostly pertain to the Anastasia Formation, described below. Exceptions in Volusia County include annelid worm tubes, bryozoans, gastropods, bivalves, barnacles, and echinoderms at the Late Pleistocene-age Daytona Beach Bone Bed (or Daytona Bone Bed), about 32 km (20 miles) northwest of CANA. Exceptions in Brevard County include: coral, gastropods, bivalves, and echinoids collected 12-15 m (40-50 ft) below the surface at Lake Poinsett about 37 km (23 miles) southwest of CANA, possibly from the Upper Pliocene or Lower Pleistocene Nashua Formation; and Holocene silicoflagellate algae, stonewort algae, diatoms, foraminifera, gastropods, bivalves, crabs, and ostracodes from Salt Lake, about 8 km (5 miles) west of CANA (Florida Museum of Natural History 2008a).

Vertebrate sites date to the Late Pleistocene. In Volusia County, these sites include Lake Monroe, about 39 km (24 miles) west of CANA; Enterprise, on the north shore of Lake Monroe, about 40 km (25 miles) west of CANA; and the Daytona Beach Bone Bed, about 32 km (20 miles) northwest of CANA. Brevard County vertebrate sites include Merritt Island; Cocoa, about 32 km (20 miles) south of CANA; Melbourne, about 65 km (40 miles) south of CANA; and Melbourne Golf Course (Florida Museum of Natural History 2008b).

Lake Monroe vertebrates include anseriforms (ducks, geese, and swans), falconiforms (falcons, vultures, hawks, and eagles), galliforms (chickens, turkeys, and allies), gaviiformes (loons), gruiforms (cranes and allies), pelecaniforms (pelicans and allies), podicipediforms (grebes), and armadillos. Enterprise vertebrates include turtles, alligators, sloths, equids, deer, camelids, and mammoths. Daytona Beach Bone Bed vertebrates in the FLMNH database include fish, opossums, armadillos, glyptodonts, sloths, insectivorans, bats, bears, a variety of rodents (geomyids, sciurids, and cricetids), and lagomorphs (Florida Museum of Natural History 2008b). Also present are proboscideans, known from the Daytona area since early in the 20th century (Sellards 1916; Simpson 1929), and wood and herbaceous plants (Baldwin et al. 1980). A whale rib is also known from Daytona (Sellards 1916). The Daytona Beach Bone Bed is thought to have formed during the same period of time as the Silver Bluff terrace (Baldwin et al. 1980). Merritt Island vertebrates, excluding the mastodon remains kept at CANA, include turtles, bears, canids, felids, porcupines, equids, bovids, deer, and mammoths. Melbourne vertebrates in the FLMNH database

include turtles, alligators, glyptodonts, geomyid rodents, deer, and mastodonts (Florida Museum of Natural History 2008b). Other Melbourne taxa include bats and felids (Ray et al. 1963; Ray 1964). Melbourne Golf Course vertebrates include equids, peccaries, and mammoths. Cocoa vertebrates include felids (Florida Museum of Natural History 2008b). Sirenian rib fragments, while not as common as in Miocene and Pliocene deposits, are present in marine and river deposits of the Pleistocene (Simpson 1932).

Anastasia Formation (Upper Pleistocene)

The Anastasia Formation is a sandy coquina, exposed along the east coast of Florida from Anastasia Island to Palm Beach (Stauble and McNeill 1985). Coquina is a type of poorly-consolidated limestone made up of shell fragments (Kenworthy and Santucci 2006). In the Anastasia Formation, mollusk shells are common, from whole specimens to fragments to molds. Both gastropods and bivalves are present, with the donacid clam *Donax* dominant (Stauble and McNeill 1985). Donacid clams are colloquially known as coquina, and the geological term “coquina” is derived from this name (Kenworthy and Santucci 2006). Thus, the Anastasia Formation coquina is composed of the archetypical coquina clam (Kenworthy and Santucci 2006). Cape Canaveral is underlain by coquina (Kurz 1942), and the area of CANA west of Mosquito Lagoon and north of Merritt Island has exposures of the Anastasia Formation (Scott et al. 2001).

The Anastasia Formation is interpreted as very shallow marine, deposited in settings from beach foreshore zones to barrier bars. The major period of deposition is dated to about 110,000 years ago (Stauble and McNeill 1985), although some deposition may have been substantially younger, as young as about 7,000 years ago for dunes and barrier islands (Portell et al. 2002). Successions of cemented and uncemented beds in this formation may represent beachrock on prograding shorelines (Missimer and McNeill 1992). Aside from mollusks, Anastasia Formation fossils include foraminifera (Cole 1931), coral (Lovejoy 1998), ghost crabs and their burrows (Portell et al. 2002), echinoids (Oyen and Portell 2001), and vertebrates (Stauble and McNeill 1985; Lovejoy 1998). Vertebrates include cartilaginous fish, bony fish, frogs, salamanders, turtles, lizards, snakes, alligators, birds, armadillos, cricetid rodents, lagomorphs, camelids, deer, and gomphotheriid proboscideans (Florida Museum of Natural History 2008b), although this fauna was recovered over 112 km (70 miles) northwest of CANA, near St. Augustine and Castillo de San Marcos National Monument (CASA) (R. Hulbert, collections manager, Division of Vertebrate Paleontology, Florida Museum of Natural History, pers. comm., November 2008).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following formations within CANA, most of which would be found 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.

Mixed and undetermined formations (Upper Miocene to Pleistocene)

The underlying geology of Volusia and Brevard counties has been described in several publications (Wyrick 1960; Brown et al. 1962; Baldwin et al. 1980; Planert and Aucott 1985; Rutledge 1985; Kimrey 1990; Phelps 1990; Schmalzer and Hinkle 1990; Schmalzer et al. 2001). Because the sediments nearest to the surface are most likely to be sampled, the following discussion will be confined to the sediments from the surface to 30 m (100 ft) below the surface.

The general components of the upper subsurface in southeastern Volusia County and northwestern Brevard County are an upper sandy shell layer thought to be Pleistocene to Holocene in age, over Upper Miocene or Pliocene sand, clay, and shells, over Eocene Ocala Limestone. Some authors differentiate a layer pertaining to the Hawthorn Formation or Group between the Miocene-Pliocene sediments and Eocene limestone. Invertebrate fossils are known throughout the shallow subsurface (Wyrick 1960; Brown et al. 1962; Planert and Aucott 1985; Rutledge 1985; Phelps 1990; Schmalzer and Hinkle 1990;

Schmalzer et al. 2001). Schmalzer and Hinkle (1990) and Schmalzer et al. (2001) provide the descriptions closest to CANA.

Schmalzer and Hinkle (1990) found the upper subsurface of western CANA to consist of about 14 m (45 ft) of Pleistocene and Holocene deposits over about 20 m (65 ft) of Upper Miocene and Pliocene deposits. The Pleistocene and Holocene deposits are mostly fine to medium sands, with smaller amounts of sandy shell beds and sandy mollusk coquina. The Anastasia Formation is included in these upper deposits. The Upper Miocene and Pliocene deposits are made up of fine sand, marl, clay, silt, and shells, with about 1.5 m (5 ft) of thin limestone at the base in some locations, pertaining to the Tamiami Formation. The Upper Miocene and Pliocene deposits may be equivalent (in part) to the Caloosahatchee Formation. Schmalzer et al. (2001) found the subsurface geology of Kennedy Space Center and Merritt Island to include surficial deposits of Pleistocene and Holocene sand and coquina, over Upper Miocene or Pliocene sand, shells, and clay, over Miocene clay and phosphate deposits, over Eocene limestone.

For reference, the Tamiami Formation is a heterogeneous, poorly defined unit of Pliocene age. Fossils include calcareous nannofossils, foraminifera, corals, mollusks, barnacles, and echinoids, and are found as casts, molds, and original material (Scott 2001). The Caloosahatchee Formation is somewhat problematic; Scott (2001) noted that identification of this unit, and differentiating it from others of similar age in Florida, depends on recognition of specific mollusks. It is a lateral equivalent of the Nashua Formation in southwestern Florida, and it is debated as to where one formation ends and the other begins (R. Portell, collections manager, Division of Invertebrate Paleontology, Florida Museum of Natural History, pers. comm., January 2009). It dates to the Pliocene-Pleistocene, and is interpreted as a semitropical to tropical offshore continental shelf deposit, laid down under water at depths of 30 m (100 ft) and less. Mollusks are the predominant fossils, although foraminifera, corals, echinoids, and vertebrates including fish, turtles, crocodilians, armadillos, equids, camelids, and cetaceans are also known (DuBar 1958).

Other fossils that are known from Miocene or Pliocene deposits in the area include sirenian rib fragments, which are common in shallow-water and estuarine deposits from the Miocene (particularly the Hawthorn Group) and Pliocene in Florida (Simpson 1932).

Quaternary and older offshore deposits

There is also the potential for reworked offshore fossils to wash up on the beaches at CANA. The continental shelf outside of CANA is known to produce mollusk and barnacle fossils (Milliman et al. 1972). A variety of other fossils may also be present, including those of algae, foraminifera, corals, bryozoans, polychaete worm tubes, ostracodes, barnacles, and echinoids (Macintyre and Milliman 1970). The Canaveral nearshore system has an outer “bar” probably composed of Anastasia Formation coquina (Bauer and Allen 1995), so in addition to Anastasia Formation coquina exposed at CANA, fossils may wash up from this unit as well. Terrestrial remains such as peat and proboscidean teeth may also wash up, as the coast had been farther east at the last glacial maximum, leading to now-drowned offshore terrestrial deposits (Milliman et al. 1972). For example, the offshore shelf area of the cape is a submerged coastal plain (Stauble 1985).

Black staining of mollusks is one of the characteristics of Quaternary fossil mollusks, and may indicate deposition in low energy coastal swamps during a time of lower sea level (Milliman et al. 1972). Boring by other invertebrates (Pilkey et al. 1969), abrasion, and trace element composition can also be used to distinguish modern from fossil shells (Wehmiller et al. 2003). The more worn, damaged, and bored a specimen is, the older it probably is.

Park Collections

Aside from the uncataloged mastodon bones from the Merritt Island National Wildlife Refuge that are stored at CANA, there are three CANA fossil specimens repositied at the Southeast Archeological Center (SEAC). CANA 14817, a turtle bone, came from the Kars Park location. CANA 15056 is an otherwise

unidentified specimen from the Aerial Map J4 location. CANA 15088 is an otherwise unidentified specimen from the Haulover Canal Midden location (B. Carter, SEAC supervisory museum specialist, pers. comm., August 2008). Further identification of these specimens and their provenance is needed.

Fossils Found in Cultural Resource Contexts

CANA is archeologically rich, with multiple periods of human habitation. Because of this, fossils may be found associated with cultural resources, such as fossils altered or modified by humans. Remains of the biota that was contemporaneous with these archeological resources are also of paleontological interest. At least 129 sites of prehistoric cultural remains are known at CANA (Hellmann 2008), and the remains of shellfish, fish, reptiles, birds, and other animals may be found, as well as tools and other artifacts made of their remains (Ehrenhard 1976; Hellmann 2008). Notable sites include Seminole Rest, Turtle Mound, and Castle Windy. Seminole Rest is a shell midden that was in use from about 4,000 years ago to 500 years ago (Anderson 2006). Turtle Mound, the largest shell midden in the nation, has been used as a navigational landmark since the time of Spanish exploration. It currently extends over 183 m (600 ft) along the Indian River shoreline (Ste. Claire 1992) and is approximately 11 m (35 ft) tall (J. Stiner, pers. comm., December 2008), but was once over 23 m (75 ft) tall (Ste. Claire 1992). Shells from Turtle Mound have been dated to 690 CE $\pm$ 70 years (Hellmann 2008), in the St. Johns Period. Smaller Castle Windy extends for about 91 m (300 ft) along Mosquito Lagoon (Ste. Claire 1992). Castle Windy is from later in the St. Johns Period. Charcoal from several zones within Castle Windy has been dated and show it was in use over an extended period of time, from 840 $\pm$ 165 to 636 $\pm$ 132 calendar years ago (930 $\pm$ 100 to 630 $\pm$ 100 radiocarbon years before present (ybp); radiocarbon dates must be calibrated to yield calendar dates. These were calibrated using Calib 5.0.2 at <http://calib.qub.ac.uk/calib/> (Hellmann 2008). People from the St. Johns Period also made ceramics with sponge spicule paste (Hammersten 1988). In addition to archeological value, clams from shell middens are also utilized for stable isotope studies, which can help illustrate past climate (Jones et al. 2005). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

One notable site in the vicinity of CANA, about 18 km (11 miles) to the southwest, is Windover Pond, where human remains from the early Archaic Period have been preserved in a swampy, peat pond. In some cases, brain tissue was preserved, dating from 8,290 to 7,790 years ago (Doran et al. 1986). The remains of 168 people have been found at this burial site, along with artifacts, including some made from wood, bones, and antlers. Pollen has also been found at the site. Various samples dated from the site give a range of 8,120 $\pm$ 70 years ago to 6,990 $\pm$ 70 years ago (Richardson 1997). Another site, about 53 km (33 miles) south of CANA, in the vicinity of Melbourne, has bone artifacts. This burial site was dug into a lower stratigraphic layer that has produced sloth, horse, and mammoth fossils (Irwin 1975).

Other archeological sites in the region also have vertebrates. Fossils of the tortoise *Gopherus* are known from archeological sites, including: the Lake Monroe Outlet Midden (about 7,000 to 5,000 years old), 37 km (23 miles) east of CANA; Cotton (at least 2,500 years old), about 45 km (28 miles) north of CANA; Hontoon Island (about 1,950 years old), about 45 km (28 miles) northwest of CANA; and Tick Island (about 7,000 to 5,000 years old), about 53 km (33 miles) northeast of CANA (Franz and Quitmyer 2005).

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division has not yet conducted a geologic resource scoping session for CANA.
- Further identification of the CANA fossil specimens housed at SEAC is required.
- Southeast Coast Network parks such as CAHA, CALO, CANA, CASA, CUIS, FOCA, FOFR, FOMA, FOPU, FOSU, and TIMU are geologically very young, making it difficult to determine what material is a fossil and what would be considered modern. The National Park Service defines a fossil as any remains of life preserved in a geologic context. This definition does not include an arbitrary date where older specimens are considered fossils, and younger specimens

are not. The “geologic context” phrase is intended to imply some level of antiquity, however. Generally, specimens dating back to the late Pleistocene are considered fossils. Late Holocene (last few hundred or thousand years, “Recent”) specimens are usually considered modern and not fossils. Pleistocene remains may differ from younger remains by having dark staining and being heavily worn and bored, but this does not always hold true. Surface and subsurface specimens collected at CANA span this range between Pleistocene and Holocene. Regardless of what label is assigned to them, these specimens are important natural resources and valuable pieces of the history of life on earth.

- Some coastal park units in the NPS experience unauthorized casual collecting of fossils (beach-combing) from beach areas. This activity is not well documented in the SECN. Further investigation into casual collecting could lead to development of a park or regional policy related to such collecting.
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Southeast Archeology Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at CANA.

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Data Sets

Canaveral National Seashore Paleontological Archives

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

Canaveral National Seashore Museum Collections

1975–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by CANA staff; status: Active.

Southeast Archeological Center (SEAC)

1975–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by SEAC staff; status: Active.

Cape Hatteras National Seashore

Cape Hatteras National Seashore (CAHA) was established to protect a large portion of North Carolina's Outer Banks, a string of barrier islands. CAHA preserves a variety of natural and cultural resources. The seashore was authorized on August 17, 1937, and established January 12, 1953. CAHA encompasses 12,282.46 ha (30,350.65 acres), all but 2.93 ha (7.24 acres) of which are under Federal administration. The land area of CAHA is 10,653.85 ha (26,326.24 acres).

Fort Raleigh National Historic Site and Wright Brothers National Memorial

CAHA is one of three National Park units administered by the Outer Banks Group. The other two are: Fort Raleigh National Historic Site (FORA), designated April 5, 1941; and Wright Brothers National Memorial (WRBR), authorized March 2, 1927 (as Kill Devil Hill Monument). FORA was established to preserve remains of the first English settlements in the New World. It had boundary changes August 17, 1961 and November 16, 1990, and today protects 207.58 ha (512.93 acres), 143.85 ha (355.45 acres) of which are under Federal administration. FORA is located at the north end of Roanoke Island, about 10 km (6 miles) northwest of the north tip of CAHA. WRBR was established in recognition of the first sustained flight of a heavier-than-air machine, performed here by the Wright Brothers on December 17, 1903. WRBR was transferred from the War Department August 10, 1933, and redesignated and renamed December 5, 1953. Its boundaries were changed June 23, 1959, and it now encompasses 173.38 ha (428.44 acres), all but 2.68 ha (6.63 acres) of which are under Federal administration. WRBR is located about 13 km (8 miles) north of CAHA's north tip.

These two parks have essentially the same geology as CAHA, so anything in this section that is not specifically attributed to CAHA (such as fossil specimens) is also relevant to FORA and WRBR. Neither FORA nor WRBR are officially included in the Southeast Coast Network, but they are mentioned here due to their proximity and geologic similarity to CAHA.

Geologic Background

CAHA is located off the east coast of mainland North Carolina, including portions of several of the Outer Banks barrier islands in Dare and Hyde Counties. CAHA's section of barrier islands extends from Ocracoke Island in the south to Whalebone Junction on Bodie Island to the north, also incorporating Hatteras Island. Pea Island National Wildlife Refuge is located between sections of CAHA. As of 2008, CAHA is split by Hatteras Inlet and Oregon Inlet, although other inlets have been open in the past. Southwest of Ocracoke Island, on the opposite side of Ocracoke Inlet, is the portion of the barrier chain administered by the National Park Service as Cape Lookout National Seashore (CALO; see CALO section of this report). For most of its length, CAHA separates Pamlico Sound to the west from the Atlantic Ocean to the east. At its northern extreme, Roanoke Sound and Island are interposed to the west, with Albemarle Sound to the north.

CAHA, as a series of sandy barrier islands, lacks rock exposures, and was largely formed by processes operating only as far back as the Pleistocene (see Figure 2 for a geologic time scale). Despite this, its geology has been described in a number of publications, particularly in regards to environmental and climate changes during the Pleistocene and Holocene. CAHA's geology has been the subject of scientific publications and abstracts (Berryhill 1948; Kimrey 1960; Pierce and Colquhoun 1970; Dolan 1972; Byrum 1979; Byrum and Snyder 1979; Edelman 1982; Popenoe 1983; Barwick 1984; Bart et al. 2001; Riggs et al. 2002; Wehmiller and York 2002; Woolard and Colby 2002; Hoffman 2003; Pendleton et al. 2004; Ricardo et al. 2005; Farrell et al. 2007), theses (Brown 1919; Boyd 1971; Wright 1971; Edelman 1984; Twamley 2006), and internal National Park Service reports (Potter and Trager 1938; Dolan 1969; National Park Service Geologic Resources Division and Natural Resources Information Division 2000), not including publications devoted to nearby features or coastal geology over a wider area.

In general, the east coast of the United States has had relatively little tectonic activity since North America and Africa rifted apart during the Late Triassic and Jurassic, although there are occasional earthquakes (one caused slump deposits of 100 cubic kilometers in the Hatteras Abyssal Plain about 16,000 years ago [Elmore 2003]). Complex Paleozoic basements of metamorphic and igneous rocks are present 915 to 3,050 m (3,000 to 10,000 ft) below the surfaces of Albemarle and Pamlico sounds (Denison et al. 1967), recording a period of continental assembly. A relatively deep well at CAHA, the Hatteras Light Well No. 1, reached granite basement at a depth of 3,011 m (9,878 ft) (Berryhill 1948). Late Triassic and Jurassic basin deposits on land in North Carolina and Virginia formed in the early stages of the North American-African split (Olsen et al. 1978; Won et al. 1979); such rocks are deeply buried at CAHA. For example, at the Esso-Cape Hatteras Light well, 1,000 m (3,280 ft) of Cenozoic rocks and sediments and then 1,800 m (5,900 ft) of Cretaceous rocks overlie Jurassic rocks (Perry et al. 1975).

During the time following the Jurassic rifting, there has been deposition of sedimentary rocks in environments varying from open marine to coastal settings, depending on sea level. As with the Jurassic rocks, these rocks are largely buried in the CAHA area, although accessible through drilling. Extensive submergence of eastern North Carolina occurred during the Cretaceous, Paleocene, Eocene, late Miocene, and parts of the Pliocene and Pleistocene (Richards 1968; Carter et al. 1988). An important feature of Atlantic Coastal Plain geology is the well-developed set of marine terraces, which document ancient shorelines. Over time, terraces formed progressively closer to the modern shore, in distance and elevation. The Suffolk Scarp is one such relict shoreline (Wells and Kim 1989), and there is a set of named terraces that are used in geologic descriptions. From oldest to most recent, these include the Capitol, Hazelhurst, Cohaire, Sunderland, Okefenokee, Wicomico, Penholoway, Talbot, Pamlico, Princess Anne, Silver Bluff, and Recent terraces (Colquhoun and Johnson 1968; Colquhoun 1969). These terraces were formed between the Pleistocene and the present in response to sea level fluctuations over a long period of marine regression (Colquhoun 1969; Richards et al. 1971).

The underlying geomorphic setting that resulted in the development of Cape Hatteras appears to have been molded by processes related to shifts in the Gulf Stream's location since the Eocene (Popenoe 1983). It and the rest of the Outer Banks only took form as barrier islands less than five thousand years ago (Godfrey and Godfrey 1976), following the most recent cycle of sea-level fall and rise. At the end of the most recent glacial period, about 18,000 to 14,000 years ago, sea level was about 91 m (300 ft) lower than at present, putting North Carolina's Atlantic coastline about 80 to 120 km (50 to 75 miles) farther east (Dolan and Lins 1986). The islands were probably formed as a combination of beach dunes separated from land by rising sea levels, and spit extension from headlands (Godfrey and Godfrey 1976; Dolan and Lins 1986). The islands from CAHA to CALO are underlain by a combination of surfaces that weathered above water (39%) and continental shelf surfaces (61%). CAHA has more area underlain by subaerial surfaces than CALO (Pierce and Colquhoun 1970).

The recent terrestrial past of the barrier islands is shown by pre-Holocene valley and river deposits under the shelf and barrier deposits (Farrell et al. 2007). Rising sea levels drowned lowlands behind the coast; Pamlico Sound, which had been a river valley, was flooded about 7,000 years ago (Stanton et al. 2007). Sea-level rise drove former beach ridges landward until about four thousand years ago, when the rate of sea-level rise slowed. At this point, sediment delivery was great enough to permit seaward building, and the barriers began to approach their current geography (Dolan and Lins 1986). The sedimentation rate on barrier islands can be substantial; when natural overwash is permitted, a meter of sediment (about three and a quarter ft) can be added in 25 years (Godfrey and Godfrey 1976). Sea-level rise was not continuous, but included pauses and small fluctuations, and the barriers were sometimes more widely breached than they are now, resulting in more open circulation (Sager and Riggs 1998). For example, Pamlico Sound is thought to have been open about 4,000 years ago, and between about 1,200 and 500 years ago (Grand Pre et al. 2005a and b; Rosenberger et al. 2006).

The Cenozoic formations of North Carolina, particularly those from the Neogene and Quaternary, have complex histories, with different correlations, ages, and names proposed for the rock units. From the Pliocene to the Holocene, there are several periods of deposition that are known under multiple names.

Often there is a northern and a southern name for approximately correlative units, and usage varies by stratigrapher. In general, from oldest to youngest, listed by north/south approximate correlatives, there are the Pliocene-age Yorktown/Duplin formations and Chowan River/Bear Bluff formations, the Pleistocene-age James City/Waccamaw formations and Flanner Beach/Canepatch formations, and surficial deposits (Carter et al. 1988). One reason for this is the presence of structural highs, such as the Cape Lookout High that divided Miocene sedimentation (Snyder and Riggs 1989), and the Cape Fear Arch to the south, which thinned other pre-Quaternary units (Wehmiller et al. 1992). Geologic dating can be problematic for several reasons. For example, the dating of the Pliocene-Pleistocene boundary worldwide is a current topic of dispute. A particular issue for the Coastal Plain setting is the choice of dating method: aminostratigraphy (using amino acid changes in fossils) may produce significantly different results from radioisotope dating methods (compare Belknap and Wehmiller [1982]'s aminostratigraphic dates to radioisotopes dates from McCartan et al. [1982a, b] for several Pliocene-Pleistocene units of the Atlantic Coastal Plain).

The stratigraphy is further complicated by the use of marine terraces in the Atlantic Coastal Plain. Some of the terrace terms have also been used for formations. In North Carolina, this is particularly true for the Pamlico Formation/Terrace. While this practice is now discouraged (Huddlestun 1988), it is something to watch for in older publications. For the sake of consistency, we have opted to use the 1985 North Carolina state geologic map (found at <http://www.geology.enr.state.nc.us/usgs/geomap.htm>) as first source for stratigraphy, with North Carolina Geologic Survey Bulletin 89 (Carter et al. 1988) to complement it. While CAHA itself only has Quaternary sediments exposed (North Carolina Geological Survey 1985), including Holocene beach and dune sand with organic matter and shells (Johnson et al. 1986), it also has potential fossil resources that may be sampled by shallow drilling (less than 30 m or 100 ft below sea level). Fossils also wash up on CAHA beaches, including a walrus skull (see below).

Sources of Paleontological Resources

The fossils of CAHA present opportunities for education, interpretation, and continued or future scientific research in the park. Aside from the material described in this section, fossils from CAHA are repositied in the CAHA/FORA/WRBR Museum Resources Center, and a specimen from FORA is stored at the Southeast Archeological Center (SEAC). These fossils are documented below, as part of the “Park Collections” section following “Potential Sources of Paleontological Resources.”

Subsurface rocks and sediments (Oligocene-Holocene)

The near subsurface at CAHA includes the Buxton Woods aquifer of Pleistocene to Holocene age. The upper 12 m (39 ft), identified as the upper Buxton Woods aquifer, are of Holocene age and are composed of sand and shell fragments, with buried wetlands. The next 3 m (10 ft), from a Pleistocene headland unit, lack fossils. The final 9.5 m (31 ft) are identified as the lower Buxton Woods aquifer, are of Pleistocene age, and include shell hash and lenses of shells in its sand (Anderson et al. 2000).

Although Quaternary fossils are most likely to be found at CAHA, older fossils may be found from deep drilling. For example, Richards (1968) reported Oligocene-age microfossils from an unnamed formation, recovered from wells at CAHA. These fossils show that while most of North Carolina was above water at this time (and not depositing sediments), the eastern portion was under water.

There are several fossiliferous formations or informally defined layers in the geographic vicinity of CAHA that are buried to varying depths. Brief descriptions are included here because they may be sampled during drilling operations, and in such cases are liable to produce fossils because their faunas consist largely of common shelled marine invertebrates. In subsurface cores, the rock formations may or may not be identifiable, because of the limited samples, so some of the formations listed may correspond to an informal unit. Since the shallowest rocks would be encountered most frequently, the descriptions are restricted to rock units known to about 30 m (100 ft) below sea level. For completeness, both formal lithologic units (the Duplin or Yorktown Formation, Pliocene) and informally defined units that fit this

definition are included in this discussion. These deposits are covered in this report under “Potential Sources of Paleontological Resources.”

Undifferentiated nearsurface Quaternary deposits (Pleistocene-Holocene)

One issue with determining the fossil resources of CAHA and other coastal parks is differentiating between truly fossil material and the remains of coastal organisms that died recently. Staining can be helpful: stained fossils are considered to be pre-modern (Riggs et al. 1995; Wehmiller et al. 2003). Black or brown stained fossils may correspond to anoxic coastal swamps that existed when sea level was lower (Milliman et al. 1972), or to estuarine deposits (Miller 1995). Brown shells may be younger (Pleistocene or Holocene) than black shells (reworked from Pleistocene outcrops) (Miller 1995). Another color scale, for the common bivalve *Mercenaria* per Wehmiller et al. (2003), is chalky white (modern) to yellow-orange (Holocene) to Pleistocene (gray-black). Some of the black shells are dated to about 16,000 years ago (Elmore 2003). Stained fossils are common near the inlets of CAHA and CALO (Milliman et al. 1968). A photo of six Pleistocene and Holocene shells from Cape Point can be found at <http://www.geology.udel.edu/wehmiller/shellsHatteras.html>. It must be noted, though, that under the proper conditions (reducing sediments), shells can become blackened in as little as three weeks (Pilkey et al. 1969). Boring by other invertebrates (Pilkey et al. 1969), abrasion, and trace element composition can also be used to distinguish modern from fossil shells (Wehmiller et al. 2003). The more worn, damaged, and bored a specimen is, the older it probably is.

Because CAHA is a seashore composed of barrier islands, it lacks rock outcrops, but its deposits of sand and finer sediments may hold the remains of nearshore organisms, particularly mollusks. One location at CAHA is even called Coquina Beach, coquina being both a genus of bivalve and a type of sedimentary rock made up of slightly cemented shells. Shell fragments and other such fossils are common and are often mentioned in passing in documents concerned with other topics. For example, in a description of Ocracoke Island’s sedimentology, it is noted that shell debris forms part of the sand (Barwick 1984). Similar shell debris is noted by Moslow and Heron (1989), Anderson et al. (2000), Jomp et al. (2004), Farrell et al. (2007), and Hale et al. (2007). Shells from the Outer Banks were collected by Horace G. Richards (Richards 1936). Mixed assemblages of Pleistocene marine shells are abundant on North Carolina beaches (Riggs et al. 1995), but foraminifera (amoeba-like shelled animals) and ostracodes (small shelled crustaceans) are lacking in high-energy foreshore deposits (Benson 1967). Cores taken from the Outer Banks preserve fossils (Pierce and Colquhoun 1970), and those from the Outer Banks of Dare County also include Pleistocene foraminifera (Byrum and Snyder 1979). Also commonly mentioned in passing are fossil mollusks used for aminostratigraphy. Such specimens from CAHA have been taken from north of Oregon Inlet (Riggs et al. 1995), Cape Point, Rodanthe, and Oregon Inlet (Wehmiller 1995; Wehmiller et al. 1995), and Oregon Inlet to Cape Point (Bart et al. 2001), for example. Fossil mollusk shells from CAHA and CALO are discussed in terms of dating in a semi-technical publication by Wehmiller and York (2002). Microfossils from the CAHA area have also been used to reconstruct sea levels (Kemp et al. 2005). Another potential find in Pleistocene and Holocene coastal sediments, particularly those from high-energy littoral and shallow neritic settings, is crustacean burrows (Weimer and Hoyt 1964).

Collection of empty shells is permitted at CAHA. Shell collecting is common at CAHA but not at FORA and WRBR. No commercial shell collecting operations are known to be working in the Outer Banks Group parks, although local merchants may use shells in shell lamps. Shell collecting is most common in the summer (M. Carfioli, CAHA resource program manager, pers. comm., December 2008).

Remnants of forests and swamps that once grew on the back side of the barrier islands are another source of Quaternary (and possibly older) fossils at CAHA. The landward recession of the barrier islands uncovers freshwater peat deposits and tree stumps on the sea side, left behind from these earlier settings (Potter and Trager 1938; Dolan and Lins 1986). Peat and tree stumps are also known on Roanoke Island and in Croatan Sound (O’Connor et al. 1972). Relict inlets of the barrier system are another source of

fossils near the surface at CAHA and the rest of the Outer Banks; shell fragments are present at the base of these deposits (Moslow and Heron 1977, 1978b, 1989; Herbert and Heron 1978).

Undifferentiated Quaternary deposits near CAHA (Pleistocene-Holocene)

In addition to marine fossils currently present at CAHA, marine fossils are also continually washing up on shore. Outcrops of a Quaternary coquina (in this case a sedimentary rock layer dominated by shell fragments) are found offshore of CAHA in only 9 to 12 m (30 to 40 ft) of water. This coquina is largely correlated to the “Pamlico Formation” or terrace of the late Pleistocene, and fragments of varying size frequently wash up on nearby beaches. Typical fossils include bivalves and gastropods; specimens may be colonized by more recent encrusters like corals. Sponges, bryozoans, scaphopods, polychaete worm tubes, barnacles, and echinoderms have also been recovered with this coquina. The chance recovery of coquina fossils makes absolute determination of stratigraphy difficult, but there appears to be a warm-water Pamlico Terrace-age fauna as well as at least one cold-water fauna that predates or postdates the formation of the Pamlico Terrace (Wells and Richards 1962). Offshore ridges of coralline algae (a type of reef-forming algae), up to 26,250 years old, also contribute to the sediment that may wash up (Cleary and Thayer 1973).

The continental shelf of CAHA produces a variety of fossils, including those of algae, foraminifera, corals, bryozoans, mollusks, polychaete worm tubes, ostracodes, barnacles, and echinoids (Macintyre and Milliman 1970; Cleary and Thayer 1973). The Holocene shelf sediments nearest to CAHA are dominated by mollusks, followed by echinoids (Milliman et al. 1972), with bivalves making up the majority of the mollusk fraction (Cleary and Thayer 1973). Grab samples from just offshore of CAHA may include 10% mollusk fragments (Cleary and Thayer 1973). There are also fossils of terrestrial organisms seaward of the barriers, from the times when sea level was much lower and the coast farther to the east (Swift et al. 1970).

Vertebrate remains also wash up, the best known being an excellent skull of the walrus *Odobenus rosmarus*. This specimen, with catalog number CAHA-00110 (M. Carfioli, pers. comm., September 2008), was dated by radiocarbon to $36,760 \pm 570$ radiocarbon years before present (ybp); radiocarbon years have to be calibrated to yield calendar years (National Park Service, Geologic Resources Division, Paleontology Program 2002). The skull washed up on the beach at Salvo in 1990 and was studied at the Smithsonian (Stover 2002). It is currently in storage in the Museum Resource Center at FORA (J. Powell, CAHA museum technician, pers. comm., October 2008). Terrestrial mammals may also be found, such as a specimen found in the surf at Oregon Inlet and now in the collections of the National Museum of Natural History’s Paleobiology Department. This specimen, USNM PAL 347315, is a nearly complete skull of a female *Bootherium bombifrons* (Harlan’s Muskox or Woodland Muskox) collected by Odessa Wasili and figured in McDonald and Ray (1993).

Fossils are also present behind the barrier islands. Foraminifera, shells, wood and peat from the last few thousand years are known in Albemarle Sound (Sager and Riggs 1998), and foraminifera from Pamlico Sound indicate that there were two breaches of the barrier permitting marine influx in the last 7,000 years, about 4,000 years ago and 1,200 to 500 years ago (Grand Pre et al. 2005a, b). Buried estuarine mollusks are also known from behind the barrier system (Godfrey and Godfrey 1976). Finally, relict river-related deposits from the late Pleistocene and early Holocene, such as are present in the vicinity of CAHA, may host peat, proboscidean teeth, and other subaerial fossils (Milliman et al. 1972).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following formations or resource settings within CAHA, most of which would be found 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.

Yorktown Formation (Pliocene, partially equivalent to the Duplin Formation)

The Yorktown Formation is a heterogeneous Pliocene unit found from Virginia to at least South Carolina, if the Duplin Formation is included. The division between the two formations is the Neuse River, with the Yorktown Formation being the name commonly used north of the river and the Duplin Formation commonly used south of it, although the Yorktown may be used for rocks in both areas. The two are differentiated by fauna and geography instead of rock type, with the Duplin Formation fauna being more diverse and adapted to a warmer, tropical to subtropical environment (Carter et al. 1988). The Duplin Formation preserves foraminifera (amoeba-like shelled animals), corals, bryozoans, gastropods, bivalves (DuBar and Howard 1964), scaphopods, chitons (DuBar and Solliday 1961), barnacles, ostracodes (small shelled crustaceans), echinoids (DuBar and Howard 1964), sharks, reptiles, whales, and terrestrial mammals (Carter et al. 1988). In northern North Carolina, the Yorktown Formation preserves an assemblage of fossils including mollusks, shark teeth, and cetacean bones from a warm temperate nearshore to open marine setting (Carter et al. 1988). Nannofossils, foraminifera (Bybell and Poore 1981), and ostracodes are also known from this unit (Gibson 1983). Terrestrial vertebrates including canids, equids, protoceratids, camelids, cervids, antelopes, and proboscideans are known from Aurora, Beaufort County, roughly 80 km (50 miles) from CAHA (Carter et al. 1988). The Yorktown Formation was laid down after about 4.4 Ma (million years ago), and is found under CAHA (Gibson 1983). Under nearby CALO, the upper 2.4 to 3.1 m (7.9 to 10.2 ft) of the Yorktown Formation are altered into a caprock (Herbert 1978; Moslow and Heron 1978a).

Informally differentiated subsurface Quaternary deposits (Pleistocene-Holocene)

Using the nearby North Core Banks (between New Drum Inlet and Ocracoke Inlet) as a model, the immediate subsurface includes several informally-defined sedimentary units, below which is the Yorktown Formation. From oldest to youngest, these are the Core Creek Sand, Atlantic Sand, Diamond City Clay, and Core Banks Sand or Outer Banks Sand (Herbert 1978; Moslow and Heron 1978a). The Core Creek Sand is found to about 30 m (98 ft) below sea level. It is made up of fine to coarse sand with abundant shells and shell fragments, with some silt and clay, and overlays Tertiary sand and limestones (Susman and Heron 1979). This unit is overlain by either the Atlantic Sand, which is limited in extent, or the Diamond City Clay (Herbert 1978). In some locations, there is an organic-rich clay, probably representing a freshwater swamp, between the Core Creek Sand and overlying Diamond City Clay (Susman and Heron 1979). The Core Creek Sand represents nearshore marine (Moslow and Heron 1978a) to back-barrier and barrier settings, and is heavily fossiliferous. It is dated to approximately 75,000 to 50,000 years old, and has four distinct faunal assemblages. Two correlate to James City/Waccamaw Formation fossils, one correlates to Flanner Beach/Canepatch Formation fossils, and one has an unknown correlative (see below). Fossils found in the Core Creek Sand include corals, bryozoans, bivalves, polychaete tubes, barnacles, ostracodes, and echinoderms (Herbert 1978).

The next unit up is the Atlantic Sand, from a transgressive barrier island complex (Moslow and Heron 1978a). It is not an extensive unit, and may represent the deposits of estuarine barriers. When not present, the Diamond City Clay directly overlies the Core Creek Sand (see below). There are no shells at the top, perhaps due to leaching, but mollusks are present in shell hashes at the base. Other fossils include bryozoans, barnacles, and echinoids (Herbert 1978).

The Diamond City Clay is usually found between 9 m (30 ft) (Moslow and Heron 1978b) and 22.2 m (73 ft) below mean sea level. It is interpreted as a regressive lagoon deposit (Moslow and Heron 1978a), and it has no onshore correlative (Herbert 1978). It consists of alternating beds of unfossiliferous silty to sandy clay and shell hash beds in a sandy clay matrix (Susman and Heron 1979). Its fossils include shell hashes, corals (Susman and Heron 1979), bryozoans, mollusks, polychaete tubes, barnacles, decapods, and ostracodes, dated to $30,465 \pm 800$ radiocarbon years before present (ybp) to $22,760 \pm 2,120 - 2890$ radiocarbon ybp (Herbert 1978), supported by dates of 30,000 to 21,200 ybp on wood and peat (Moslow and Heron 1978b). However, it may be a complex mosaic of older Pleistocene deposits, contaminated by “live” radiocarbon: aminostratigraphy suggests an age of 700,000 to 500,000 years for its base (Snyder et al.

1982). The Diamond City Clay was officially named in 1979 by Susman and Heron for deposits on Shackleford Banks (CALO) (Susman and Heron 1979).

The uppermost portion, present to at least 6 m (20 ft) below sea level and sometimes much deeper where filling old inlets, is informally known as the Core Banks Sand (Herbert 1978) or Outer Banks Sand (Susman and Heron 1979). It is a heterogeneous unit that is still being deposited, with at least eight depositional environments. Befitting its diverse settings, the Core Banks Sand preserves peat, plant fragments, bryozoans, bivalves and other mollusks, polychaete worm tubes, barnacles, and echinoderms (Herbert 1978). The Core Banks Sand is regarded as Holocene in age (Moslow and Heron 1978b).

For reference, the James City Formation (equivalent in part to the Waccamaw Formation, which is the name commonly used to describe this unit in the area of CAHA, and to the Croatan Formation) is a shelly sand and clay unit from the lower Pleistocene. It may record a marine transgression following warming and ice melting (Blackwelder 1981). Foraminifera, ostracodes (Howard 1974), and mollusks are known from this unit (Blackwelder 1981). The depositional setting is interpreted as bay to open shallow shelf, with a subtropical to temperate climate. Mainland deposits may have terrestrial vertebrate remains, but these fossils may have come from other Pliocene and Pleistocene units. The Waccamaw Formation, a sandy shelly unit found south of the Cape Fear River (Carter et al. 1988), has a more diverse fauna, including nannofossils, foraminifera (Bybell and Poore 1981), corals, bryozoans, mollusks, barnacles (Carter et al. 1988), ostracodes (Howard 1974), echinoids, and sharks (Carter et al. 1988). The Waccamaw and James City formations are dated to about 1 Ma (McCartan et al. 1982a).

The Flanner Beach Formation (equivalent to the Socastee Formation [Belknap and Wehmiller 1982; McCartan et al. 1982a] and upper Canepatch Formation, in part to the Croatan and Pamlico formations) is a heterogeneous upper Pleistocene unit from cypress grove, estuarine, and nearshore marine setting. Fossils in the Flanner Beach Formation include peat, wood, corals, gastropods, and bivalves (Carter et al. 1988). Nannofossils and foraminifera are also known (Bybell and Poore 1981). It dates to about 200,000 years ago (McCartan et al. 1982a). Its rough equivalent, the Canepatch Formation, includes sediments from a variety of coastal to marine settings. Fossils in the Canepatch Formation include corals, gastropods, bivalves, echinoids, and a few terrestrial mammals (Carter et al. 1988).

Park Collections

Aside from the walrus skull, the Outer Banks Group Museum Resources Center has records of two other catalog numbers applied to CAHA fossils, although one has been lost. This lost material consisted of pieces of whale vertebrae, which were deaccessioned in 2002. The other specimen is CAHA-270, a group of three auditory bullae (hollow structures enclosing part of the ear) pertaining to whales (M. Carfioli, pers. comm., September 2008). No CAHA specimens are on record as being at the Southeast Archeological Center (SEAC). SEAC does have a record of a specimen from Fort Raleigh, though: FORA 1884, an unidentified fossil. It is currently repositied at SEAC in storage box 2689 L2Q2 (B. Carter, SEAC supervisory museum specialist, pers. comm., August 2008). Further identification of this specimen and its provenance is needed.

Fossils Found in Cultural Resource Contexts

There is also the possibility of finding fossils associated with cultural resources, such as fossils altered or modified by humans. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts. Humans are not known at CAHA before about three thousand years ago, but there are at least twenty-nine archeological sites in the North Carolina Outer Banks Study Area (Kitty Hawk to Ocracoke Inlet, including Roanoke Island) that date to between about three thousand years ago and the period of European contact. Twenty of these sites are shell middens (human-made shell dumps) or otherwise involve shells (Thompson 1977). Excavations at

FORA in 2008 unearthed artifacts from the late 16th century, including oyster shells associated with copper plates that may have been strung together in a necklace (National Park Service 2008).

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division coordinated geologic scoping for CAHA during April 2000. The participants of the CAHA Geologic Scoping meeting developed a series of recommendations for future work.
- Further identification of the FORA fossil specimen housed at SEAC is required. Additionally, there are shells at the Outer Banks Group Museum Resource Center that may be fossils, so further investigation here is warranted.
- SECN parks such as CAHA, CALO, CANA, CASA, CUIS, FOCA, FOFR, FOMA, FOPU, FOSU, and TIMU are geologically very young, making it difficult to determine what material is a “fossil” and what would be considered “modern.” The National Park Service defines a fossil as any remains of life preserved in a geologic context. This definition does not include an arbitrary date where older specimens are considered fossils, and younger specimens are not. The “geologic context” phrase is intended to imply some level of antiquity, however. Generally, specimens dating back to the late Pleistocene are considered fossils. Late Holocene (last few hundred or thousand years, “Recent”) specimens are usually considered modern and not fossils. Pleistocene remains may differ from younger remains by having dark staining and being heavily worn and bored, but this does not always hold true. Surface and subsurface specimens collected at CAHA span this range between Pleistocene and Holocene. Regardless of what label is assigned to them, these specimens are important natural resources and valuable pieces of the history of life on earth.
- Some coastal park units in the NPS experience unauthorized casual collecting of fossils (beach-combing) from beach areas. This activity is not well documented in the SECN. Further investigation into casual collecting could lead to development of a park or regional policy related to such collecting. Collection of empty shells is permitted at CAHA.
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Southeast Archeology Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- The dredge spoils from CAHA may provide an opportunity to identify paleontological resources from the subsurface deposits.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at CAHA.

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Data Sets

Cape Hatteras National Seashore Paleontological Archives

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

Outer Banks Group Museum Resource Center at Fort Raleigh National Historic Site

1953–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by MRC staff; status: Active.

National Museum of Natural History

1953–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by USNM staff; status: Active.

Fort Raleigh National Historic Site Collections at the Southeast Archeological Center

1941–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by SEAC staff; status: Active.

Cape Lookout National Seashore

Cape Lookout National Seashore (CALO) was established to protect an undeveloped section of North Carolina's Outer Banks, a chain of barrier islands. CALO preserves a variety of natural and cultural resources. The seashore was authorized March 10, 1966, and had a boundary change October 26, 1974. In 1986 it was designated a Biosphere Reserve. The area of the national seashore within the boundary established in 1974 is 11,943 ha (28,400 acres), including the 37 ha (91 acre) administrative site on Harkers Island. 10,187.62 ha (25,173.62 acres) of the total are under Federal administration. The emergent land (above mean high water) of the barrier islands proper totals 7,446 ha (18,400 acres).

Geologic Background

CALO is located off the east and southeast coasts of mainland North Carolina, including portions of the Outer Banks barrier islands in Carteret County. CALO's section of barrier islands extends from Ocracoke Inlet in the northeast to Beaufort Inlet in the southwest, incorporating Core Banks, Shackleford Banks, and a portion of Harkers Island (note that the terminology used for the islands varies). As of 2008, from northeast to southwest, it is split by Old Drum Inlet, New Drum Inlet, Ophelia Inlet, and Barden Inlet, although other inlets have been open in the past. Old Drum Inlet, New Drum Inlet, and Ophelia Inlet separate Core Banks into North and South Core Banks. Portsmouth Flats or Island is in North Core Banks, and Cape Lookout itself is in South Core Banks. Northeast of North Core Banks, on the opposite side of Ocracoke Inlet, is the portion of the barrier chain administered by the National Park Service as Cape Hatteras National Seashore (CAHA; see CAHA section of this report). CALO separates several bodies of water on its landward side from the Atlantic Ocean to the southeast. From northeast to southwest, these include Pamlico Sound, Core Sound, and Back Sound. Cape Lookout itself is the boundary separating the Atlantic Ocean's Raleigh Bay to the northeast from Onslow Bay to the southwest.

CALO, as a series of sandy barrier islands, lacks rock exposures, and was largely formed by processes operating only as far back as the Pleistocene (see Figure 2 for a geologic time scale). Despite this, its geology has been described in a number of publications, particularly in regards to environmental and climate changes during the Pleistocene and Holocene. CALO's geology has been the subject of scientific publications and abstracts (Cobb 1907; Susman and Heron 1976, 1979; Moslow and Heron 1977, 1978a and b, 1979, 1981; Herbert and Heron 1978; Winner 1978; Steele et al. 1980; Heron et al. 1984; Stephenson 1984; Berelson and Heron 1985; Haddad and Martens 1990; Bernstein et al. 2001; Wells et al. 2002; White et al. 2002; Camann and Wells 2004; Young 2004; Rosenberger et al. 2006), theses (Rochna 1961; Brauer 1974; Susman 1975; Moslow 1977; Herbert 1978; Berelson 1979; Rosenberger 2006), and internal National Park Service reports (Godfrey and Godfrey 1976; National Park Service Geologic Resources Division and Natural Resources Information Division 2000), not including publications devoted to nearby features or coastal geology over a wider area.

In general, the east coast of the United States has had relatively little tectonic activity since North America and Africa rifted apart during the Late Triassic and Jurassic, although there are occasional earthquakes (one caused slump deposits of 100 cubic kilometers in the Hatteras Abyssal Plain about 16,000 years ago [Elmore 2003]). Complex Paleozoic basements of metamorphic and igneous rocks are present 915 to 3,050 m (3,000 to 10,000 ft) below the surfaces of Albemarle and Pamlico Sounds (Denison et al. 1967), recording a period of continental assembly. A relatively deep well at CAHA, the Hatteras Light Well No. 1, reached granite basement at a depth of 3,011 m (9,878 ft) (Berryhill 1948). Late Triassic and Jurassic basin deposits on land in North Carolina and Virginia formed in the early stages of the North American-African split (Olsen et al. 1978; Won et al. 1979); such rocks are deeply buried in the Outer Banks. For example, at the Esso-Cape Hatteras Light well, 1,000 m (3,280 ft) of Cenozoic rocks and sediments and then 1,800 m (5,900 ft) of Cretaceous rocks overlie Jurassic rocks (Perry et al. 1975).

During the time following the Jurassic rifting, there has been deposition of sedimentary rocks in environments varying from open marine to coastal settings, depending on sea level. As with the Jurassic

rocks, these rocks are largely buried in the CALO area, although accessible through drilling. Extensive submergence of eastern North Carolina occurred during the Cretaceous, Paleocene, Eocene, late Miocene, and parts of the Pliocene and Pleistocene (Richards 1968; Carter et al. 1988). An important feature of Atlantic Coastal Plain geology is the well-developed set of marine terraces, which document ancient shorelines. Over time, terraces formed progressively closer to the modern shore, in distance and elevation. The Suffolk Scarp is one such relict shoreline (Wells and Kim 1989), and there is a set of named terraces that are used in geologic descriptions. From oldest to most recent, these include the Capitol, Hazelhurst, Cohaire, Sunderland, Okefenokee, Wicomico, Penholoway, Talbot, Pamlico, Princess Anne, Silver Bluff, and Recent terraces (Colquhoun and Johnson 1968; Colquhoun 1969). These terraces were formed between the Pleistocene and the present in response to sea level fluctuations over a long period of marine regression (Colquhoun 1969; Richards et al. 1971).

The underlying geomorphic setting that resulted in the development of Cape Lookout is related to a north-south running hinge belt to the west. Because of this, Cape Lookout's movement responds to structural controls as well as coastal processes (Stephenson 1984). The present location of the cape was probably the site of at least one pre-Holocene cusped foreland (Moslow and Heron 1989). However, the cape itself seems to have moved southwest from at least the region of Drum Inlet, with the Shackleford Banks to the west replacing an older stretch of barrier islands that included Harkers Island (Benson 1967). CALO and the rest of the Outer Banks only took form as barrier islands less than five thousand years ago (Godfrey and Godfrey 1976), following the most recent cycle of sea-level fall and rise. At the end of the most recent glacial period, about 18,000 to 14,000 years ago, sea level was about 91 m (300 ft) lower than at present, putting North Carolina's Atlantic coastline about 80 to 120 km (50 to 75 miles) farther east (Dolan and Lins 1986). The islands were probably formed as a combination of beach dunes separated from land by rising sea levels, and spit extension from headlands (Godfrey and Godfrey 1976; Dolan and Lins 1986). The islands from CAHA to CALO are underlain by a combination of surfaces that weathered above water (39%) and continental shelf surfaces (61%). CALO has more area underlain by continental shelf surfaces than CAHA, and probably was formed more from spit extension (Pierce and Colquhoun 1970). The islands north of Cape Lookout have a Quaternary framework, while those south of the Cape have thin Quaternary units over Tertiary and Cretaceous units (Riggs et al. 1995).

The recent terrestrial past of the barrier islands is shown by pre-Holocene valley and river deposits under the shelf and barrier deposits (Farrell et al. 2007). Rising sea levels drowned lowlands behind the coast; Pamlico Sound, which had been a river valley, was flooded about 7,000 years ago (Stanton et al. 2007). The Neuse River also leads into a drowned river valley (Wells and Kim 1989). Sea-level rise drove former beach ridges landward until about four thousand years ago, when the rate of sea-level rise slowed. At this point, sediment delivery was great enough to permit seaward building, and the barriers began to approach their current geography (Dolan and Lins 1986). The sedimentation rate on barrier islands can be substantial; when natural overwash is permitted, a meter of sediment (3.3 ft) can be added in 25 years (Godfrey and Godfrey 1976). Sea-level rise was not continuous, but included pauses and small fluctuations, and the barriers were sometimes more widely breached than they are now, resulting in more open circulation (Sager and Riggs 1998). For example, Pamlico Sound is thought to have been open about 4,000 years ago, and between about 1,200 and 500 years ago (Grand Pre et al. 2005a and b; Rosenberger et al. 2006). Fluctuations in the changing rate of sea level rise are also recorded in the position of Cape Lookout, which has moved 6.7 km (4.2 miles) landward since about 7,000 years ago. Most of the movement was before about 4,000 years ago, when Cape Lookout was moving landward by 79 to 98 m (259 to 322 ft) per century; after that time, it slowed to about a meter (3.3 ft) per century (Moslow and Heron 1978a).

The Cenozoic formations of North Carolina, particularly those from the Neogene and Quaternary, have complex histories, with different correlations, ages, and names proposed for the rock units. From the Pliocene to the Holocene, there are several periods of deposition that are known under multiple names. Often there is a northern and a southern name for approximately correlative units, and usage varies by stratigrapher. In general, from oldest to youngest, listed by north/south approximate correlatives, there are the Pliocene-age Yorktown/Duplin formations and Chowan River/Bear Bluff formations, the

Pleistocene-age James City/Waccamaw formations and Flanner Beach/Canepatch formations, and surficial deposits (Carter et al. 1988). One reason for this is the presence of structural highs, such as the Cape Lookout High that divided Miocene sedimentation (Snyder and Riggs 1989), and the Cape Fear Arch to the south, which thinned other pre-Quaternary units (Wehmiller et al. 1992). Geologic dating can be problematic for several reasons. For example, the dating of the Pliocene-Pleistocene boundary worldwide is a current topic of dispute. A particular issue for the Coastal Plain setting is the choice of dating method: aminostratigraphy (using amino acid changes in fossils) may produce significantly different results from radioisotope dating methods (compare Belknap and Wehmiller [1982]'s aminostratigraphic dates to radioisotopes dates from McCartan et al. [1982a, b] for several Pliocene-Pleistocene units of the Atlantic Coastal Plain).

The stratigraphy is further complicated by the use of marine terraces in the Atlantic Coastal Plain. Some of the terrace terms have also been used for formations. In North Carolina, this is particularly true for the Pamlico Formation/Terrace. While this practice is now discouraged (Huddlestun 1988), it is something to watch for in older publications. For the sake of consistency, we have opted to use the 1985 North Carolina state geologic map (found at <http://www.geology.enr.state.nc.us/usgs/geomap.htm>) as first source for stratigraphy, with North Carolina Geologic Survey Bulletin 89 (Carter et al. 1988) to complement it. While CALO itself only has Quaternary sediments exposed (North Carolina Geological Survey 1985), including Holocene beach and dune sand with organic matter and shells (Johnson et al. 1986), it also has potential fossil resources that may be sampled by shallow drilling (less than 30 m or 100 ft below sea level).

Sources of Paleontological Resources

The fossils of CALO present opportunities for education, interpretation, and continued or future scientific research in the park.

Undifferentiated nearsurface deposits (Pliocene-Holocene)

There are several fossiliferous formations or informally defined layers in the geographic vicinity of CALO that are buried to varying depths. Brief descriptions are included here because they may be sampled during drilling operations, and in such cases are liable to produce fossils because their faunas consist largely of common shelled marine invertebrates. In subsurface cores, the rock formations may or may not be identifiable, because of the limited samples, so some of the formations listed may correspond to an informal unit. Since the shallowest rocks would be encountered most frequently, the descriptions are restricted to rock units known to about 30 m (100 ft) below sea level. For completeness, both formal lithologic units (the Duplin or Yorktown Formation, Pliocene) and informally defined units that fit this definition are included in this discussion.

Duplin or Yorktown Formation (Pliocene)

The Duplin Formation and the approximately equivalent Yorktown Formation are heterogeneous Pliocene units found from Virginia to at least South Carolina. The division between the two formations is the Neuse River, with the Yorktown Formation being the name commonly used north of the river and the Duplin Formation commonly used south of it, although the Yorktown may be used for rocks in both areas. The two are differentiated by fauna and geography instead of rock type, with the Duplin Formation fauna being more diverse and adapted to a warmer, tropical to subtropical environment (Carter et al. 1988). The Duplin Formation preserves foraminifera (amoeba-like shelled animals), corals, bryozoans, gastropods, bivalves (DuBar and Howard 1964), scaphopods, chitons (DuBar and Solliday 1961), barnacles, ostracodes (small shelled crustaceans), echinoids (DuBar and Howard 1964), sharks, reptiles, whales, and terrestrial mammals (Carter et al. 1988). In northern North Carolina, the Yorktown Formation preserves an assemblage of fossils including mollusks, shark teeth, and cetacean bones from a warm temperate nearshore to open marine setting (Carter et al. 1988). Nannofossils, foraminifera (Bybell and Poore 1981), and ostracodes are also known from this unit (Gibson 1983). Terrestrial vertebrates including canids, equids, protoceratids, camelids, cervids, antelopes, and proboscideans are known from

Aurora, Beaufort County, roughly 67 km (42 miles) from CALO (Carter et al. 1988). The Yorktown Formation was laid down after about 4.4 million years ago (Gibson 1983).

Both the Duplin and Yorktown formations may be present under CALO's section of the Outer Banks (Gibson 1983). If the interpretation of one formation with two faunas is followed, this suggests that both the Duplin and Yorktown faunas are present. Under CALO, the upper 2.4 to 3.1 m (7.9 to 10.2 ft) of the Duplin/Yorktown Formation are altered into a caprock (Herbert 1978; Moslow and Heron 1978a); fossils are rare under the caprock in the South Core Banks (Herbert 1978).

Informally differentiated subsurface Quaternary deposits (Pleistocene-Holocene)

Several publications are based on cores from CALO locations, which often include fossils of Quaternary foraminifera or mollusks. Such publications (not including theses) include Benson (1967), Pierce and Colquhoun (1970), Moslow and Heron (1977, 1978a and b, 1981), Susman and Heron (1976, 1979), Herbert and Heron (1978), Blackwelder (1981), Heron et al. (1984), and Rosenberger et al. (2006).

Under the northern Core Banks, the immediate subsurface (to about 30 m or 100 ft below mean sea level) includes several informally-defined sedimentary units, below which is the Yorktown Formation. From oldest to youngest, these are the Core Creek Sand, Atlantic Sand, Diamond City Clay, and Core Banks Sand or Outer Banks Sand (Herbert 1978; Moslow and Heron 1978a). The Core Creek Sand is found to about 30 m (98 ft) below sea level. It is made up of fine to coarse sand with abundant shells and shell fragments, with some silt and clay, and overlays Tertiary sand and limestones (Susman and Heron 1979). This unit is overlain by either the Atlantic Sand, which is limited in extent, or the Diamond City Clay (Herbert 1978). In some locations, there is an organic-rich clay, probably representing a freshwater swamp, between the Core Creek Sand and overlying Diamond City Clay (Susman and Heron 1979). The Core Creek Sand represents nearshore marine (Moslow and Heron 1978a) to back-barrier and barrier settings, and is heavily fossiliferous. It is dated to approximately 75,000 to 50,000 years old, and has four distinct faunal assemblages. Two correlate to James City/Waccamaw Formation fossils, one correlates to Flanner Beach/Canepatch Formation fossils, and one has an unknown correlative (see below). Fossils found in the Core Creek Sand include corals, bryozoans, bivalves, polychaete tubes, barnacles, ostracodes, and echinoderms (Herbert 1978).

The next unit up is the Atlantic Sand, from a transgressive barrier island complex (Moslow and Heron 1978a). It is not an extensive unit, and may represent the deposits of estuarine barriers. When not present, the Diamond City Clay directly overlies the Core Creek Sand (see below). There are no shells at the top, perhaps due to leaching, but mollusks are present in shell hashes at the base. Other fossils include bryozoans, barnacles, and echinoids (Herbert 1978).

The Diamond City Clay is usually found between 9 m (30 ft) (Moslow and Heron 1978b) and 22.2 m (73 ft) below mean sea level. It is interpreted as a regressive lagoon deposit (Moslow and Heron 1978a), and it has no onshore correlative (Herbert 1978). It consists of alternating beds of unfossiliferous silty to sandy clay and shell hash beds in a sandy clay matrix (Susman and Heron 1979). Its fossils include shell hashes, corals (Susman and Heron 1979), bryozoans, mollusks, polychaete tubes, barnacles, decapods, and ostracodes, dated to $30,465 \pm 800$ radiocarbon years before present (ybp) to $22,760 + 2,120 - 2890$ radiocarbon ybp (Herbert 1978), supported by dates of 30,000 to 21,200 radiocarbon ybp on wood and peat (Moslow and Heron 1978b) (radiocarbon ybp are radiocarbon years before the present; radiocarbon years have to be calibrated to yield calendar dates). However, it may be a complex mosaic of older Pleistocene deposits, contaminated by "live" radiocarbon: aminostratigraphy suggests an age of 700,000 to 500,000 years for its base (Snyder et al. 1982). The Diamond City Clay was officially named in 1979 by Susman and Heron for deposits on Shackleford Banks (Susman and Heron 1979).

The uppermost portion, present to at least 6 m (20 ft) below sea level and sometimes much deeper where filling old inlets, is informally known as the Core Banks Sand (Herbert 1978) or Outer Banks Sand (Susman and Heron 1979). It is a heterogeneous unit that is still being deposited, with at least eight

depositional environments. Befitting its diverse settings, the Core Banks Sand preserves peat, plant fragments, bryozoans, bivalves and other mollusks, polychaete worm tubes, barnacles, and echinoderms (Herbert 1978). The Core Banks Sand is regarded as Holocene in age (Moslow and Heron 1978b).

Under the Shackleford Banks, Tertiary basement is present 24 to 30 m (80 to 100 ft) below mean sea level, in the form of a Miocene- or Pliocene-age sand sometimes capped by a limestone with molds of fossils (Susman and Heron 1976), regarded as equivalent to the Yorktown Formation. Above this layer are the Pleistocene-age silty fossiliferous sand deposits of the Core Creek Sand, deposited in a nearshore open marine setting. This sand layer is sometimes capped by freshwater peat. The Diamond City Clay is found above, representing back-barrier deposition. A 12,000 year-old freshwater peat layer caps the Diamond City Clay, separating it from the Holocene-age Core Banks Sand. Early and Middle Pleistocene deposits are not present under the Shackleford Banks (Susman and Heron 1979).

For reference, the James City Formation (equivalent in part to the Waccamaw Formation, which is the name commonly used to describe this unit in the area of CALO, and to the Croatan Formation) is a shelly sand and clay unit from the lower Pleistocene. It may record a marine transgression following warming and ice melting (Blackwelder 1981). Foraminifera, ostracodes (Howard 1974), and mollusks are known from this unit (Blackwelder 1981). The depositional setting is interpreted as bay to open shallow shelf, with a subtropical to temperate climate. Mainland deposits may have terrestrial vertebrate remains, but these fossils may have come from other Pliocene and Pleistocene units. Blackwelder (1981) reported a unit correlated with the James City Formation based on mollusks as present beneath CALO's Portsmouth Bank at two sites. This unit was found at a depth of 27.7 to 28.7 m (90.9 to 94.2 ft) and 32.9 to 34.4 m (107.9 to 112.9 ft). The Waccamaw Formation, a sandy shelly unit found south of the Cape Fear River (Carter et al. 1988), has a more diverse fauna, including nannofossils, foraminifera (Bybell and Poore 1981), corals, bryozoans, mollusks, barnacles (Carter et al. 1988), ostracodes (Howard 1974), echinoids, and sharks (Carter et al. 1988). The Waccamaw and James City formations are dated to about 1 Ma (McCartan et al. 1982a).

The Flanner Beach Formation (equivalent to the Socastee Formation [Belknap and Wehmiller 1982; McCartan et al. 1982a] and upper Canepatch Formation, in part to the Croatan and Pamlico formations) is a heterogeneous upper Pleistocene unit from cypress grove, estuarine, and nearshore marine setting. Fossils in the Flanner Beach Formation include peat, wood, corals, gastropods, and bivalves (Carter et al. 1988). Nannofossils and foraminifera are also known (Bybell and Poore 1981). It dates to about 200,000 years ago (McCartan et al. 1982a). In Carteret County deposits of the Flanner Beach Formation (as the Neuse Formation), diatoms, foraminifera, corals, bryozoans, bivalves, gastropods, barnacles, ostracodes, shark teeth, and fish teeth are present (Fallaw and Wheeler 1969; Fallaw 1973). The Flanner Beach Formation is thought to be absent under the Shackleford Banks (Susman and Heron 1979). Its rough equivalent, the Canepatch Formation, includes sediments from a variety of coastal to marine settings. Fossils in the Canepatch Formation include corals, gastropods, bivalves, echinoids, and a few terrestrial mammals (Carter et al. 1988).

Undifferentiated nearsurface Quaternary deposits (Pleistocene-Holocene)

One issue with determining the fossil resources of CALO and other coastal parks is differentiating between truly fossil material and the remains of coastal organisms that died recently. Staining can be helpful: stained fossils are considered to be pre-modern (Riggs et al. 1995; Wehmiller et al. 2003). Black or brown stained fossils may correspond to anoxic coastal swamps that existed when sea level was lower (Milliman et al. 1972), or to estuarine deposits (Miller 1995). Brown shells may be younger (Pleistocene or Holocene) than black shells (reworked from Pleistocene outcrops) (Miller 1995). Another color scale, for the common bivalve *Mercenaria* per Wehmiller et al. (2003), is chalky white (modern) to yellow-orange (Holocene) to Pleistocene (gray-black). Some of the black shells are dated to about 16,000 years ago (Elmore 2003). Stained fossils are common near the inlets of CALO and CAHA (Milliman et al. 1968). A photo of six Pleistocene and Holocene shells from Cape Point at CAHA can be found at <http://www.geology.udel.edu/wehmiller/shellsHatteras.html>. It must be noted, though, that under the

proper conditions (reducing sediments), shells can become blackened in as little as three weeks (Pilkey et al. 1969). Boring by other invertebrates (Pilkey et al. 1969), abrasion, and trace element composition can also be used to distinguish modern from fossil shells (Wehmiller et al. 2003). The more worn, damaged, and bored a specimen is, the older it probably is.

Because CALO is a seashore composed of barrier islands, it lacks rock outcrops, but its deposits of sand and finer sediments may hold the remains of nearshore organisms, particularly mollusks. Shell fragments and other such fossils are common and are often mentioned in passing in documents concerned with other topics. Such debris is noted by Cobb (1907), Benson (1967), Mixon and Pilkey (1976), Moslow and Heron (1977, 1978b, 1981, 1989), Susman and Heron (1976, 1979), Herbert and Heron (1978), Winner (1978), and Rosenberger et al. (2006). Shells from the Outer Banks were collected by Horace G. Richards (Richards 1936). Mixed assemblages of Pleistocene marine shells are abundant on North Carolina beaches (Riggs et al. 1995), but foraminifera and ostracodes are lacking in high-energy foreshore deposits (Benson 1967). Also commonly mentioned in passing are fossils used for radiocarbon dating (Susman and Heron 1976, 1979; Moslow and Heron 1978b, 1981; Herbert 1978; Macintyre et al. 1978; Heron et al. 1984), or aminostratigraphic dating (Wehmiller et al. 1995). Fossil mollusk shells from CAHA and CALO are discussed in terms of aminostratigraphic dating in a semi-technical publication by Wehmiller and York (2002). Another potential find in Pleistocene and Holocene coastal sediments, particularly those from high-energy littoral and shallow neritic settings, is crustacean burrows (Weimer and Hoyt 1964).

Remnants of forests and swamps that once grew on the back side of the barrier islands are another source of Quaternary (and possibly older) fossils at CALO. The landward recession of the barrier islands uncovers freshwater peat deposits and tree stumps on the sea side, left behind from these earlier settings (Potter and Trager 1938; Dolan and Lins 1986). At Shackleford Banks, drowned forests are known, although they are less than 200 years old (Godfrey and Godfrey 1976), and multiple peat deposits are known from the shallow subsurface of this island (Susman and Heron 1976). Marsh deposits are not known from Cape Lookout itself (Benson 1967), although they are known in its back-barrier area (Moslow and Heron 1981). Fossil marshes are also present in Core Sound (Benson et al. 1962). Relict inlets of the barrier system are another source of fossils near the surface at CALO and the rest of the Outer Banks; shell fragments are present at the base of these deposits (Moslow and Heron 1977, 1978b, 1989; Herbert and Heron 1978).

Undifferentiated Quaternary deposits near CALO (Pleistocene-Holocene)

In addition to marine fossils currently present at CALO, marine fossils are also continually washing up on shore. Outcrops of a Quaternary coquina (a sedimentary rock layer dominated by shell fragments) are found offshore of CALO in only 9 to 12 m (30 to 40 ft) of water. This coquina is largely correlated to the “Pamlico Formation” or terrace of the late Pleistocene, and fragments of varying size frequently wash up on nearby beaches. Typical fossils include bivalves and gastropods; specimens may be colonized by more recent encrusters like corals. Sponges, bryozoans, scaphopods, polychaete worm tubes, barnacles, and echinoderms have also been recovered with this coquina. The chance recovery of coquina fossils makes absolute determination of stratigraphy difficult, but there appears to be a warm-water Pamlico Terrace-age fauna as well as at least one cold-water fauna that predates or postdates the formation of the Pamlico Terrace (Wells and Richards 1962). Offshore ridges of coralline algae (a type of reef-forming algae), up to 26,250 years old, also contribute to the sediment that may wash up (Cleary and Thayer 1973). There is also the potential for vertebrate remains to wash up, as demonstrated by an excellent Pleistocene-age skull of the walrus *Odobenus rosmarus* that washed up at Salvo in CAHA in 1990 (Stover 2002), or the nearly complete skull of a female *Bootherium bombifrons* (Harlan’s Muskox or Woodland Muskox) collected by Odessa Wasili from the surf at Oregon Inlet (McDonald and Ray 1993).

The continental shelf of CALO produces a variety of fossils, including those of algae, foraminifera, corals, bryozoans, mollusks, polychaete worm tubes, ostracodes, barnacles, and echinoids (Macintyre and Milliman 1970; Cleary and Thayer 1973). The Holocene shelf sediments nearest to CALO are dominated by mollusks and coated sediment grains called ooids (Milliman et al. 1972), with bivalves making up the

majority of the mollusk fraction (Cleary and Thayer 1973). Grab samples from just offshore of CALO may include 10% mollusk fragments (Cleary and Thayer 1973). There are also fossils of terrestrial organisms seaward of the barriers, from the times when sea level was much lower and the coast farther to the east (Swift et al. 1970).

Fossils are also present behind the barrier islands. Foraminifera from Pamlico Sound indicate that there were two breaches of the barrier permitting marine influx in the last 7,000 years, about 4,000 years ago and 1,200 to 500 years ago (Grand Pre et al. 2005a, b). Buried estuarine mollusks are also known from behind the barrier system (Godfrey and Godfrey 1976). Middle Marsh and Back Sound, landward from CALO, have bivalves, gastropods, and echinoids, dated to $4,800 \pm 100$ radiocarbon ybp, $3,780 \pm 90$ radiocarbon ybp, and $1570 \pm$ radiocarbon ybp (Berelson and Heron 1985). Finally, relict river-related deposits from the late Pleistocene and early Holocene, such as are present in the vicinity of CALO, may host peat, proboscidean teeth, and other subaerial fossils (Milliman et al. 1972).

Potential Sources of Paleontological Resources

Fossils may be found in cultural resource contexts, as described below following the “Park Collections” section.

Park Collections

There are no known CALO specimens in the collections database of the Southeast Archeological Center (SEAC). Michael Rikard (CALO resource program manager, pers. comm., September 2008) did not know of any paleontological resources in CALO collections.

Fossils Found in Cultural Resource Contexts

There is also the possibility of finding fossils associated with cultural resources, such as fossils altered or modified by humans. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts. At nearby CAHA, humans are not known before about three thousand years ago, but there are at least twenty-nine archeological sites in the North Carolina Outer Banks Study Area (Kitty Hawk to Ocracoke Inlet, including Roanoke Island) that date to between about three thousand years ago and the period of European contact. Twenty of these sites are shell middens (human-made shell dumps) or otherwise involve shells. West of CALO, on White Oak River and Topsail Island, at least another 18 middens are present (Thompson 1977).

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division coordinated geologic scoping for CALO during April 2000. The participants of the CALO Geologic Scoping meeting developed a series of recommendations for future work.
- SECN parks such as CAHA, CALO, CANA, CASA, CUIS, FOCA, FOFR, FOMA, FOPU, FOSU, and TIMU are geologically very young, making it difficult to determine what material is a “fossil” and what would be considered “modern.” The National Park Service defines a fossil as any remains of life preserved in a geologic context. This definition does not include an arbitrary date where older specimens are considered fossils, and younger specimens are not. The “geologic context” phrase is intended to imply some level of antiquity, however. Generally, specimens dating back to the late Pleistocene are considered fossils. Late Holocene (last few hundred or thousand years, “Recent”) specimens are usually considered modern and not fossils. Pleistocene remains may differ from younger remains by having dark staining and being heavily worn and bored, but this does not always hold true. Surface and subsurface specimens collected at CALO span this range between Pleistocene and Holocene. Regardless of what label is assigned to them, these specimens are important natural resources and valuable pieces of the history of life on earth.

- Some coastal park units in the NPS experience unauthorized casual collecting of fossils (beach-combing) from beach areas. This activity is not well documented in the SECN. Further investigation into casual collecting could lead to development of a park or regional policy related to such collecting. CALO allows collecting of shells if the shell does not contain a live animal (M. Rikard, pers. comm., November 2008).
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Southeast Archeology Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at CALO.

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Data Sets

Cape Lookout National Seashore Paleontological Archives

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

Cape Lookout National Seashore Museum Collections

1966–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by CALO staff; status: Active.

Castillo de San Marcos National Monument

Castillo de San Marcos National Monument (CASA) preserves the historic Castillo de San Marcos, the oldest masonry fort in the continental United States. This fort was constructed between 1672 and 1695, and was built by the Spanish to protect St. Augustine, Florida. The current floor plan dates to the 18th century. CASA was proclaimed on October 15, 1924, as Fort Marion National Monument (Fort Marion was the name used for the fort between 1821 and 1942). The site was transferred from the War Department to the National Park Service August 10, 1933, and renamed on June 5, 1942. CASA's boundaries were changed June 29, 1936, July 5, 1960, and December 23, 2004. The monument encompasses 8.18 ha (20.21 acres), all but 0.01 ha (0.03 acres) of which are under Federal administration.

Geologic Background

CASA is located in eastern St. Johns County, northeastern Florida, in the city of St. Augustine. It is about 2.75 km (1.70 miles) west of the Atlantic Ocean. Villano Beach (to the north) and Anastasia Island (to the south) shelter CASA from the ocean. CASA overlooks Matanzas Harbor, part of the Matanzas River and the Intracoastal Waterway.

In general, the east coast of the United States, including the St. Augustine region, has had relatively little tectonic activity since the events surrounding the formation and subsequent rifting of the supercontinent Pangaea. In the area of the Southeast Coast Network, this activity involved the African and North American continents. The collision of these two continents was the culmination of a long series of events, with multiple deformations recorded in the Appalachian Mountains. North America and Africa rifted apart during the Late Triassic and Jurassic, and are still moving apart today (see Figure 2 for a geologic time scale).

The land beneath the St. Augustine area has only been part of North America since Pangaea rifted apart. What is now the east coast of North America was assembled from small landmasses that collided with the continent during the assembly of Pangaea during the Paleozoic (Hatcher 2001). The final portion that was added was the landmass that now underlies Florida and parts of southern Alabama and Georgia. This landmass, called the Suwannee Terrane, had been part of the much larger landmass known as Gondwana, which included most of today's southern continents and India. The Suwannee Terrane had been attached to Gondwana near the northern junction of South America and Africa, but was incorporated into North America during the breakup of Pangaea (Scotese et al. 1979; Horton et al. 1989). Sedimentary rocks of the Suwannee Terrane, deposited in the hundred million years before the North American-African collision, resemble those of similar age in Guinea and Senegal of western Africa (Horton et al. 1989). Rifting occurred from the Late Triassic to the Middle Jurassic, creating basins by faulting (Gottfried et al. 1977; Gohn et al. 1983), and promoting basalt flows (Gottfried et al. 1983). During the time following the rifting, there has been deposition of sedimentary rocks in environments varying from open marine to coastal plain settings in northeastern Florida, depending on sea level. Rocks older than the Cenozoic are deeply buried in St. Johns County; at 620 m (2,035 ft) below sea level, the rocks are only as old as the Paleocene (Brown et al. 1986).

The sediments of the St. Augustine area were laid down south of the Southeast Georgia Embayment (or Okefenokee Embayment), and east of the Peninsular Arch (Puri and Vernon 1964); the area is a local structural high known as the St. Johns Platform (Lane 1994). Sporadic movements of the embayment affected the quantity of deposition during various periods, for example leading to very thick Miocene deposits (Huddleston 1988). The modern, relatively narrow shelf offshore from Georgia and northern Florida was formed during the Eocene. There had been a broader shelf before, including what is now the Blake Plateau, but the plateau submerged after the Middle Cretaceous (Dillon et al. 1978). Florida was generally under water in the Paleogene, with a shallow-water setting like the present-day Bahama Banks. These conditions led to thick fossiliferous limestone deposits. Rock fragments are uncommon in these deposits because the sources (the Appalachian Mountains) were distant and a powerful current running

in the Gulf Trough, in the vicinity of the Florida-Georgia border, swept away what was delivered to the area. Near the end of the Paleogene, the Appalachian Mountains were uplifted and shed enough material to fill in the trough. Combined with falling sea levels beginning in the Late Oligocene, more and more of the state was above sea level for longer and longer periods. Terrestrial exposure and deposition moved from north to south (Lane 1994).

An important feature of Atlantic Coastal Plain geology is the well-developed set of marine terraces, which document ancient shorelines. Over time, terraces formed progressively closer to the modern shore, in distance and elevation. There is a set of named terraces that are used in geologic descriptions. In Florida, from oldest to most recent, these include the Hazelhurst, Cohaire, Sunderland, Wicomico, Penholoway, Talbot, Pamlico, and Silver Bluff terraces (Healy 1975). These terraces were formed between the Pleistocene and the present in response to sea level fluctuations over a long period of marine regression (Colquhoun 1969; Richards et al. 1971). Penholoway, Talbot, Pamlico, and Silver Bluff marine terraces are present in St. Johns County (Readle 1983), and CASA is east of a relict Pamlico barrier island (Hoyt 1969). Terraces typically have a marine layer at the base with a thicker sequence of coastal terrestrial sediments above, such as beach sands, barrier island sands, estuarine or back-barrier sands and clays, and floodplain deposits left behind by receding shorelines (Thornberry-Ehrlich 2006). The terrace deposits are probably similar to those of Georgia's Coastal Plain, which include two major lithologies: linear sand ridges from old barrier islands, and clayey sand plains that represent back-barrier tidal lagoons or marshes (Radtko 1985). The respective heights of marine terraces above sea level in adjoining Duval County, 26 km (16 miles) north of St. Augustine, are 0-3.0 m (0-10 ft; Silver Bluff), 3.0-7.5 m (10-25 ft; Pamlico), 7.5-13.0 m (25-42 ft, Talbot), and 13.0-21.0 m (42-70 ft; Penholoway) (Phelps 1994). The youngest of these terraces, the Silver Bluff terrace, is over 40,000 years old (Booth et al. 1999).

Chronologically interspersed with the terraces are marine lowstands, some with sea levels significantly lower than the present as water was taken up into ice sheets during major ice advances in the Pleistocene ("Ice Age"). During the last maximum ice advance, 25,000 years ago, sea level dropped to about 122 m (400 ft) below the modern level. It began to rise again about 11,000 years ago, and rose rapidly until about 5,000 years ago, after which it then slowly rose to its present level (Griffin 1982), with fluctuations. Local sea level reached a lowstand of 3.0 to 4.0 m (9.8 to 13.1 ft) below the present sea level between 3,100 and 2,400 years ago, and then rose rapidly, leading to extensive erosion (Howard and DePratter 1978).

The Cenozoic formations of Florida, particularly those from the Neogene and Quaternary, have complex histories, with different correlations, ages, and names proposed for the rock units. Geologic dating can be problematic for several reasons. For example, the dating of the Pliocene-Pleistocene boundary worldwide is a current topic of dispute. A particular issue is the choice of dating method: aminostratigraphy (using amino acid changes in fossils) may produce significantly different results from radioisotope dating methods (compare Belknap and Wehmiller [1982]'s aminostratigraphic dates to radioisotopes dates from McCartan et al. [1982a, b] for several Pliocene-Pleistocene units of the Atlantic Coastal Plain). The stratigraphy is further complicated by the use of marine terraces in the Atlantic Coastal Plain. Some of the terrace terms have also been used for formations. While this practice is now discouraged (Huddleston 1988), it is something to watch for in older publications.

The surface geology of CASA is composed of Holocene sediments, with deposits of the Anastasia Formation (Pleistocene) nearby (Scott et al. 2001). The Holocene sediments were derived from a beach setting (Scott et al. 1986). Underlying rocks in the shallow subsurface, down to about 30 m (100 ft), include undifferentiated sand, clay, shell, and limestone dating from the Upper Miocene to the Holocene, over similarly heterogeneous deposits from a Hawthorn Group unit (Readle 1983; Spechler and Hampson 1984; Odum et al. 1997). All of these units are known to produce fossils (Spechler and Hampson 1984; Huddleston 1988; Odum et al. 1997), with some fossils in CASA museum collections curated at the Southeast Archeological Center (SEAC). Additionally, although the Anastasia Formation is not exposed at CASA, at least not in exposures large enough to have been mapped, fossilized shells from this unit have been used to construct Castillo de San Marcos itself.

Sources of Paleontological Resources

The fossils of CASA present opportunities for education, interpretation, and continued or future scientific research in the park. Aside from the material described in this section, fossils from CASA are stored at the Southeast Archeological Center (SEAC). These fossils are documented below, as part of the “Park Collections” section. There are also fossils found within cultural resource contexts in CASA as described in the “Fossils found in cultural resource contexts” section, below.

Anastasia Formation (Upper Pleistocene)

The Anastasia Formation is a sandy coquina, exposed along the east coast of Florida from Anastasia Island to Palm Beach (Stauble and McNeill 1985). Coquina is a type of poorly-consolidated limestone made up of shell fragments (Kenworthy and Santucci 2006). In the Anastasia Formation, mollusk shells are common, from whole specimens to fragments to molds. Both gastropods and bivalves are present, with the donacid clam *Donax* dominant (Stauble and McNeill 1985). Donacid clams are colloquially known as coquina, and the geological term “coquina” is derived from this name. Anastasia Formation coquina from nearby Anastasia Island was used to construct Castillo de San Marcos; the historic quarries are now part of Anastasia State Park. Thus, both the Anastasia Formation coquina and Castillo de San Marcos are composed of the archetypical coquina clam (Kenworthy and Santucci 2006).

The Anastasia Formation is interpreted as very shallow marine, deposited in settings from beach foreshore zones to barrier bars. The major period of deposition is dated to about 110,000 years ago (Stauble and McNeill 1985), although some deposition may have been substantially younger, as young as about 7,000 years ago for dunes and barrier islands (Portell et al. 2002). Successions of cemented and uncemented beds in this formation may represent beachrock on prograding shorelines (Missimer and McNeill 1992). Aside from mollusks, Anastasia Formation fossils include foraminifera (Cole 1931), coral (Lovejoy 1998), ghost crabs and their burrows (Portell et al. 2002), echinoids (Oyen and Portell 2001), and vertebrates (Stauble and McNeill 1985; Lovejoy 1998). One Anastasia Formation site that has produced vertebrate remains in St. Johns County is Wilson Coquina Quarry (now called Lakeview Dirt Company Quarry), about 8 km (5 miles) southwest of CASA (R. Hulbert, collections manager, Division of Vertebrate Paleontology, Florida Museum of Natural History, pers. comm., November 2008; R. Portell, collections manager, Division of Invertebrate Paleontology, Florida Museum of Natural History, pers. comm., January 2009). Vertebrates known from this site include sharks, rays, bony fish, frogs, salamanders, turtles, lizards, snakes, alligators, grebes, rails, armadillos, cricetid rodents, lagomorphs, camelids, deer, and gomphotheriid proboscideans (Florida Museum of Natural History 2008).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following formations within CASA, most of which would be found 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.

Mixed and undetermined formations (Upper Miocene to Holocene)

The underlying geology of St. Johns County has been described in several publications (Readle 1983; Spechler and Hampson 1984; Brown et al. 1986; Odum et al. 1997). Because the sediments nearest to the surface are most likely to be sampled, the following discussion will be confined to the sediments from the surface to 30 m (100 ft) below sea level. The components of the upper subsurface are an upper heterogeneous layer thought to be Late Miocene to Quaternary in age, over a heterogeneous unit identified as the Miocene-age Hawthorn Formation (now Hawthorn Group). Shells are known throughout the shallow subsurface (Readle 1983; Spechler and Hampson 1984; Brown et al. 1986; Odum et al. 1997).

The division between the two units varies by author. Odum et al. (1997) found the upper subsurface of St. Johns County to consist of 7 to 36 m (23 to 118 ft) of undifferentiated surficial deposits over 30 to 152 m

(100 to 500 ft) of Miocene-age Hawthorn Group (Hawthorn Formation of this reference) deposits. Spechler and Hampson (1984) found the upper subsurface to consist of 12 to 58 m (40 to 190 ft) of surficial deposits over 15 to 69 m (50 to 225 ft) of Miocene-age Hawthorn Group (Hawthorn Formation of this reference) deposits. Spechler and Hampson (1984) further split the surficial deposits into two subunits. The upper 6 to 27 m (20 to 90 ft) of the surficial deposits are from the Pleistocene and Holocene, and are made up of sand, clay, shells, and coquina. The Anastasia Formation is included in the upper section. The lower 6 to 30 m (20 to 100 ft) of the surficial deposits date from the Late Miocene and Pliocene, and are composed of sand, shell, and silty clay over limestone beds. In the area of CASA, there are about 9 m (30 ft) of undifferentiated Upper Miocene-Holocene deposits. Below this are roughly 43 m (140 ft) of Hawthorn Group (Formation of this reference) deposits (Spechler and Hampson 1984).

Hawthorn Group subsurface deposits in St. Johns County are composed of phosphatic sand, sandy clays, clayey sands, marl, sandy limestone (Spechler and Hampson 1984), silt, and dolomite, with some shell beds (Odum et al. 1997). Per Scott et al. (2001), the Hawthorn Group formation nearest to CASA is the Coosawhatchie Formation. The Coosawhatchie Formation is mostly made up of sand with some clay and phosphate and occasional beds of dolomite or limestone (Scott 2001), and dates to the Middle Miocene (about 13.8 to 11.6 Ma). The Coosawhatchie Formation includes several members that differ in composition. The Meigs Member is the lowest member in the west and the Tybee Phosphorite Member is the lowest in the east. The Berryville Clay Member is next highest, followed by the Ebenezer Member and finally, in some locations, the Charlton Member (formerly Charlton Formation). Of the five subunits, the Meigs Member and Tybee Phosphorite Member are the least likely to be present in the CASA area (Huddlestun 1988).

Of the other three Coosawhatchie Formation members, each is fossiliferous, but to different degrees. The Berryville Clay Member is the most clay-rich, and has a fossil fauna including nannofossils, silicoflagellates, diatoms, radiolarians, foraminifera, ostracodes, fish scales, and rare shelly material and barnacles. It is interpreted as a continental shelf deposit from the inner to probably middle neritic zone. The Ebenezer Member is sandy and generally unfossiliferous, except for molds and casts of bivalves and other mollusks, and fine vertebrate debris like fish scales. It is regarded as a nearshore (but not coastal) marine deposit from the inner neritic part of a continental shelf, under relatively cool conditions (Huddlestun 1988). The Charlton Member (formerly Charlton Formation) is made up of carbonate-rich silty to sandy clays. It is locally fossiliferous (Scott 2001), and is known to produce foraminifera, gastropods and other mollusks, barnacles, and echinoids (Jones and Portell 1988). Shells are often preserved as internal or external molds (Auffenberg and Portell 1990).

Other fossils that are known from Miocene or Pliocene deposits in the area include sirenian rib fragments, which are common in shallow-water and estuarine deposits from the Miocene (particularly the Hawthorn Group) and Pliocene in Florida (Simpson 1932), and microfossils. In 1886, diatoms, foraminifera, polycystine radiolarians, and sponge spicules were recovered from clay layers at levels of 27 and 37 m (90 and 120 ft) in an artesian well sunk at a St. Augustine hotel. At the time, the deposits could only be dated to the Miocene or Pliocene (Boyer 1895).

Surficial Quaternary rocks and sediments (Pleistocene-Holocene)

The surficial deposits of CASA have not been assigned to a formation, although the presence of Pamlico and Silver Bluff marine terraces indicates that the Satilla Formation nomenclature of Huddlestun (1988) would be applicable for at least some of the sediments. The Satilla Formation is composed of shoreline complex deposits from the Pamlico, Princess Anne, Silver Bluff, and Holocene marine terraces, and includes clay-rich back-barrier deposits, sandy barrier island deposits, and shelly sands and clays from offshore continental coast settings. The four marine terraces formed at different times during the deposition of the Satilla Formation. The Satilla Formation is regarded as Late Pleistocene to Holocene in age (roughly 126,000 thousand years ago to the present). Typical fossils include burrows, foraminifera, bivalves and other mollusks (Huddlestun 1988; Pirkle et al. 2007), and vertebrates including fish, turtles, crocodilians, ground sloths, castorid rodents, tapirids, equids, deer, bovids, and proboscideans

(Markewich et al. 1992). The term “Satilla Formation” was only brought into use in 1988, so most references use marine terrace names for identification of deposits, or do not assign the deposits to a formation.

Invertebrate fossils are common in the undifferentiated surficial Quaternary deposits in the vicinity of CASA. CASA is underlain by shelly sand and clay (Scott 1979), and shells have been mentioned in passing for Quaternary-age deposits in the vicinity of CASA (Scott 1979; Spechler and Hampson 1984; Odum et al. 1997). Beaches in the vicinity of CASA are known to produce shells ranging in age from the Pleistocene to the modern (Martens 1931, 1935; Scott et al. 1986). Crustacean burrows are known in other Pleistocene and Holocene coastal sediments, particularly those from high-energy littoral and shallow neritic settings (Weimer and Hoyt 1964), so may be present at CASA as well.

Vertebrate remains are also known from the deposits in the area. Remains of Pleistocene animals including the sea turtle *Trachemys* (Hay 1916), deer, bison, mastodon, and mammoth are known from Station 120, a site on the Intracoastal Waterway 32 km (20 miles) north of St. Augustine. Similar remains are known from Allen’s Farm, a site 32 km (20 miles) south of St. Augustine on the Intracoastal Waterway. Mammals from this site include ground sloths, cetaceans, horses, mastodons, and mammoths (Simpson 1929). Fossils of the turtles *Gopherus* and *Hesperotestudo* have been found at Jacksonville Beach, about 45 km (28 miles) north of St. Augustine (Franz and Quitmyer 2005). A fossiliferous Pleistocene conglomerate about 87 km (54 miles) northwest of St. Augustine, at Stokes Ferry on the St. Mary’s River, has produced a shark tooth, a turtle shell fragment, whale ear bones, and horse and mammoth teeth (Matson and Clapp 1909). Fossils of the ground sloth *Paramylodon* (*Mylodon* at the time) are mentioned in passing from the Pleistocene of St. Johns County, although the location is not certain. The location was given as Sarasota, St. John County (Holmes and Simpson 1931), but there does not appear to be a Sarasota in St. Johns County. Sirenian rib fragments, while not as common as in Miocene and Pliocene deposits, are present in marine and river deposits of the Pleistocene (Simpson 1932).

Park Collections

There are twelve CASA specimens repositated at the Southeast Archeological Center (SEAC). All of the specimens are chondrichthyan fossils from the Castillo de San Marcos Complex. Given the description and the types of fossils common along the southeast coast, they are probably shark teeth. CASA 5048, 5089, 5471, 5671, 5872, 6169, and 6405 are single specimens, CASA 6055 is a lot of two specimens, and CASA 6325 is a lot of three specimens (B. Carter, SEAC supervisory museum specialist, pers. comm., August 2008). No definite fossils are housed at CASA, although younger shells, bones, and bone fragments are known (A. Rich, CASA resource program manager, pers. comm., October 2008).

Fossils Found in Cultural Resource Contexts

CASA has a notable place in the category of fossils associated with cultural resources. Castillo de San Marcos, as noted above, is composed of the archetypical “coquina clam” that lent its name to the geological term coquina (Kenworthy and Santucci 2006). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts, including at CASA.

Although the coquina fort is the most obvious example of fossils in a cultural context at CASA, there are many archeological sites in northeastern Florida that include shells, bones, and tools, so there may be older archeological specimens in the subsurface of the park. Coquina clams from two midden sites in the vicinity of CASA, among several other sites in northeastern Florida, have been used for stable isotope analyses intended to examine Holocene climate. The Guana Shell Ring about 19 km (12 miles) north of St. Augustine, has shells from the Orange Period, about $3,600 \pm 50$ radiocarbon years before present (ybp) or $3,516 \pm 128$ calendar years ago (radiocarbon years must be calibrated to yield calendar years; this calibration was made using Calib 5.0.2 [<http://calib.qub.ac.uk/calib/>]). The SAUFL Station at Crescent

Beach, 19 km (13 miles) south of St. Augustine, has shells from about $4,240 \pm 60$ radiocarbon ybp, or $4,342 \pm 226$ calendar ybp. One *Donax* shell was used from each site. High warm season temperatures, as interpreted from stable oxygen isotope ratios, may indicate greater seasonality at the time the organisms in the shells were alive (Jones et al. 2005).

Other archeological sites in the region also have vertebrates. Fossils of the tortoise *Gopherus* are known from sites at Crescent Beach, 19 km (13 miles) south of St. Augustine [about 2 km (1.25 miles) north of FOMA], and Summer Haven, 26 km (16 miles) south of St. Augustine [about 1 km (0.6 miles) southeast of FOMA]; specimens at both of these sites are about 5,000 to 2,500 years old (Franz and Quitmyer 2005).

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division has not yet conducted a geologic resource scoping session for CASA.
- SECN parks such as CAHA, CALO, CANA, CASA, CUIS, FOCA, FOFR, FOMA, FOPU, FOSU, and TIMU are geologically very young, making it difficult to determine what material is a “fossil” and what would be considered “modern.” The National Park Service defines a fossil as any remains of life preserved in a geologic context. This definition does not include an arbitrary date where older specimens are considered fossils, and younger specimens are not. The “geologic context” phrase is intended to imply some level of antiquity, however. Generally, specimens dating back to the late Pleistocene are considered fossils. Late Holocene (last few hundred or thousand years, “Recent”) specimens are usually considered modern and not fossils. Pleistocene remains may differ from younger remains by having dark staining and being heavily worn and bored, but this does not always hold true. Surface and subsurface specimens collected at CASA span this range between Pleistocene and Holocene. Regardless of what label is assigned to them, these specimens are important natural resources and valuable pieces of the history of life on earth.
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Southeast Archeology Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at CASA.

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Data Sets

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

Southeast Archeological Center (SEAC)
1924–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by SEAC staff; status: Active.

Chattahoochee River National Recreation Area

Chattahoochee River National Recreation Area (CHAT) was established to preserve significant cultural and natural sites along the Chattahoochee River in the Atlanta area. CHAT was established August 15, 1978, and had a boundary change October 30, 1984. It encompasses 3,751.72 ha (9,270.70 acres), 1,949.27 ha (4,816.75 acres) of which are under Federal administration.

Geologic Background

CHAT follows the Chattahoochee River along the borders between several counties northeast to north of Atlanta, Georgia. The counties on the northwest side of the river, from north to south, are Forsyth, Fulton, and Cobb, and those on the southeast are Gwinnett, DeKalb, and Fulton (the park cuts through Fulton County). The lands administered by CHAT are split into many small units that are separated by private land. From northeast to southwest, the named Federal units include Bowmans Island, Orrs Ferry, Settles Bridge, McGinnis Ferry, Suwanee Creek, Abbotts Bridge, Medlock Bridge, Jones Bridge, Chattahoochee River Environmental Education Center (CREEC), Holcomb Bridge, Island Ford, Vickery Creek, Gold Branch, Johnson Ferry, Cochran Shoals, and Palisades.

The Atlanta area lies mostly within the Piedmont physiographic province, divided into northern and southern components by the Brevard Zone (McConnell and Abrams 1984, although note that the Brevard Zone is sometimes used to divide the eastern Blue Ridge physiographic province from the Piedmont), a large strike-slip fault zone last active about 300 Ma (millions of years ago) (see Figure 2 for a geologic time scale) (McConnell and Costello 1980). CHAT is mostly found in the Brevard Zone (McConnell 1980), but also passes through the northern and southern Piedmont (McConnell and Abrams 1984).

The Atlanta area was added to North America during the events that led to the formation of the supercontinent Pangaea, during the Paleozoic. The Allatoona and Hayesville faults, northwest of the metro region, mark the boundary between an old North American margin on the northwest side and accreted lands on the southeast side (Holm and Farmer 2002; Eckert and Hatcher 2003). The accreted lands included slivers of oceanic crust and Ordovician-age volcanic island arcs (Eckert and Hatcher 2003). These terranes were added about 460 Ma as the basin between the arc and North America was subducted, during a mountain-building event known as the Taconic Orogeny (Hatcher 2001).

In the Georgia Piedmont, extensive deformations of the existing rock took place throughout most of the Paleozoic. Metamorphism peaked about 370 to 360 Ma (Dallmeyer 1978), and igneous rocks intruded at the same time or slightly before (McConnell and Abrams 1984). Another episode of igneous intrusion around 300 Ma was responsible for the formation of the granites of several Atlanta-area landmarks, such as Panola Mountain (Atkins and Griffin 1977) and Stone Mountain, dated to approximately 291 Ma (Whitney and Jones 1976). These igneous bodies are related to the Pennsylvanian-age Alleghenian Orogeny, the final stage of the formation of Pangaea, when Africa and North America collided. North America and Africa then rifted apart during the Late Triassic and Jurassic, and are still moving apart today. Deposition younger than the Paleozoic is not recorded in the Atlanta area, except as Quaternary surficial soil and river deposits. Crystalline rocks (igneous, or previously molten) persist at or near the surface until the Fall Line (about 110 km or 70 miles southeast of the metro area) (Lawton et al. 1976).

CHAT is underlain by several metamorphic rock units. These rocks have complicated structural geology and are difficult to interpret, with multiple naming schemes and interpretations since the late 1970s (Higgins and McConnell 1978; Abrams and McConnell 1984; McConnell and Abrams 1984; Higgins et al. 1988; Crawford et al. 1999). Therefore, terminology will vary by source. Higgins et al. (2003) is used for this report. The rocks exposed at CHAT include, roughly from oldest to youngest: the Long Island Creek Gneiss from sometime between the Precambrian and the Permian; several units from sometime between the Precambrian and Ordovician, including an informal mixed unit, the Crider Gneiss, a garnet-rich schist, the Ropes Creek Metabasalt, and the Powers Ferry Member of the Stonewall Gneiss; muscovite

quartzite, aluminous schist, and the Chattahoochee Palisades Quartzite of the Sandy Springs Group (Cambrian; the latter named for exposures at CHAT's Chattahoochee Palisades [Higgins and McConnell 1978]); and an unnamed button schist and sheared amphibolite from sometime between the Late Ordovician and Permian, derived from shearing of the informal mixed unit (Higgins et al. 2003). Additionally, the Lithonia Gneiss (Devonian per Higgins et al. 2003) and another button schist unit (Upper Ordovician-Permian) may be present, but Higgins et al. (2003) does not include all of CHAT. There are also Quaternary deposits associated with the Chattahoochee River (Higgins 1968). These Quaternary river deposits are the only potentially fossiliferous units at CHAT. Fossils associated with cultural resources are another possibility.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following formations or cultural resource settings (see "Fossils found in cultural resource contexts section") within CHAT. However, these units are known to preserve fossils elsewhere, and future field investigations within the park may recover fossils from one or both (or none) of them.

Quaternary rocks and deposits (Pleistocene-Holocene)

The Chattahoochee River has left Quaternary-age deposits in CHAT. Because the local bedrock contains no fossils, there will be no reworked fossils from these units in the Quaternary deposits. Quaternary fossils such as algal cysts, pollen, leaves, and wood may be present in the deposits. Fossils like these are found in former marshy areas at Congaree National Park (CONG), another Southeast Coast Network park with active rivers (see the CONG chapter of this report for a detailed discussion). If present, such fossils could be useful for paleoclimatological and paleoecological studies.

Park Collections

There are no known CHAT specimens in the collections database of the Southeast Archeological Center. Rick Slade (CHAT resource program manager, pers. comm., September 2008) reported that there were no paleontological specimens in CHAT collections.

Fossils Found in Cultural Resource Contexts

CHAT is rich in archeological resources. Because of this, there is the possibility of finding fossils associated with cultural resources, such as fossils altered or modified by humans. Remains of the biota that was contemporaneous with these archeological resources are also of paleontological interest. People are known to have been present at CHAT from about 10,000 to 8,000 years ago to the present. As of 1982, 70 archeological sites were known in CHAT. 47 of these pertain to prehistoric Indians and the other 23 are historic. The heaviest usage of sites occurred during the Woodland Period, from about 3,000 to 1,000 years ago. Sites are also known from the Archaic (10,000 to 8,000 years ago) and Mississippian (1,000 to 350 years ago) periods. The inhabitants left behind rock shelters, fish weirs, special-use areas, villages, and camps (Ehrenhard 1982). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division has not yet conducted a geologic resource scoping session for CHAT
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock

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

- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Southeast Archeology Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at CHAT.

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Data Sets

Chattahoochee River National Recreation Area Paleontological Archives

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

Congaree National Park

Congaree National Park (CONG) preserves the largest remaining tract of southern bottomland hardwood forest in the United States. The park was originally set aside for this forest ecosystem, its biodiversity, and the champion size of its old-growth trees—which include several state and national champions. CONG was authorized as a National Monument October 18, 1976, and underwent boundary changes October 24, 1988 and November 10, 2003, after which it became a National Park. CONG was designated a Biosphere Reserve in 1983, and a wilderness area was designated within CONG October 24, 1988. CONG encompasses 10,742.73 ha (26,545.86 acres), of which 8,809.52 ha (21,768.79) are under Federal administration. 6,070.28 ha (15,000 acres) of the total area are included in the wilderness area.

Geologic Background

CONG is located in southern Richland County, on the north side of the border with Calhoun County, within the Inner or Upper Coastal Plain province in central South Carolina. The Congaree River forms the southern border of the park, and the Wateree River forms the eastern border. The Federal portion of CONG is split into two sections by a parcel of privately-held land, resulting in a larger western section and a smaller eastern section. CONG is about 24 km (15 miles) southeast of Columbia, the capital of South Carolina. The Orangeburg Scarp, separating the Inner Coastal Plain from the Middle Coastal Plain, is found to the southeast of CONG. The Fall Line, separating the Piedmont from the Coastal Plain, is north of CONG in the vicinity of Columbia, about 32 km (20 miles) away. Geologic, geomorphic, and hydrogeological aspects of CONG have been the subjects of publications, abstracts, theses, and dissertations (Patterson et al. 1985; Rikard 1988; Cooney 1990; Cohen et al. 2004, 2005a, b, 2006; Shelley et al. 2004, 2008; Shelley and Meitzen 2005; Shelley 2007).

In general, the east coast of the United States has had relatively little tectonic activity since the events surrounding the formation and subsequent rifting of the supercontinent Pangaea. In the area of the Southeast Coast Network, this activity involved Africa and North America. The collision of these two continents was the culmination of a long series of events, with multiple deformations recorded in the Appalachian Mountains. In western South Carolina, at least four episodes of deformation occurred from before 315 Ma (million years ago) to about 267 Ma. Associated with these deformations were metamorphism and intrusion of igneous rocks (Secor et al. 1986). North America and Africa rifted apart during the Late Triassic and Jurassic, and are still moving apart (see Figure 2 for a geologic time scale).

During the time following the rifting, there has been deposition of sediment in environments varying from open marine to coastal plain settings in South Carolina southeast of the Fall Line, depending on sea level. Triassic and Jurassic basalts and sedimentary red beds filled the new rift valleys, and were in turn overlain by Coastal Plain sediments (Gohn et al. 1983; Gottfried et al. 1983). The Coastal Plain sediments of South Carolina form a wedge-shaped package of rocks and unconsolidated deposits, over 1.6 km (1 mile) thick near the coast in southeastern South Carolina but disappearing at the Fall Line to the west (Rankin 1977). In general, locations in South Carolina in the Inner Coastal Plain have some combination of Cretaceous, Paleocene, and Eocene rocks, with isolated exposures of Pliocene and Pleistocene rocks (Kite 1987, 1988). There are sometimes Miocene rocks as well (Johnson 1959; Kite 1988). At CONG, pre-Cretaceous rocks of igneous and metamorphic origins are found beneath approximately 150 m (500 ft) of younger unconsolidated sand and clay layers. The unconsolidated sediment has as its base roughly 45 m (150 ft) of sediments from the Upper Cretaceous Middendorf Formation, overlain by 90 m (295 ft) of an Upper Cretaceous unit equivalent to the Black Creek Group, and finally 17 m (55 ft) of Holocene alluvium (Patterson et al. 1985). There has also been some faulting since the Miocene. The Bates Mill Creek Fault runs through CONG, and there is 18 m (60 ft) of up-to-the-west motion between contacts in the Gadsden and Wateree 7.5 minute quadrangles, with most of the west part of CONG in the Gadsden quadrangle and most of the east part of CONG in the Wateree quadrangle (Shelley 2007a; D. Shelley, education coordinator, Old-Growth Bottomland Forest Research and Education Center, CONG, pers. comm., October 2008).

CONG has had only terrestrial deposition since the Pliocene, with the Pliocene-age Duplin Formation being the youngest exposed marine unit in the area, and the Orangeburg Scarp to the southeast forming a Pliocene shoreline (DuBar and DuBar 1980). Southeast of the Orangeburg Scarp are marine terraces formed from the Pleistocene to the Holocene, showing the locations of ancient shorelines from the long stretch of time persisting to the present when sea level were generally falling and leaving their mark closer and closer to the modern shoreline (Colquhoun and Johnson 1968; Colquhoun 1969; Richards et al. 1971). Fluvial terraces in the Congaree River valley and elsewhere on the Coastal Plain are related to the marine terraces, although establishing direct correlations between fluvial and marine terraces is problematic (Shelley 2007a, b). The climate of the Coastal Plain as far back as perhaps 140,000 years ago has been studied using pollen and other fossils buried in the sand sheets that have filled the oriented elliptical depressions known as Carolina bays. Carolina bays are not present in the floodplain deposits that underlie CONG, but a Carolina bay in the vicinity of the Congaree-Wateree river junction that forms the southeast corner of CONG shows several distinct plant assemblages. These include a base with pollen from a warm open environment either 134,000 to 75,000 years ago or 65,000 to 32,000 years ago, middle deposits from a cool environment perhaps 75,000 to 65,000 years ago, and upper deposits from a cool and dry or warm and dry setting (Brooks et al. 2001).

The surficial geology of CONG is composed of Quaternary alluvium of the Congaree River Floodplain Complex and Pliocene-Pleistocene river valley terrace deposits of the Congaree River Terrace Complex, with small exposures of Pliocene-age Duplin Formation deposits. CONG is underlain by Upper Cretaceous Sawdust Landing rocks and undifferentiated Upper Cretaceous rocks. Other units may contribute rocks and sediment to CONG by eroding into the Congaree or Wateree rivers that form some of CONG's borders. These units include, from oldest to youngest, the Lang Syne Formation (Upper Paleocene), Congaree Formation (Middle Eocene), Warley Hill Formation (Middle Eocene), and Orangeburg District bed (upper Middle Eocene) (Willoughby 2003; Shelley 2007a, b). With the exception of the Warley Hill Formation, these units are found in the steep bluffs on the south side of the Congaree River, just outside of CONG's borders. All of the units present in the park or immediately adjacent to it are fossiliferous to some extent, with definite CONG fossils known from an unknown Cretaceous unit and the Congaree River Floodplain Complex (see below).

Sources of Paleontological Resources

The fossils of CONG present opportunities for education, interpretation, and continued or future scientific research in the park. Bone fragments from CONG may have been found in a cultural resource context as described in the "Fossils in cultural resource contexts" section.

Undifferentiated Upper Cretaceous rocks

The undifferentiated Upper Cretaceous rocks in the CONG region consist of deposits that vary in composition from sand to clay, mostly coarse to very coarse sand. Many Cretaceous rock units are difficult to distinguish at a regional scale in South Carolina; Shelley (2007a, b) suggests that the deposits immediately below the Sawdust Landing Formation in the CONG area are probably from the Peedee Formation, but may also include Black Creek Group strata and Cape Fear Formation correlatives; these three units are briefly described below. Several graded sequences are present.

CONG naturalist Fran Rametta reported to David Shelley (pers. comm., September 2008) that drilling operations at CONG in the early to mid 1980s recovered echinoid spines and shark teeth. Shelley reported that these would have to be of latest Cretaceous age, probably from the Maastrichtian faunal stage (about 70.6 to 65.5 Ma). Patterson et al. (1985) did not report on the presence or absence of fossils in their lithologic logs from CONG. David Shelley (pers. comm., September 2008) has collected Cretaceous fossils from the bluffs south of the Congaree River, just south of CONG. These could pertain to any of the named Cretaceous formations known from the area.

For reference, the Cape Fear Formation is made up of sand, mud, and clay beds, thought to be from marine, estuarine, and lagoonal environments (Carter et al. 1988) or a tide-dominated delta system (Gohn 1992). It was deposited during the Late Cretaceous between 89 and 86 Ma (Campbell et al. 1996). Fossils from the Cape Fear Formation include nannofossils (Gohn 1992) and plant palynomorphs (organic microfossils such as pollen and spores) (Carter et al. 1988).

What had been called the Black Creek Formation has been raised to group status as the Black Creek Group, with several formations included in it (Owens 1989; Sohl and Owens 1991). In South Carolina, the formations included, from top to bottom, are the Donoho Formation, the Bladen Formation, the Coachman Formation, and the Cane Acre Formation (Campbell et al. 1996). The division of the Black Creek Formation was published relatively recently, so references older than 1990 likely include everything as the Black Creek Formation. The Black Creek Group is approximately 81 to 72 million years old (Campbell et al. 1996). Black Creek Group deposits are generally composed of dark, thinly-bedded clays, stringers of fine sand, and thick lenses of cross-bedded sand (Carter et al. 1988). Depositional settings include deltas (Straight et al. 1997; Ross and Cuffey 2003), tidal flats and channels, estuaries, and shallow marine bays (Carter et al. 1988). Fossils of the Black Creek Group include pollen, diverse fossil plants, wood, amber, trace fossils, marine invertebrates, sharks, bony fishes, turtles, marine reptiles, crocodilians (Robb 1989b), several types of dinosaurs (Weishampel et al. 2004), and birds (Straight et al. 1997).

The Peedee Formation is a heterogeneous, extremely fossiliferous unit composed mostly of sand, clayey sand, and clay, with some clayey or sandy limestone. It was mostly deposited in open marine settings (Carter et al. 1988) with some shallower shelf deposits (Cunliff and Textoris 1969; Hattner and Wise 1979), and dates to the late Maastrichtian faunal stage (Self-Trail et al. 2002), between 68.5 and 65.5 Ma. Fossils from the Peedee Formation include algae (Dockal et al. 1998), plants, trace fossils (Carter et al. 1988), nannofossils, foraminifera (amoeba-like shelled organisms), bryozoans, brachiopods (Dockal et al. 1998), cephalopods, gastropods, bivalves, scaphopods (Carter et al. 1988), ostracodes (small shelled crustaceans; Van Nieuwenhuise and Kanes 1976), starfish (Blake and Sturgeon 1995), echinoids (Carter et al. 1988), sharks, rays, bony fishes (Robb 1989a), mosasaurs (Blake and Sturgeon 1995), and indeterminate vertebrate teeth and bones (Carter et al. 1988). Peedee Formation fossils are particularly notable in that the hard part of a Peedee Formation belemnite (an extinct type of cephalopod) from South Carolina was used to establish the PDB (Peedee Belemnite) standard for stable oxygen isotopes (Boggs 2001).

Congaree River Floodplain Complex (Pleistocene-Holocene)

Quaternary floodplain deposits at CONG are made up of sand, clay, and peat. They were deposited in a number of different settings, including intra-floodplain terraces, meanderbelts, alluvial fans, dune fields, and rimswamps, and are collectively termed the Congaree River Floodplain Complex (Shelley and Cohen 2007). Such deposits form the surficial geology of much of CONG, where they were mostly deposited by the Congaree River, with some contribution from the Wateree River along the eastern border (Willoughby 2003; Shelley 2007a, b).

Late Quaternary microfossils are known from a peat deposit in Muck Swamp at CONG, which is a groundwater rimswamp on the northern margin of the Congaree River Valley (Shelley et al. 2004; Cohen et al. 2004, 2005a, b, 2006). These deposits, which are approximately 3 m (10 ft) thick, include three lithostratigraphic intervals: a basal peaty clay (3.0-2.6 m or 9.8-8.5 ft), overlain by a thick interval of muck and peat (2.6-0.2 m or 8.5-0.7 ft), in turn capped by a thin stringer of clay at the surface (0.2-0.0 m or 0.7-0.0 ft). The peat deposits at Muck Swamp are older and thicker than comparable deposits in the Southeast (Cohen et al. 2005a, b). These fossils include pollen, spores, plant fragments, diatoms, and freshwater sponge spicules. Microtome sections of the peat also display micro-trace fossils. The pollen samples and residues reside in Art Cohen's laboratory at the University of South Carolina (D. Shelley, pers. comm., September 2008). Systematic analysis of pollen and peat petrography indicates that the deposit can be divided into four zones with distinct paleoecological associations (Cohen et al. 2005b).

Zone 1 corresponds to the oldest lithostratigraphic interval, Zones 2 and 3 make up the middle interval, and Zone 4 makes up most of the upper interval.

The oldest lithostratigraphic interval has been dated by radiocarbon to approximately 21,000 years old (Shelley et al. 2004). Fossils from this interval include pollen from spruce, evening primrose, and short-spined members of the aster family, and a variety of indicators of ponded conditions, including algal remains, freshwater diatoms, water lily debris, and sponge spicules. These suggest an ox-bow lake setting under colder and drier conditions than the present (Cohen et al. 2004, 2005b). Pollen from this interval was also assigned to hemlock (*Tsuga*), but this may be a misidentification (D. Shelley, pers. comm., November 2008). The deposit is interpreted to represent river, floodplain, and oxbow lake deposits, capped by organic-poor sediments from a pause in deposition (Shelley et al. 2004).

The middle lithostratigraphic interval has produced charcoal, fungal spores, pollen, and fecal pellets (Shelley et al. 2004). Plant fossils are dominated by gum, holly, hickory, elm, sweetgum, and heath pollen, along with sedges and spores from ferns and mosses. The only radiocarbon date currently available at CONG indicates that these deposits were accumulating by 3,500 years ago, but this is likely a young date as regional wetland deposits record a pulse of deposition beginning between 4,000 and 7,000 years ago (D. Shelley, pers. comm., November 2008). This interval is thought to represent a non-ponded wetland, and has been divided into two paleoecological zones (Cohen et al. 2004). Zone 2, the lower portion of the middle interval, has increases in oak, chestnut, juniper, hickory, walnut, and elm pollen, and the disappearance of spruce. The presence of emergent aquatic plants like arrowhead, pipewort, and pickerel weeds suggests a shift to a relatively shallow open marsh, with occasional prolonged periods of standing water that supported floating aquatics. Zone 3 above has increases in pine, sweetgum, alder, and maple pollen, and the appearance of tupelo, cypress, and magnolia pollen, which suggest warm temperate swamps. Herbaceous plants present indicate intermittent wet and dry periods and relatively unshaded conditions (Cohen et al. 2005b).

The upper lithostratigraphic interval is dominated by inorganic sediments. Palynological remains in this upper interval are somewhat similar to those in the middle interval (Cohen et al. 2004), but there are increases in tupelo, holly, heath, and ferns compared to the lower zones (Cohen et al. 2005b). This interval, along with 40 cm (16 in) of the interval below, represent the paleoecological Zone 4 of the deposit. The flora is similar to what is seen today in southeastern warm temperate coastal plain river swamps. Zone 4 is thought to represent a forested wetland controlled mostly by groundwater flow from the bluffs (Cohen et al. 2005b). Environmental changes indicated here are likely related to local land use changes; alternatively, they may reflect the influence of the Saluda Dam, which began regulating the flow of the Congaree River in 1930 (Shelley et al. 2004).

Muck Swamp has the best-known paleontological resources at CONG, but other fossils are known or are very likely present. A very recent specimen (perhaps 1,000 years old), consisting of freshwater mussel periostracum (cuticle), was recovered from an abandoned channel called Tom's Slough by David Shelley (pers. comm., September 2008). Burrows are also common, especially crayfish burrows, but are poorly preserved (D. Shelley, pers. comm., September 2008). Floodplain deposits likely contain rare, poorly preserved materials including woody debris, additional freshwater mussels, and rare vertebrate remains (D. Shelley, pers. comm., September 2008).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following formations or resource settings within CONG, most of which would be found below the land surface or just outside of the park, near enough to contribute eroded material to the drainage running through CONG. 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.

David Shelley (pers. comm., September 2008) has collected Cretaceous, Paleocene, and Eocene fossils from the bluffs south of the Congaree River, just south of CONG. There are several formations in the bluffs that could have been sources for these fossil. The presence of fossils in the bluffs raises the possibility of fossils eroding from them and becoming deposited on the CONG side of the river.

Sawdust Landing Formation (Upper Cretaceous)

The Sawdust Landing Formation is composed of interbedded sand and clay at its base, grading upward into clayey sand and grit (Nystrom 1989; Shelley 2007a, b). It was first described as the Sawdust Landing Member of the Rhems Formation (Muthig and Colquhoun 1988), and is interpreted as representing an upper delta plain environment (Shelley 2007a, b). The name Sawdust Landing Formation is sometimes used in preference to Rhems Formation (Fallaw and Price 1992). It had been thought to date from the early Paleocene (Nystrom 1989), but is now dated to the Late Cretaceous (Fredericksen 2000; Christopher and Prowell 2002), 70.6 to 65.5 Ma. Fossils in the Sawdust Landing Formation include palynomorphs (Fredericksen 2000; Christopher and Prowell 2002).

Exposures of the Sawdust Landing Formation are found in the bluffs south of CONG on the opposite side of the Congaree River, and the formation is also present in the subsurface of part of CONG. Bluff exposures can be as close as about 95 m (310 ft) south of CONG, so it would not be difficult for eroded Sawdust Landing Formation material to be redeposited on the CONG side of the river.

Lang Syne Formation (Upper Paleocene)

The Lang Syne Formation, like the Sawdust Landing Formation, was first identified as a member of the Rhems Formation (Muthig and Colquhoun 1988). It is also equivalent to part of the Ellenton Formation, a term which is sometimes abandoned in favor of the Lang Syne Formation (Fallaw and Price 1992). The Lang Syne Formation is mostly composed of clay, with some sand (Shelley 2007a, b); black clay is a characteristic lithology near the top of the unit (Willoughby 2003). It is interpreted as representing a lower delta plain (Shelley 2007a, b). Fossils indicate it was deposited during the Late Paleocene (Fallaw and Price 1992), between 61.1 and 55.8 Ma. The Lang Syne Formation preserves fossils including trace fossils (Shelley 2007a, b), nannofossils, dinoflagellates (Fallaw and Price 1992), and silicified shell hash containing abundant gastropods and bivalves (Shelley 2007a, b). Exposures of the Lang Syne Formation are found in the bluffs south of CONG on the opposite side of the Congaree River. Bluff exposures can be as close as about 120 m (400 ft) south of CONG.

Congaree Formation (Middle Eocene)

The Congaree Formation is a sand unit (Nystrom 1989), with some silica cement (Carver 1980). In the CONG region, Congaree Formation deposits are mostly fine to medium quartz sand, with lenses of coarser sand, glauconitic sand ("greensand"), and clay (Shelley 2007a, b). It is interpreted as an inner shelf to littoral unit (Fallaw et al. 1995), and grades into the Huber Formation farther from the coast (Nystrom and Willoughby 2000). Congaree Formation fossils include nannofossils (Laws et al. 1992), dinoflagellates (Lucas-Clark 1992), bivalves (Nystrom and Willoughby 2000) and other mollusks (Nystrom et al. 1988), found in shell hashes and altered to silica (Shelley 2007a, b). This deposit is at least Middle Eocene (48.6 Ma) in age (Harris et al. 1997). Exposures of the Congaree Formation are found in the bluffs south of CONG on the opposite side of the Congaree River. Bluff exposures can be as close as about 135 m (440 ft) south of CONG (Shelley 2007a, b).

Warley Hill Formation (Middle Eocene)

The Warley Hill Formation is a clayey sand unit (Nystrom et al. 1988) with abundant glauconite that helps distinguish it from other Eocene formations in the CONG area (D. Shelley, pers. comm., October 2008). It is interpreted as representing deeper water environments than the Congaree Formation, with which it intergrades in places (Colquhoun et al. 1969). Fossils in the Warley Hill Formation include nannofossils (Laws et al. 1992), dinoflagellates (Lucas-Clark 1992), bryozoans (Willoughby 2007), bivalves (Nystrom and Willoughby 2000) and other mollusks, echinoids (Willoughby 2007), and shark teeth (Willoughby

2003). It was deposited in the Middle Eocene, either close to the middle (Harris et al. 1997; between 48.6 and 40.4 Ma), or shortly thereafter (Shelley 2007a, b).

The Warley Hill Formation is mappable in the Fort Motte 7.5 minute quadrangle, south of CONG (Willoughby 2003), but becomes very patchy and thin in this quadrangle. David Shelley (pers. comm., October 2008) reports that it disappears in the Gadsden and Wateree quadrangles, perhaps because it eroded before the deposition of the overlying Orangeburg District bed, transitioned to a less distinct lithology, or weathered to the point of being unrecognizable. It is included in this report because of the latter possibility.

Orangeburg District bed (upper Middle Eocene)

The Orangeburg District bed is an informal name for a layer that had been considered the upper part of the McBean Formation (Dockery and Nystrom 1992a). It is mostly composed of sand with variable amounts of interstitial clay, and is thought to be a shallow marine deposit (Shelley 2007a, b). The Orangeburg District bed is known to have preserved a diverse fauna of mollusks that have been replaced by silica (Dockery and Nystrom 1992a, b). It was deposited late in the Middle Eocene (Shelley 2007a, b; sometime between about 40.4 and 37.2 Ma). Exposures of the Orangeburg District bed are found capping the bluffs south of CONG on the opposite side of the Congaree River. Bluff exposures can be as close as about 245 m (800 ft) south of CONG (Shelley 2007a, b).

Duplin Formation (Pliocene)

The Duplin Formation and the approximately equivalent Yorktown Formation are heterogeneous Pliocene units found from Virginia to at least South Carolina. The division between the two formations is the Neuse River, with the Yorktown Formation being the name commonly used north of the river and the Duplin Formation commonly used south of it. The two are differentiated by fauna and geography instead of rock type, with the Duplin Formation fauna being more diverse and adapted to a warmer, tropical to subtropical environment (Carter et al. 1988). In South Carolina, the Duplin Formation is interpreted as having formed in a brackish to open marine environment (Campbell et al. 1975). In the CONG area, the Duplin Formation is characterized by quartz grains of medium sand to granule size with some clay (Shelley 2007b). The Duplin Formation preserves foraminifera, corals, bryozoans, gastropods, bivalves (DuBar and Howard 1964), scaphopods, chitons (DuBar and Solliday 1961), barnacles, ostracodes, echinoids (DuBar and Howard 1964), sharks, reptiles, whales, and terrestrial mammals (Carter et al. 1988). Although diverse fossils are known from Duplin Formation deposits, in some locations fossils are absent because calcitic material has been leached (Jorgeson et al. 1970). The Duplin Formation dates to some time between 4.0 and 3.0 Ma, with most dates closer to 3.0 Ma (Campbell and Campbell 1995; Liddicoat et al. 2000; Brooks et al. 2001). Small but mappable exposures of the Duplin Formation are present at CONG (Shelley 2007b).

Congaree River Valley Terrace Complex (Pliocene-Pleistocene)

The Congaree River Valley has at least 14 estuarine and fluvial terrace surfaces, including the current floodplain, left by changes in drainage. These deposits typically have gravel lags near the base, followed by structureless deposits of medium to very coarse sand grading upwards into sandy clay and red clay (Shelley 2007a, b). Because the modern floodplain is just the youngest such deposit, older terrace deposits may have similar fossils. A carbonized wood fragment is known from a mid to late Pleistocene terrace deposit just north of CONG (D. Shelley, pers. comm., September 2008).

Park Collections

There are no known CONG specimens in the collections database of the Southeast Archeological Center (SEAC).

Fossils Found in Cultural Resource Contexts

There is also the possibility of finding fossils associated with cultural resources, such as fossils altered or modified by humans. David Shelley (pers. comm., September 2008) reports that archeologists from the Southeast Archeological Center have found bone fragments at CONG. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division has not yet conducted a geologic resource scoping session for CONG.
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Southeast Archeology Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at CONG.

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Data Sets

Congaree National Park Paleontological Archives

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

University of South Carolina

2000?–present. (pollen samples and residues; associated specimen notes; collection records; maps; etc.). Originated by Cohen, Art; status: Active.

Cumberland Island National Seashore

Cumberland Island National Seashore (CUI) was established to protect the majority of Cumberland Island, a largely undeveloped barrier island and the largest of Georgia's Golden Isles. CUI preserves a wide variety of natural and cultural resources, from records of human activity from thousands of years ago to Gilded Age estates. CUI was established October 23, 1972. Its boundaries were changed November 10, 1978, and December 8, 2004. A wilderness area was designated within CUI September 8, 1982, and CUI was designated part of the Carolinian-South Atlantic Biosphere Reserve in 1986. CUI encompasses 14,736.68 ha (36,415.13 acres), of which 7,880.33 ha (19,472.72 acres) are under Federal administration. The wilderness area of CUI is 3,577.42 ha (8840 acres), and the land area is 10,583.78 ha (26,153.1 acres).

Geologic Background

CUI is located in southeastern Camden County, Georgia, and occupies most of Cumberland Island. CUI's boundaries also surround Little Cumberland Island, a small privately-held landmass separated from the rest of Cumberland Island by Christmas Creek. Cumberland Island is separated from mainland Georgia by the Cumberland River and Sound on its west. The Satilla River and St. Andrews Sound are found to the north, and the St. Marys River drains into the Atlantic Ocean south of the island, separating CUI from Florida's Amelia Island. The next island to the north of CUI is Jekyll Island. The geology of CUI is discussed in several publications (Swann 1980; McLemore et al. 1981; Griffin 1982; Knaus 1991; Nakashima et al. 1991; Walsh and Goldstein 1991; Wilson et al. 1991a, b; Mack et al. 1993; Robertson et al. 2001; Barrett et al. 2003; Dougherty and Fry 2003; Pendleton et al. 2004), internal National Park Service documents (University of Georgia Marine Institute and the Skidaway Institute of Oceanography 1973) and unpublished theses (Roberts 1975; Martinez 1980; Wilson 1990; Herndon 1991; Robertson 2001).

In general, the east coast of the United States, including CUI and the surrounding region, has had relatively little tectonic activity since the events surrounding the formation and subsequent rifting of the supercontinent Pangaea. In the area of the Southeast Coast Network, this activity involved the African and North American continents. The collision of these two continents was the culmination of a long series of events during the Paleozoic, with multiple deformations recorded in the Appalachian Mountains (see Figure 2 for a geologic time scale). North America and Africa rifted apart during the Late Triassic and Jurassic, and are still moving apart today. The modern southeastern portion of Georgia developed during and after the rifting; before the events leading to the North American-African collision, the southeastern coast of North America had been closer to the Appalachian Mountains. During the collision, several smaller intervening landmasses were welded onto North America. Some slivers of Africa were also added to southeastern North America (Hatcher 2001). Rifting occurred from the Late Triassic to the Middle Jurassic, creating basins by faulting (Gottfried et al. 1977; Gohn et al. 1983), and promoting basalt flows (Gottfried et al. 1983).

During the time following the rifting, there has been deposition of sedimentary rocks in environments varying from open marine to coastal plain settings in eastern Georgia, depending on sea level. The geology of the Georgia Coastal Plain features a seaward-thickening wedge of Early Cretaceous and younger sedimentary rocks and deposits over a basement of older Triassic to Precambrian rocks (Herrick and Vorhis 1963). The basement is deeply buried in Camden County, with about 1,675 m (5,500 ft) of Cretaceous to Holocene rocks and deposits over Proterozoic quartz-rich volcanic rocks or Paleozoic metamorphic rocks (Leeth 1999).

The Coastal Plain sediments of the Cumberland Island area were laid down in the Southeast Georgia Embayment (or Okefenokee Embayment) and southeast of the Woodbine Dome centered about 26 km (16 miles) away (Leeth 1999). Sporadic movements of the embayment affected the quantity of deposition during various periods, for example leading to very thick Miocene deposits (Huddleston 1988). The modern, relatively narrow shelf offshore from Georgia and northern Florida was formed during the

Eocene. There had been a broader shelf before, including what is now the Blake Plateau, but the plateau submerged after the Middle Cretaceous (Dillon et al. 1978). Some faulting occurred on the Coastal Plain in the Oligocene, with southeast-trending faults that lowered eastern blocks, northeast-trending faults forming basins, and small north-south running faults. These faults appear to be responses to tension (Cramer and Arden 1978).

An important feature of Atlantic Coastal Plain geology is the well-developed set of marine terraces, which document ancient shorelines. Over time, terraces formed progressively closer to the modern shore, in distance and elevation. There is a set of named terraces that are used in geologic descriptions. In Georgia, from oldest to most recent, these include the Hazelhurst, Pearson, Claxton, Argyle, Waycross, Okefenokee, “Wicomico,” Penholoway, “Talbot,” Pamlico, Princess Anne, Silver Bluff, and Recent terraces (Huddlestun 1988; names in quotation marks had originally been used for formations, but adequate reference locations in Georgia that could be used to give alternate names were unavailable). These terraces were formed between the Pleistocene and the present in response to sea level fluctuations over a long period of marine regression (Colquhoun 1969; Richards et al. 1971). The terraces typically have a marine layer at the base with a thicker sequence of coastal terrestrial sediments above, such as beach sands, barrier island sands, estuarine or back-barrier sands and clays, and floodplain deposits left behind by receding shorelines (Thornberry-Ehrlich 2006). Pleistocene-age Georgia Coastal Plain terrace deposits include two major lithologies: linear sand ridges from old barrier islands, and clayey sand plains that represent back-barrier tidal lagoons or marshes (Radtko 1985). Heights of marine terraces on the lower Georgia Coastal Plain are 1.4 m (4.5 ft; Silver Bluff), 4.0 m (13 ft; Princess Anne), and 7.3 m (24 ft; Pamlico) (Carver and Waters 1984).

The coastal islands of Georgia were built by Piedmont rivers draining into the Atlantic, as landward-migrating washover terraces. These terraces stabilized about 4,500 years ago (Hayes 1988). Archeological evidence indicates that there are 3 to 6 relict shoreline positions dated between roughly 4,500 and 100 years ago for Georgia’s coastal islands, with most of the islands’ current shorelines dating to about 1,600 years old. The oldest shoreline positions were about 1.5 to 2.0 m (4.9 to 6.6 ft) below the present sea level. Local sea level reached a lowstand of 3.0 to 4.0 m (9.8 to 13.1 ft) below the present sea level between 3,100 and 2,400 years ago, and then rose rapidly, leading to extensive erosion (Howard and DePratter 1978). A major change in drainage near CUIS occurred between about 2,400 and 1,480 years ago, when the Brunswick River shifted course from emptying between Cumberland Island and Jekyll Island to its present location north of Jekyll Island (Chowns et al. 2007).

Cumberland Island developed as a Pleistocene island during Silver Bluff time, about 40,000 years ago. Sea level then dropped about 25,000 years ago, to a level about 122 m (400 ft) below the modern level, and the Silver Bluff core of Cumberland Island was exposed to erosion for 15,000 to 20,000 years. Sea level began to rise again about 11,000 years ago, and rose rapidly until about 5,000 years ago, after which it then slowly rose to its present level. Rising sea level forced sediment deposits up to the old relict core, which became the Holocene sand on the east side of the island (Griffin 1982).

The Cenozoic formations of Georgia, particularly those from the Neogene and Quaternary, have complex histories, with different correlations, ages, and names proposed for the rock units. Geologic dating can be problematic for several reasons. For example, the dating of the Pliocene-Pleistocene boundary worldwide is a current topic of dispute. A particular issue for the Coastal Plain setting is the choice of dating method: aminostratigraphy (using amino acid changes in fossils) may produce significantly different results from radioisotope dating methods (compare Belknap and Wehmiller [1982]’s aminostratigraphic dates to radioisotopes dates from McCartan et al. [1982a, b] for several Pliocene-Pleistocene units of the Atlantic Coastal Plain). The stratigraphy is further complicated by the use of marine terraces in the Atlantic Coastal Plain. Some of the terrace terms have also been used for formations. While this practice is now discouraged (Huddlestun 1988), it is something to watch for in older publications. Huddlestun (1988) and Leeth (1999) are the main sources for stratigraphy for this chapter.

The surface geology of CUIS has a core of Pleistocene-age Silver Bluff barrier island sand, surrounded by Holocene shoreline complex deposits. Holocene barrier island sand is found on the east side of the island, and Holocene marsh and lagoonal sediments make up the west side (University of Georgia Marine Institute and the Skidaway Institute of Oceanography 1973; Lawton et al. 1976; Kellem 1986; Scott et al. 1986). Barrier island deposits and back-barrier marsh and lagoon deposits from the Pamlico and Princess Anne shoreline complexes make up the immediate vicinity (Lawton et al. 1976; Scott et al. 1986). These various Late Pleistocene shoreline complexes are included in the Satilla Formation (Huddlestun 1988). Pliocene and Miocene sedimentary rocks and deposits underlie Cumberland Island as close to the surface as 12 to 20 m (39 to 66 ft) below sea level (Griffin 1982), and Miocene limestone may even outcrop at the extreme southern tip of CUIS (Mack et al. 1993). The units present in the immediate subsurface of CUIS and the surrounding area, from the surface down to about 30 m (100 ft), include the Satilla Formation, the Late Pliocene-age Cypresshead Formation, and several members of the Middle Miocene-age Coosawhatchie Formation (the Ebenezer Member over the Berryville Clay Member over the Tybee Phosphorite Member, and possibly the Charlton Member at the top in some locations) (Huddlestun 1988; Leeth 1999), all of which may produce fossils (Huddlestun 1988). CUIS is known to produce a variety of fossils, from foraminifera (amoeba-like single celled animals that secrete shells) and other microfossils to shark teeth and turtle fragments, and it also has produced museum specimens and paleontological resources in association with cultural resources.

Sources of Paleontological Resources

The fossils of CUIS present opportunities for education, interpretation, and continued or future scientific research in the park. Aside from the material described in this section, fossils from CUIS are stored at the Southeast Archeological Center (SEAC). These fossils are documented below, as part of the “Park Collections” section. There are also fossils found in cultural resource contexts within the park, as described in the “Fossils found in cultural resource contexts” section.

Mixed and undetermined formations (Miocene to Holocene)

CUIS is known for producing abundant loose fossils, particularly Miocene- and Pliocene-age shark and ray teeth (D. Schwimmer, Columbus State University professor, pers. comm., October 2008). These fossils come from dredge spoils removed from Cumberland River and Sound when the waterways were being prepared for the nearby military installation now known as Naval Submarine Base Kings Bay. Two such spoil piles were left on Cumberland Island, and material from them is mined to maintain the roads on the island (J. Fry, CUIS resource program manager, pers. comm., Oct. 2008), making them the source of the small black fragments of shark and ray teeth described by Schwimmer (pers. comm., October 2008) as frequently turning up in road material. The dredge spoil piles, found near the westernmost tip of the south end of the island, have produced vertebrate remains including shark and ray teeth, drum fish teeth, turtle plates (Griffin 1982), and uncommon mammal material, including horse fossils (J. Fry, pers. comm., October 2008). Griffin (1982) reports that most of these fossils are of Pliocene age. Fossils from the spoils in Raccoon Keys Salt Marsh were detailed by McLemore et al. (1981). Most of the remains they described belonged to various cartilaginous and bony fishes, including eleven to fourteen taxa of sharks, three or four taxa of rays, gars, sea drums, and porcupine fish. These animals were represented mostly by teeth. Tetrapod remains were also present, including splinters of horse teeth probably from the Pliocene or Pleistocene, a partial vertebra probably from a dolphin or porpoise, shell fragments from freshwater turtles, a probable crocodilian scute, and a large battered conical tooth that could pertain to anything from an alligator to a Mesozoic sea reptile to a whale.

Fry (pers. comm., October 2008) reports that unidentified material that may be bone is sometimes found, but left by collectors in favor of shark teeth. Limited collecting that does not specifically exclude fossil teeth and shells is permitted at CUIS, as set out in the “frequently asked questions” section of the CUIS website (<http://www.nps.gov/cuis/faqs.htm#16>): “Unoccupied shells may be collected (limit 2 gallons), shark teeth, dead sea stars, sea urchins and sand dollars are also allowed. Feathers, bones, and artifacts should not be disturbed.” Finally, there is a possible but unverified report of mastodon material (J. Bjork,

CUIS resource management specialist 1994-2001, pers. comm. to V. Santucci, September 1997). Although unverified, such a discovery would not be an unprecedented occurrence, as proboscidean teeth are sometimes found in coastal Pleistocene swamps in Georgia (D. Schwimmer, pers. comm., October 2008).

The subsurface of CUIS was described by Griffin (1982), Huddlestun (1988), and Wilson et al. (1991a), and the subsurface of sites about 8 km (5 miles) west of CUIS by Leeth (1999). Because the sediments nearest to the surface are most likely to be sampled, the following discussion will be confined to the sediments from the surface to 30 m (100 ft) below sea level. Formal unit names follow Leeth (1999), the most recent publication. At CUIS, within these bounds is a combination of deposits ranging in age from Holocene near the top to Miocene. The uppermost level is composed of Pleistocene and Holocene deposits ranging from 8 to 20 m (26 to 66 ft) in thickness. Below are 4 to 8 m (13 to 26 ft) of Pleistocene-age marsh and lagoonal deposits, starting at about 8 m (26 ft) below sea level. Below the Pleistocene deposits are about 4 to 8 m (13 or 26 ft) of Pliocene deposits, followed by Miocene limestone starting just above 20 m (66 ft) below sea level (Griffin 1982). Although Miocene deposits are better known in the subsurface at CUIS, seismic profiles suggests that Miocene-age limestone may outcrop in the southernmost part of the island (Mack et al. 1993). West of Cumberland Island in Camden County, undifferentiated Pleistocene and Holocene sand and organics make up the upper 11 to 14 m (35 to 45 ft) of deposits, followed by 11 to 14 m (35-45 ft) of sand assigned to the Pliocene-age Cypresshead Formation, and about 62 m (205 ft) of sand and clay assigned to the Miocene-age Hawthorn Formation (Leeth 1999). At least some of the Pleistocene deposits belong to the Satilla Formation (Leeth 1999).

Coosawhatchie Formation (Middle Miocene)

The Coosawhatchie Formation is mostly made up of sand with some clay and phosphate and occasional beds of dolostone or limestone (Scott 2001). It belongs to the Hawthorn Group, and dates to the Middle Miocene (about 13.8 to 11.6 Ma). The Coosawhatchie Formation includes several members that differ in composition. The Meigs Member is the lowest member in the west and the Tybee Phosphorite Member is the lowest in the east. The Berryville Clay Member is next highest, followed by the Ebenezer Member and finally, in some locations, the Charlton Member. The Tybee Phosphorite Member, Berryville Clay Member, and Ebenezer Member are present under CUIS, and the Charlton Member may be present in the area (Huddlestun 1988; Wilson et al. 1991a). In Leeth's (1999) study area west of CUIS, Coosawhatchie Formation deposits mostly consist of sand and clay.

The Tybee Phosphorite Member is made up of quartz sand and phosphate, with some clay and dolomite. It is regarded as a marine unit that was deposited over a shallow continental shelf distant from shore. Fossils include burrows and other trace fossils, molds and impressions of mollusks, and abundant fine vertebrate debris, like fish scales and teeth, small bones, and vertebrae (Huddlestun 1988).

The Berryville Clay Member is the most clay-rich of the Coosawhatchie Formation members, and has a fossil fauna including nannofossils, silicoflagellates, diatoms, radiolarians, foraminifera, ostracodes, fish scales, and rare shelly material and barnacles. It is interpreted as a continental shelf deposit from the inner to probably middle neritic zone (Huddlestun 1988).

The Ebenezer Member is sandy and generally unfossiliferous, except for molds and casts of bivalves and other mollusks, and fine vertebrate debris like fish scales. It is regarded as a nearshore (but not coastal) marine deposit from the inner neritic part of a continental shelf, under relatively cool conditions (Huddlestun 1988).

The Charlton Member (formerly Charlton Formation) is made up of carbonate-rich silty to sandy clays (Scott 2001). It is locally fossiliferous (Scott 2001), and is known to produce foraminifera, gastropods and other mollusks, barnacles, and echinoids (Jones and Portell 1988). Shells are often preserved as internal or external molds (Auffenberg and Portell 1990). Wilson et al. (1991a) identified a fossiliferous dolomite layer encountered between about 20 to 27 m (65 to 90 ft) beneath CUIS as a Charlton Formation deposit, with both actual shell fossils and molds and casts.

Diatoms, silicoflagellates (both types of silica-secreting algae), and foraminifera of Middle Miocene age are known from cores and cuttings from CUIS. These organisms include examples adapted to both warm and cool water, suggesting the presence of a nearby offshore upwelling of cool water (Hoenstine and Wise 1982). Hoenstine and Wise did not specify the lithologic unit from which the specimens were recovered, but based on age a Coosawhatchie Formation member is likely.

Cypresshead Formation (Upper Pliocene)

The Cypresshead Formation is made up of pebbly, coarse sand, tending to be coarser farther inland and more clay-rich farther seaward. It is thought to date from the Late Pliocene (about 3.6 to 2.6 Ma) in Georgia. The depositional setting of the Cypresshead Formation is coastal marine, perhaps an enclosed sound (Huddlestun 1988). Original fossils are rare in these deposits, and are sometimes reported as absent altogether (Scott 2001), but trace fossils (Huddlestun 1988) and microfossils such as foraminifera are present (Markewich et al. 1992), and casts and molds of mollusks are sometimes found (Scott 2001). Different authors have considered it equivalent to the Bear Bluff Formation of North and South Carolina (Markewich et al. 1992) or the slightly younger Waccamaw Formation of the same area (Campbell 1992).

Diatoms and silicoflagellates of Early Pliocene age were reported from the same cores and cuttings from CUIS in which Hoenstine and Wise (1982) also found Middle Miocene taxa. Unlike the Middle Miocene fauna, no cool water taxa are represented in the Pliocene diatomaceous sediments (Hoenstine and Wise 1982). While the Early Pliocene age is not the same as the Cypresshead Formation, there are no other Pliocene units reported under CUIS, and it is possible that the fossils found by Hoenstine and Wise correspond to a fauna that has been redated to a slightly younger age. Leeth (1999) reported shells in Cypresshead Formation deposits west of CUIS. The deposits graded from fine or medium sand to sandy clayey silt as the unit increased in depth, with more shells toward the base.

Satilla Formation and other Quaternary deposits (Pleistocene-Holocene)

The Satilla Formation is composed of shoreline complex deposits from the Pamlico, Princess Anne, Silver Bluff, and Holocene marine terraces, and includes clay-rich back-barrier deposits, sandy barrier island deposits, and shelly sands and clays from offshore continental coast settings. The four marine terraces formed at different times during the deposition of the Satilla Formation. The Satilla Formation is regarded as Late Pleistocene to Holocene in age (roughly 126,000 thousand years ago to the present). Typical fossils include burrows, foraminifera, bivalves and other mollusks (Huddlestun 1988; Pirkle et al. 2007), and vertebrates including fish, turtles, crocodilians, ground sloths, castorid rodents, tapirids, equids, deer, bovids, and proboscideans (Markewich et al. 1992). The term “Satilla Formation” was only brought into use in 1988, so most references use marine terrace names for identification of deposits, or do not assign the deposits to a formation. Silver Bluff and Holocene shoreline complex deposits are present at CUIS, and Pamlico and Princess Anne shoreline complex deposits are present in the immediate vicinity (Lawton et al. 1976; Kellam 1986; Scott et al. 1986).

A variety of invertebrate fossils are present in the Quaternary deposits of CUIS. Shells are known from the upper 14 m (45 ft) of deposits (Wilson et al. 1991a). Four cores from the south tip of CUIS yielded *Donax* shells of late Holocene age, for use in stable isotope studies on coastal environment responses to fluctuations of sea level, salinity, and water temperature (Robertson et al. 2001). Shell fragments are found on the beaches, and at least one extinct oyster reefs is present in a marsh in the southwest part of the island (Griffin 1982). Microfossils in the form of benthic (bottom-dwelling) Holocene foraminifera are known from cores recovered from the back-barrier salt marshes of CUIS, at depths of 3.5 to 5.5 (11 to 18 ft) as sediment graded from clay to sand (Walsh and Goldstein 1991). Crustacean burrows are known in other Pleistocene and Holocene coastal sediments, particularly those from high-energy littoral and shallow neritic settings (Weimer and Hoyt 1964), so may be present at CUIS as well.

Although Quaternary sediments at CUIS are better known for invertebrates, vertebrates may also be present. Quaternary vertebrates from the Satilla Formation are well-known in the Brunswick area of

Glynn County, about 19 km (12 miles) north of CUIS (Hulbert and Pratt 1998). Typical Pleistocene vertebrates from Brunswick sites include fish, crocodilians (Ray 1979), opossums, armadillos, ground sloths, rodents including sciurids, castorids, cricetids, geomyids, and caviids, possible camelids, bovids, deer, tapirs, equids, mastodons, and mammoths (Hulbert and Pratt 1998). Watkins Quarry has also produced fish and crocodilian remains. The richest site is Clark Quarry, found within the Princess Anne shoreline complex of the Satilla Formation. To date, fossil taxa represented at Clark Quarry include: gastropods; bivalves; arthropods; rays; bony fishes including gars and drum fish (Mead and Spell 2002); frogs; salamanders; turtles; lizards; snakes; alligators (J. Clark et al. 2008); at least five orders of birds, including anseriforms (ducks, geese, and swans), pelecaniforms (pelicans and allies), gruiforms (cranes and allies), charadriiforms (shorebirds, gulls, and allies), and passeriforms (perching birds) (K. Clark et al. 2008); camelids; bovids; equids; and *Mammuthus* (Mead and Spell 2002). Clark Quarry is interpreted as a low-energy coastal stream entering a back-barrier (Bahn and Mead 2005).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following formations within CUIS. However, these units are known to preserve fossils elsewhere, and future field investigations within the park may recover fossils from them.

Quaternary and older offshore deposits

There is also the potential for reworked offshore fossils to wash up on the beaches at CUIS. The Miocene and Pliocene sediments around Cumberland Island produce many marine vertebrate fossils (McLemore et al. 1981). The continental shelf outside of the seashore is known to produce mollusk fossils (Milliman et al. 1972). A variety of other fossils may also be present, including those of algae, foraminifera, corals, bryozoans, polychaete worm tubes, ostracodes, barnacles, and echinoids (Macintyre and Milliman 1970). Detrital Cenozoic-age mollusk shells are locally common along Georgia estuaries and nearshore settings; fragments of worm tubes may also be present (Salazar et al. 1982). Black staining of mollusks is one of the characteristics of Quaternary fossil mollusks, and may indicate deposition in low energy coastal swamps during a time of lower sea level (Milliman et al. 1972). Boring by other invertebrates (Pilkey et al. 1969), abrasion, and trace element composition can also be used to distinguish modern from fossil shells (Wehmiller et al. 2003). The more worn, damaged, and bored a specimen is, the older it probably is.

Terrestrial remains may also wash up, as the coast had been farther east at the last glacial maximum. For example, wood, shell, bones, and a bone or antler tool are known from Gray's Reef National Marine Sanctuary and nearby J-Reef, presently under 17-20 m (56-66 ft) of water roughly 32 km (20 miles) out to sea and about 48 km (30 miles) northeast of CUIS. These remains date from between about 40,000 and 8,000 years ago (Garrison 2006).

Park Collections

Aside from the tortoise specimen in the collections of the Florida Museum of Natural History, there are two other CUIS specimens known to be in outside museum collections. CUIS 32032 is a lot possibly including one fossil bone, three pieces of slate, and a quartzite pebble. This lot came from Slave Cabin Ruins #15, and is reposited at the Southeast Archeological Center (SEAC; storage box 2614 L1Q2). CUIS 45461 is an undescribed specimen from the Dungeness Wharf Midden. It is also reposited at SEAC (storage box 1990 L2Q2) (B. Carter, SEAC supervisory museum specialist, pers. comm., August 2008). Further identification of these specimens and their provenance is needed.

Teeth of the extinct shark *Carcharodon megalodon* and other specimens are kept at CUIS (G. Hollingsworth-Cox, pers. comm. to V. Santucci, October 2008), although there are no specimens in a formal museum collection at CUIS (J. Fry, pers. comm., October 2008). A number of specimens are figured in McLemore et al. (1981), but their current whereabouts are unknown; they may be at the University of Georgia (J. Fry, pers. comm., October 2008).

Fossils Found in Cultural Resource Contexts

CUIS, like other locations in the Sea Islands, is archeologically rich. Because of this, fossils may be found associated with cultural resources, such as fossils altered or modified by humans. Remains of the biota that was contemporaneous with these archeological resources are also of paleontological interest. To date, animal remains showing evidence of human alteration or association appear to have been mostly derived from contemporaneous fauna used as food. As noted by Howard and DePratter (1980), there are thousands of archeological sites on the Georgia coast, including shell ridges, villages, and burial mounds. Dating of archeological sites is often accomplished by chronologies using ceramics found in shell middens (DePratter and Howard 1976). Middens younger than about 3,200 years old can be dated in this way (the first fiber-tempered ceramics appear at the end of the Late Archaic period, about this age; Keel et al. 1996). The Timucuan occupied Cumberland Island for more than 3,000 years, and left numerous shell middens (Griffin 1982). A specimen of the Gopher Tortoise (*Gopherus polyphemus*) is known from an archeological context at CUIS, from about 2,450 years ago. The specimen came from the Florida Museum of Natural History site 9cam + 9cam3, and has accession number 0179 (Franz and Quitmyer 2005). An issue for conservation of paleontological resources in association with cultural resources at CUIS is erosion: back-barrier erosion at CUIS threatens archeological sites from the last 4,000 years (Dougherty and Fry 2003). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

For comparison, at Fort Frederica National Monument (FOFR), about 27 km (17 miles) north of CUIS, people were present by 5,000 years ago (late Archaic phase). These people consumed shellfish and marine fish and made tools out of shells, antlers, and bone. Remains from the Wilmington phase of the late Woodland Period (about 1,300 to 1,100 years ago) indicate people were eating oysters, sharks, bony fish, turtles, alligators, raccoons, and deer (Hovarth et al. 1991). Between about 4,000 and 3,000 years ago at Cannon's Point on St. Simons Island (about 9.0 km or 5.6 miles northeast of FOFR), humans were eating bivalves, fish, opossums, raccoons, dogs, and deer, and using shells in ceramic temper (Thompson 1977).

There is one other human-potential fossil association worth noting. Construction at CUIS includes brick and tabby structures (such as Dungeness), tabby being an oyster shell concrete. The inhabitants of Cumberland Island mined ancient shell middens for the shells needed to make the tabby. Midden shells were also used for road construction and in the building of dikes and dams (Griffin 1982). Because of this practice, it is likely that there are bones and prehistoric pottery in the remains of CUIS tabby structures, as Denise Spear (FOFR resource program manager, pers. comm., September 2008) proposes for FOFR tabby structures.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division has not yet conducted a geologic resource scoping session for CUIS.
- Further identification of the CUIS fossil specimens housed at SEAC is required.
- SECN parks such as CAHA, CALO, CANA, CASA, CUIS, FOCA, FOFR, FOMA, FOPU, FOSU, and TIMU are geologically very young, making it difficult to determine what material is a "fossil" and what would be considered "modern." The National Park Service defines a fossil as any remains of life preserved in a geologic context. This definition does not include an arbitrary date where older specimens are considered fossils, and younger specimens are not. The "geologic context" phrase is intended to imply some level of antiquity, however. Generally, specimens dating back to the late Pleistocene are considered fossils. Late Holocene (last few hundred or thousand years, "Recent") specimens are usually considered modern and not fossils. Pleistocene remains may differ from younger remains by having dark staining and being heavily worn and bored, but this does not always hold true. Surface and subsurface specimens collected at CUIS

span this range between Pleistocene and Holocene. Regardless of what label is assigned to them, these specimens are important natural resources and valuable pieces of the history of life on earth.

- Some coastal park units in the NPS experience unauthorized casual collecting of fossils (beach-combing) from beach areas. This activity is not well documented in the SECN. J. Fry (CUIS resource program manager, pers. comm., October 2008) reports that unidentified material that may be bone is sometimes found, but left by collectors in favor of shark teeth. Limited collecting that does not specifically exclude fossil teeth and shells is permitted at CUIS, as set out in the “frequently asked questions” section of the CUIS website (<http://www.nps.gov/cuis/faqs.htm#16>): “Unoccupied shells may be collected (limit 2 gallons), shark teeth, dead sea stars, sea urchins and sand dollars are also allowed. Feathers, bones, and artifacts should not be disturbed.” Further investigation into casual collecting could lead to development of a park or regional policy related to such collecting.
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Southeast Archeology Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Future increases in sea level may impact paleontological (as well as archeological) sites within the park via inundation or increased erosion.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at CUIS.

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Data Sets

Cumberland Island National Seashore Paleontological Archives

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

Cumberland Island National Seashore Museum Collections

1972–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by CUIS staff; status: Active.

Florida Museum of Natural History (FLMNH)

1972–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by FLMNH staff; status: Active.

Southeast Archeological Center (SEAC)

1972–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by SEAC staff; status: Active.

Fort Frederica National Monument

Fort Frederica National Monument (FOFR) preserves the historic remains of Fort Frederica and associated fortified town Frederica. The fort was built under the direction of James E. Oglethorpe between 1736 and 1748 to protect the British colony of Georgia from attacks by Spanish forces based in Florida. Two battles were fought between the Spanish and British on St. Simons Island (where FOFR is located) July 7, 1742, with the British winning both and driving the Spanish from the island. One of the battle sites, Bloody Marsh, is also part of FOFR. FOFR was authorized May 26, 1936. Its boundaries were changed September 20, 1950, May 16, 1958, July 3, 1984, and November 30, 2004. Today FOFR encompasses 97.70 ha (241.42 acres), of which all but 0.90 ha (2.23 acres) are under Federal administration.

Geologic Background

FOFR is located in northeastern Glynn County, Georgia, on St. Simons Island. Most of the monument's land is in the Fort Frederica unit, which is split in two by the Frederica River and is found in the west part of the island. The Bloody Marsh unit is about 8 km (5 miles) southeast of Fort Frederica, in the southeastern part of the island. Little St. Simons Island wraps around the north and northeast portion of St. Simons Island, and Sea Island is interposed to the east. The center of Brunswick is about 11.8 km (7.3 miles) southwest of Fort Frederica. St. Simons Island is separated from the mainland by the Mackay River and bracketed by the mouth of the Altamaha River to the north and the mouth of the Brunswick River to the south. Wolf Island is north of St. Simons Island, and Jekyll Island is south of it. The geology of FOFR is undescribed in the published literature, but the general geology of Glynn County is known, mostly from hydrological investigations (Callahan 1959; Wait 1965; Gregg and Zimmerman 1974; Jones and Maslia 1994).

In general, the east coast of the United States, including the Brunswick region, has had relatively little tectonic activity since the events surrounding the formation and subsequent rifting of the supercontinent Pangaea. In the area of the Southeast Coast Network, this activity involved the African and North American continents. The collision of these two continents was the culmination of a long series of events during the Paleozoic, with multiple deformations recorded in the Appalachian Mountains (see Figure 2 for a geologic time scale). North America and Africa rifted apart during the Late Triassic and Jurassic, and are still moving apart today. The modern southeastern portion of Georgia developed during and after the rifting. Before the events leading to the North American-African collision, the southeastern coast of North America had been closer to the Appalachian Mountains. During the collision, several smaller intervening landmasses were welded onto North America. Some slivers of Africa were also added to southeastern North America (Hatcher 2001). Rifting occurred from the Late Triassic to the Middle Jurassic, creating basins by faulting (Gottfried et al. 1977; Gohn et al. 1983), and promoting basalt flows (Gottfried et al. 1983).

During the time following the rifting, there has been deposition of sedimentary rocks in environments varying from open marine to coastal plain settings in eastern Georgia, depending on sea level. The geology of the Georgia Coastal Plain features a seaward-thickening wedge of Early Cretaceous and younger sedimentary rocks and deposits over a basement of older Triassic to Precambrian rocks (Herrick and Vorhis 1963). The basement is deeply buried at the coast. In Glynn County, the rocks are only as old as the Eocene at a depth of 530 m (1,740 ft) (Wait 1965), and Cretaceous rocks are present as far down as at least 850 m (2,800 ft) (Jones and Maslia 1994).

The Coastal Plain sediments of the Brunswick area were laid down near the Southeast Georgia Embayment (or Okefenokee Embayment). The embayment and counterpart Cape Fear Arch (or Great Carolina Arch) to the north developed in the Miocene, resulting in existing formations undergoing differential erosion across their extent, depending on proximity to the evolving features (Colquhoun 1969). Additional sporadic episodes of movement also affected deposition (Huddleston 1988). The

Georgia Coastal Plain also had some faulting shortly before this, in the Oligocene, with southeast-trending faults that lowered eastern blocks, northeast-trending faults forming basins, and small north-south running faults. These faults appear to be responses to tension (Cramer and Arden 1978). The modern, relatively narrow shelf offshore from Georgia and northern Florida was formed in the Eocene. There had been a broader shelf before, including what is now the Blake Plateau, but the plateau submerged after the Middle Cretaceous (Dillon et al. 1978).

An important feature of Atlantic Coastal Plain geology is the well-developed set of marine terraces, which document ancient shorelines. Over time, terraces formed progressively closer to the modern shore, in distance and elevation. There is a set of named terraces that are used in geologic descriptions. In Georgia, from oldest to most recent, these include the Hazelhurst, Pearson, Claxton, Argyle, Waycross, Okefenokee, “Wicomico,” Penholoway, “Talbot,” Pamlico, Princess Anne, Silver Bluff, and Recent terraces (Huddlestun 1988; names in quotation marks had originally been used for formations, but adequate reference locations in Georgia that could be used to give alternate names were unavailable). These terraces were formed between the Pleistocene and the present in response to sea level fluctuations over a long period of marine regression (Colquhoun 1969; Richards et al. 1971). The terraces typically have a marine layer at the base with a thicker sequence of coastal terrestrial sediments above, such as beach sands, barrier island sands, estuarine or back-barrier sands and clays, and floodplain deposits left behind by receding shorelines (Thornberry-Ehrlich 2006). Pleistocene-age Georgia Coastal Plain terrace deposits include two major lithologies: linear sand ridges from old barrier islands, and clayey sand plains that represent back-barrier tidal lagoons or marshes (Radtko 1985). Heights of marine terraces on the lower Georgia Coastal Plain are 1.4 m (4.5 ft; Silver Bluff), 4.0 m (13 ft; Princess Anne), and 7.3 m (24 ft; Pamlico) (Carver and Waters 1984). The Pamlico terrace is found in western Glynn County, with the other lower, younger terraces to the east (Wait 1965).

The coastal islands of Georgia were built by Piedmont rivers draining into the Atlantic, as landward-migrating washover terraces. These terraces stabilized about 4,500 years ago (Hayes 1988). Archeological evidence indicates that there are 3 to 6 relict shoreline positions dated between roughly 4,500 and 100 years ago for Georgia’s coastal islands, with most of the islands’ current shorelines dating to about 1,600 years old. The oldest shoreline positions were about 1.5 to 2.0 m (4.9 to 6.6 ft) below the present sea level. Local sea level reached a lowstand of 3.0 to 4.0 m (9.8 to 13.1 ft) below the present sea level between 3,100 and 2,400 years ago, and then rose rapidly, leading to extensive erosion (Howard and DePratter 1978). In the Brunswick area, a major change in drainage occurred between about 2,400 and 1,480 years ago, when the Brunswick River shifted course from emptying south of Jekyll Island to its present location, and Jekyll Island expanded through the capture of a spit to its north (Chowns et al. 2007).

The Cenozoic formations of Georgia, particularly those from the Neogene and Quaternary, have complex histories, with different correlations, ages, and names proposed for the rock units. Geologic dating can be problematic for several reasons. For example, the dating of the Pliocene-Pleistocene boundary worldwide is a current topic of dispute. A particular issue for the Coastal Plain setting is the choice of dating method: aminostratigraphy (using amino acid changes in fossils) may produce significantly different results from radioisotope dating methods (compare Belknap and Wehmiller [1982]’s aminostratigraphic dates to radioisotopes dates from McCartan et al. [1982a, b] for several Pliocene-Pleistocene units of the Atlantic Coastal Plain). The stratigraphy is further complicated by the use of marine terraces in the Atlantic Coastal Plain. Some of the terrace terms have also been used for formations. While this practice is now discouraged (Huddlestun 1988), it is something to watch for in older publications.

FOFR has back-barrier material left behind from Pleistocene-age Silver Bluff and Holocene-age shorelines at its surface, and Silver Bluff barrier island sediments as well (Kellam 1986). These deposits include bioturbated salt marsh material and beach to nearshore marine sand (Scott et al. 1986). Barrier island deposits from the Pamlico, Princess Anne, and Recent shoreline complexes, and back-barrier marsh and lagoon deposits from the Pamlico and Princess Anne shorelines, make up the immediate vicinity (Lawton et al. 1976). These various Late Pleistocene shoreline complexes are included in the

Satilla Formation. The units present in the immediate subsurface near FOFR, from the surface down, probably include the Satilla Formation, the Late Pliocene-age Cypresshead Formation, and the Ebenezer Member of the Middle Miocene-age Coosawhatchie Formation, all of which may produce fossils (Huddlestun 1988). To date, there is one FOFR specimen (limited information) in museum collections. Also worth noting, although within the gray zone separating fossils from modern specimens, are animal remains associated with archeological material, and the use of shells from area middens to make the tabby concrete used in construction of Fort Frederica and associated buildings.

Sources of Paleontological Resources

The fossils of FOFR present opportunities for education, interpretation, and continued or future scientific research in the park. Because the fossils within FOFR are found in a cultural resource context, they are described below in the “Fossils found in cultural resource contexts” section. Aside from the material described in this section, a specimen from FOFR is stored at the Southeast Archeological Center (SEAC). This record is documented below, as part of the “Park Collections” section.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following formations or resource settings within FOFR, most of which would be found 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.

Shallow subsurface rocks and sediments, probably including the Coosawhatchie and Cypresshead formations (Miocene-Holocene)

The subsurface of Glynn County has been described in several publications (Callahan 1959; Wait 1965; Gregg and Zimmerman 1974; Jones and Maslia 1994). For other chapters in this report, descriptions of subsurface units are confined to deposits roughly 30 m (100 ft) and less below the surface, but because there is some disagreement concerning the division and ages of the Glynn County deposits, it was decided to describe the deposits that are known to be Miocene or younger in age. According to Huddlestun (1988), the first few layers under the FOFR area should include the Satilla Formation (Upper Pleistocene) over the Cypresshead Formation (Upper Pliocene) over the Ebenezer Member of the Coosawhatchie Formation (Middle Miocene), although none of the subsurface descriptions considered here exactly match Huddlestun’s unit descriptions. Descriptions of the Cypresshead Formation and Ebenezer Member will be found at the end of this section. Callahan (1959) will be detailed separately from the other publications because the setting is most comparable to St. Simons Island. The report by Jones and Maslia (1994) had a different focus and produced a less detailed column, and so will only be discussed in passing. The deposits described here are all probably present in varying thicknesses beneath FOFR, and are liable to produce fossils if sampled.

Callahan (1959) reported on a well from Jekyll Island, just south of St. Simons Island across St. Simons Sound. The upper 18 m (60 ft) consisted of sand containing plants and fossil fragments, at a level known to produce large Pleistocene land mammals. The next 14 m (45 ft) was composed of clay and sand beds from a marine to lagoonal setting. Below this was 44 m (145 ft) of marine clay and sand, with fossils from microscopic organisms, bryozoans, mollusks, and sharks. These three levels did not have well-constrained dating, and were identified as Pliocene to Recent in age. Below the Pliocene-Recent deposits were 91 m (300 ft) of Miocene-age sand, clay, and limestone, with marine fossils.

Wait (1965) and Gregg and Zimmerman (1974), focusing on mainland Glynn County, produced similar geologic columns, the most obvious differences being in dating and treatment of the Hawthorn Formation and related deposits. Combining the two publications, the uppermost 12 to 15 m (40 to 50 ft) or so is composed of Pleistocene and Holocene sandy deposits. Wait (1965) noted that dredging in deposits of comparable age in the Brunswick River had produced vertebrate fossils dating from perhaps the Eocene

to the Recent because the river had cut through several different layers as it flowed to the Atlantic. Both Wait (1965) and Gregg and Zimmerman (1974) reported bivalves in the uppermost deposits, Wait describing them as abundant and small, and Gregg and Zimmerman finding them to be most abundant at the base of this unit. The next unit down consists of 30 to 37 m (100 to 120 ft) of mixed sandy and coarser deposits assigned to an unnamed unit. Wait (1965) dated it as Miocene, while Gregg and Zimmerman (1974) dated it as possibly Pliocene. Wait (1965) noted the presence of fish teeth in this unit, and Gregg and Zimmerman (1974) found it to have abundant shells, almost forming a shell coquina in places. Both Wait (1965) and Gregg and Zimmerman (1974) had about 45 to 49 m (150 to 160 ft) of deposits over the Miocene-age Hawthorn Formation. Jones and Maslia (1994) produced a different interpretation, placing the top of the Hawthorn Formation at about 23 m (75 ft).

The next package of sediment is treated as one unit by Wait (1965), and three units by Gregg and Zimmerman. Wait described the unit as about 98 m (320 ft) of heterogeneous Miocene-age Hawthorn Formation deposits, with a mix of silt, sand, and limestone layers. Wait also noted that fossils in the Hawthorn Formation tended to be molds and casts of bivalves in the limestone, with rare gastropods. Gregg and Zimmerman (1974) split Wait's Hawthorn Formation into about 18 m (60 ft) of Miocene "upper unit" made up of clays and coarse material, over at least 60 m (200 ft) of heterogeneous Miocene-age Hawthorn Formation deposits (now Hawthorn Group), over at least 30 m (100 ft) of a sandstone-clay-limestone unit. They found scattered deposits of fossiliferous sand in the upper part of the Hawthorn Formation.

The Cypresshead Formation is made up of pebbly, coarse sand, tending to be coarser farther inland and more clay-rich farther seaward. It is thought to date from the Late Pliocene (about 3.6 to 2.6 Ma) in Georgia. The depositional setting of the Cypresshead Formation is coastal marine, perhaps an enclosed sound. It is largely unfossiliferous, except for trace fossils, foraminifera (Huddlestun 1988), and casts and molds of mollusks (Markewich et al. 1992). Different authors have considered it equivalent to the Bear Bluff Formation of North and South Carolina (Markewich et al. 1992) or the slightly younger Waccamaw Formation of the same area (Campbell 1992). Judging from the descriptions, it probably corresponds to Gregg and Zimmerman's (1974) Pliocene unit, although their description of abundant shells does not correspond well with Huddlestun's depiction.

The Ebenezer Member of the Coosawhatchie Formation is one of the upper units of the formation. The Coosawhatchie Formation pertains to the Hawthorn Group, and dates to the Middle Miocene (about 13.8 to 11.6 Ma). It includes several members that differ in composition. The Meigs Member is the lowest member in the west and the Tybee Phosphorite Member is the lowest in the east. The Berryville Clay Member is next highest, followed by the Ebenezer Member and finally, in some locations, the Charlton Member. The Ebenezer Member is sandy and generally unfossiliferous, except for molds and casts of bivalves and other mollusks, and fine vertebrate debris like fish scales. It is regarded as a nearshore but not coastal marine deposit from the inner neritic part of a continental shelf, under relatively cool conditions (Huddlestun 1988). This unit should correspond to Gregg and Zimmerman's (1974) Miocene "upper unit," but does not match well lithologically. It could be that another member of the Coosawhatchie Formation is also present. The Berryville Clay Member is the most clay-rich of the Coosawhatchie Formation members, and has a fossil fauna including nannofossils, silicoflagellates, diatoms, radiolarians, foraminifera, ostracodes, fish scales, and rare shelly material and barnacles. It is interpreted as a continental shelf deposit from the inner to probably middle neritic zone (Huddlestun 1988).

Satilla Formation and other Quaternary deposits (Pleistocene-Holocene)

The Satilla Formation is composed of shoreline complex deposits from the Pamlico, Princess Anne, Silver Bluff, and Holocene marine terraces, and includes clay-rich back-barrier deposits, sandy barrier island deposits, and shelly sands and clays from offshore continental coast settings. The four marine terraces formed at different times during the deposition of the Satilla Formation. The Satilla Formation is regarded as Late Pleistocene to Holocene in age (roughly 126,000 thousand years ago to the present).

Typical fossils include burrows, foraminifera, bivalves and other mollusks (Huddlestun 1988; Pirkle et al. 2007), and vertebrates including fish, turtles, crocodilians, ground sloths, castorid rodents, tapirids, equids, deer, bovids, and proboscideans (Markewich et al. 1992). The term “Satilla Formation” was only brought into use in 1988, so most references use marine terrace names for identification of deposits, or do not assign the deposits to a formation. Silver Bluff and Holocene shoreline complex deposits are present at FOFR, and Pamlico and Princess Anne shoreline complex deposits are present in the immediate vicinity (Lawton et al. 1976; Kellam 1986; Scott et al. 1986). Other, older Pleistocene units are found west of the Pamlico terrace.

Quaternary deposits of the Brunswick area are best known for their fossil mammals. Fossil bones are known from the area as far back as 1837, when what were described as possibly mastodon remains were discovered during the construction of the now-abandoned Brunswick Canal (also known as the Altamaha Barge Canal), roughly 8 to 13 km (5 to 8 miles) west to northwest of FOFR. This material was sent to the Boston Society of Natural History (Anonymous 1839). Several sites in and around Brunswick have produced Pleistocene vertebrate fossils. Three productive areas were discussed by Hulbert and Pratt (1998): Turtle River dredgings (13 km or 8 miles southwest of FOFR); Watkins Quarry (10 km or 6 miles southwest of FOFR); and the general Brunswick region (about 13 km or 8 miles southwest of FOFR). Pleistocene land mammals from these sites include opossums, armadillos, ground sloths, rodents including sciurids, castorids, cricetids, geomyids, and caviids, possible camelids, bovids, deer, tapirs, equids, mastodons, and mammoths (Hulbert and Pratt 1998). Watkins Quarry has also produced fish and crocodilian remains. A supposed turtle femur from the canal, the type specimen of the species *Chelonia couperi*, has turned out to be a clavicle from a ground sloth (Ray 1979). Marine mammal fossils from Quaternary deposits in the Brunswick area include a vertebra of the West Indian Monk Seal (*Monachus tropicalis*) from Andrews Island (13 km or 8 miles southwest of FOFR) (Sanders 2002), marking one of the most northerly records of this recently extinct species. Dredge spoils on the island have produced Pliocene marine vertebrates, Pleistocene terrestrial mammals, and possible marine Miocene fossils as well (D. Bohaska, collections manager, Vertebrate Paleontology, National Museum of Natural History, pers. comm., January 2009).

Another site, Clark Quarry, was published after Hulbert and Pratt (1998). It is located along the Brunswick Canal, which is 8 to 13 km (5 to 8 miles) west to northwest of FOFR. Clark Quarry is within the Princess Anne terrace (Bahn and Mead 2005). The formation is given as the Satilla Formation (Patterson and Mead 2008), a unit put forward by Huddlestun (1988) as a replacement for the Pamlico, Princess Anne, and Silver Bluff formations because these were originally described as marine terraces, not formations. The layer that produces vertebrate fossils is about a meter thick (3.3 ft) and sandy (Bahn and Mead 2005). Shell fragments are mixed with the sand (Mead and Spell 2002). It is underlain by a marine layer containing fossils of gastropods, bivalves, chondrichthyans, and drum fish. Vertebrate macrofossils are dominated by Giant Bison (*Bison latifrons*) and Columbian Mammoth (*Mammuthus columbi*) (Bahn and Mead 2005). To date, fossil taxa represented at Clark Quarry include: gastropods; bivalves; arthropods; rays; bony fishes including gars and drum fish (Mead and Spell 2002); frogs; salamanders; turtles; lizards; snakes; alligators (J. Clark et al. 2008); at least five orders of birds, including anseriforms (ducks, geese, and swans), peleciforms (pelicans and allies), gruiforms (cranes and allies), charadriiforms (shorebirds, gulls, and allies), and passeriforms (perching birds) (K. Clark et al. 2008); camelids; bovids; equids; and *Mammuthus* (Mead and Spell 2002). Clark Quarry may prove to be of historical interest as well; the Columbian Mammoth (*Mammuthus columbi*) is based on a partial tooth recovered from the Brunswick Canal in 1838-1839, so mammoth material from Clark Quarry could conceivably be from the same locality and thus could be used as topotypes for *M. columbi* (Patterson and Mead 2008).

Clark Quarry is interpreted as a low-energy coastal stream entering a back-barrier (Bahn and Mead 2005). The bird, amphibian, and reptile faunas suggest a riverine habitat with more moderate winters than at present (J. Clark et al. 2005; K. Clark et al. 2008), with the presence of a swamp, pond, or sluggish stream as indicated by the aquatic herpetofauna (Parmley et al. 2007). Clark Quarry has a Rancholabrean-age fauna (300,000 to 11,430 years ago) (Parmley et al. 2007). Radiocarbon dating of *Bison latifrons* remains

provides an age of $12,350 \pm 70$ radiocarbon years before present (ybp) (about $14,400 \pm 360$ calendar ybp; radiocarbon ages must be calibrated to yield calendar dates). This age would extend the stratigraphic range of *B. latifrons*, which was previously thought to have gone extinct sometime between 30,000 and 21,000 years ago. Although mapping has put the quarry in the Princess Anne terrace of the Satilla Formation, this date is younger than the typical dates given for the terrace (the shoreline is thought to have been active sometime between 80,000 and 40,000 years ago [Booth et al. 2003]). It could be that the Clark Quarry sediments are young sediments deposited by a river cutting into older Princess Anne terrace materials (Bahn and Mead 2006).

Shells may also be present at FOFR. Detrital Cenozoic-age mollusk shells are locally common along Georgia estuaries and nearshore settings; fragments of worm tubes may also be present (Salazar et al. 1982). Shell material is mentioned in passing by Martens (1935) as present on St. Simons Island, and Salazar et al. (1982) for the Turtle River and St. Simons Sound estuary just south of the island. Shells are common below the level of leaching (about 4 m or 13 ft) in Silver Bluff barrier island sand such as is present in the FOFR area (Scott et al. 1986). More recent material may be mixed in as well (Martens 1935; Salazar et al. 1982). Shells from Jekyll Island just south of St. Simons Island were used by Chowns et al. (2007) to radiometrically date settings related to changes in the location of the Brunswick River (it began flowing into the ocean at its present location sometime between 2,400 and 1,480 years ago). The geography of St. Simons Island makes it unlikely that offshore fossils will wash up in FOFR units. Another potential invertebrate find in Pleistocene and Holocene coastal sediments, particularly those from high-energy littoral and shallow neritic settings, is crustacean burrows (Weimer and Hoyt 1964).

Park Collections

There is one FOFR specimen in the collections database of the Southeast Archeological Center (SEAC). This specimen is FOFR 23996, an otherwise unidentified fossil recovered from the barracks area in the courtyard site of the southeast quarter. FOFR 23996 is repositied at SEAC in storage box 0754 L2Q3 (B. Carter, SEAC supervisory museum specialist, pers. comm., August 2008). Further identification of this specimen and its provenance is needed.

Fossils Found in Cultural Resource Contexts

FOFR, like other locations in the Sea Islands, is archeologically rich. Because of this, fossils may be found associated with cultural resources, such as fossils altered or modified by humans. Remains of the biota that was contemporaneous with these archeological resources are also of paleontological interest. To date, animal remains showing evidence of human alteration or association appear to have been mostly derived from contemporaneous fauna used as food. As noted by Howard and DePratter (1980), there are thousands of archeological sites on the Georgia coast, including shell ridges, villages, and burial mounds. Dating of archeological sites is often accomplished by chronologies using ceramics found in shell middens (DePratter and Howard 1976). Middens younger than about 3,200 years old can be dated in this way (the first fiber-tempered ceramics appear at the end of the Late Archaic period, about this age; Keel et al. 1996). At FOFR, people were present by 5,000 years ago (late Archaic phase) based on trench tests of the subsurface. These people consumed shellfish and marine fish and made tools out of shells, antlers, and bone. Remains from the Wilmington phase of the late Woodland Period (about 1,300 to 1,100 years ago) indicate people were eating oysters, sharks, bony fish, turtles, alligators, raccoons, and deer (Hovarth et al. 1991). Between about 4,000 and 3,000 years ago at Cannon's Point on St. Simons Island (about 9.0 km or 5.6 miles northeast of Fort Frederica), humans were eating bivalves, fish, opossums, raccoons, dogs, and deer, and using shells in ceramic temper (Thompson 1977). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

There is one other cultural resource context worth noting. Construction at FOFR included brick and tabby structures, tabby being an oyster shell concrete. Besides shells, Denise Spear (FOFR resource program manager, pers. comm., September 2008) reports that there are probably bones and prehistoric

pottery in the remains of FOFR tabby structures, because colonists mined local middens for the shells needed to make the tabby.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division has not yet conducted a geologic resource scoping session for FOFR.
- Further identification of the FOFR fossil specimen housed at SEAC is required.
- SECN parks such as CAHA, CALO, CANA, CASA, CUIS, FOCA, FOFR, FOMA, FOPU, FOSU, and TIMU are geologically very young, making it difficult to determine what material is a fossil and what would be considered modern. The National Park Service defines a fossil as any remains of life preserved in a geologic context. This definition does not include an arbitrary date where older specimens are considered fossils, and younger specimens are not. The “geologic context” phrase is intended to imply some level of antiquity, however. Generally, specimens dating back to the late Pleistocene are considered fossils. Late Holocene (last few hundred or thousand years, “Recent”) specimens are usually considered modern and not fossils. Pleistocene remains may differ from younger remains by having dark staining and being heavily worn and bored, but this does not always hold true. Surface and subsurface specimens collected at CANA span this range between Pleistocene and Holocene. Regardless of what label is assigned to them, these specimens are important natural resources and valuable pieces of the history of life on earth.
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Southeast Archeology Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at FOFR.

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Fort Frederica National Monument Paleontological Archives

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

Southeast Archeological Center (SEAC)

1936–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by SEAC staff; status: Active.

Fort Matanzas National Monument

Fort Matanzas National Monument (FOMA) preserves a Spanish fort built to warn St. Augustine of approaching enemies from the south. Fort Matanzas was constructed between 1740 and 1742. The name “matanzas” means “slaughter” and refers to a 1565 massacre of nearly 250 French Huguenots by the Spanish at what is now FOMA, during the Spanish campaign to eliminate the French colony at Fort Caroline (now Fort Caroline National Memorial, about 80 km or 50 miles to the north). FOMA was proclaimed October 15, 1924, and was transferred from the War Department to the National Park Service August 10, 1933. It had boundary changes January 9, 1935 and March 24, 1948, and today encompasses 121.45 ha (300.11 acres), all but 0.65 ha (1.60 acres) of which are under Federal administration.

Geologic Background

FOMA is located in eastern St. Johns County, northeastern Florida, about 23 km (14.5 miles) south of St. Augustine. FOMA is split into two parts by the Matanzas River. Part of FOMA is east of the river on the southern tip of Anastasia Island. Across the river to the west is the actual historic structure Fort Matanzas, on Rattlesnake Island. The Intracoastal Waterway separates Rattlesnake Island from the mainland. To the east of Anastasia Island is the Atlantic Ocean.

In general, the east coast of the United States, including the St. Augustine region, has had relatively little tectonic activity since the events surrounding the formation and subsequent rifting of the supercontinent Pangaea. In the area of the Southeast Coast Network, this activity involved the African and North American continents. The collision of these two continents was the culmination of a long series of events, with multiple deformations recorded in the Appalachian Mountains. North America and Africa rifted apart during the Late Triassic and Jurassic, and are still moving apart today (see Figure 2 for a geologic time scale).

The land beneath the St. Augustine area has only been part of North America since Pangaea rifted apart. What is now the east coast of North America was assembled from small landmasses that collided with the continent during the assembly of Pangaea during the Paleozoic (Hatcher 2001). The final portion that was added was the landmass that now underlies Florida and parts of southern Alabama and Georgia. This landmass, called the Suwannee Terrane, had been part of the much larger landmass known as Gondwana, which included most of today’s southern continents and India. The Suwannee Terrane had been attached to Gondwana near the northern junction of South America and Africa, but was incorporated into North America during the breakup of Pangaea (Scotese et al. 1979; Horton et al. 1989). Sedimentary rocks of the Suwannee Terrane, deposited in the hundred million years before the North American-African collision, resemble those of similar age in Guinea and Senegal of western Africa (Horton et al. 1989). Rifting occurred from the Late Triassic to the Middle Jurassic, creating basins by faulting (Gottfried et al. 1977; Gohn et al. 1983), and promoting basalt flows (Gottfried et al. 1983). During the time following the rifting, there has been deposition of sedimentary rocks in environments varying from open marine to coastal plain settings in northeastern Florida, depending on sea level. Rocks older than the Cenozoic are deeply buried in St. Johns County; at 620 m (2,035 ft) below sea level, the rocks are only as old as the Paleocene (Brown et al. 1986).

The sediments of the St. Augustine area were laid down south of the Southeast Georgia Embayment (or Okefenokee Embayment), and east of the Peninsular Arch (Puri and Vernon 1964); the area is a local structural high known as the St. Johns Platform (Lane 1994). Sporadic movements of the embayment affected the quantity of deposition during various periods, for example leading to very thick Miocene deposits (Huddleston 1988). The modern, relatively narrow shelf offshore from Georgia and northern Florida was formed during the Eocene. There had been a broader shelf before, including what is now the Blake Plateau, but the plateau submerged after the Middle Cretaceous (Dillon et al. 1978). Florida was generally under water in the Paleogene, with a shallow-water setting like the present-day Bahama Banks. These conditions led to thick fossiliferous limestone deposits. Rock fragments are uncommon in these

deposits because the sources (the Appalachian Mountains) were distant and a powerful current running in the Gulf Trough, in the vicinity of the Florida-Georgia border, swept away what was delivered to the area. Near the end of the Paleogene, the Appalachian Mountains were uplifted and shed enough material to fill in the trough. Combined with falling sea levels beginning in the Late Oligocene, more and more of the state was above sea level for longer and longer periods. Terrestrial exposure and deposition moved from north to south (Lane 1994).

An important feature of Atlantic Coastal Plain geology is the well-developed set of marine terraces, which document ancient shorelines. Over time, terraces formed progressively closer to the modern shore, in distance and elevation. There is a set of named terraces that are used in geologic descriptions. In Florida, from oldest to most recent, these include the Hazelhurst, Cohaire, Sunderland, Wicomico, Penholoway, Talbot, Pamlico, and Silver Bluff terraces (Healy 1975). These terraces were formed between the Pleistocene and the present in response to sea level fluctuations over a long period of marine regression (Colquhoun 1969; Richards et al. 1971). Penholoway, Talbot, Pamlico, and Silver Bluff marine terraces are present in St. Johns County (Readle 1983), and FOMA is east of a relict Pamlico barrier island (Hoyt 1969). Terraces typically have a marine layer at the base with a thicker sequence of coastal terrestrial sediments above, such as beach sands, barrier island sands, estuarine or back-barrier sands and clays, and floodplain deposits left behind by receding shorelines (Thornberry-Ehrlich 2006). The terrace deposits are probably similar to those of Georgia's Coastal Plain, which include two major lithologies: linear sand ridges from old barrier islands, and clayey sand plains that represent back-barrier tidal lagoons or marshes (Radtko 1985). The respective heights of marine terraces above sea level in adjoining Duval County, 48 km (30 miles) north of FOMA, are 0-3.0 m (0-10 ft; Silver Bluff), 3.0-7.5 m (10-25 ft; Pamlico), 7.5-13.0 m (25-42 ft, Talbot), and 13.0-21.0 m (42-70 ft; Penholoway) (Phelps 1994). The youngest of these terraces, the Silver Bluff terrace, is over 40,000 years old (Booth et al. 1999).

Chronologically interspersed with the terraces are marine lowstands, some with sea levels significantly lower than the present as water was taken up into ice sheets during major ice advances in the Pleistocene ("Ice Age"). During the last maximum ice advance, 25,000 years ago, sea level dropped to about 122 m (400 ft) below the modern level. It began to rise again about 11,000 years ago, and rose rapidly until about 5,000 years ago, after which it then slowly rose to its present level (Griffin 1982), with fluctuations. Local sea level reached a lowstand of 3.0 to 4.0 m (9.8 to 13.1 ft) below the present sea level between 3,100 and 2,400 years ago, and then rose rapidly, leading to extensive erosion (Howard and DePratter 1978).

The Cenozoic formations of Florida, particularly those from the Neogene and Quaternary, have complex histories, with different correlations, ages, and names proposed for the rock units. Geologic dating can be problematic for several reasons. For example, the dating of the Pliocene-Pleistocene boundary worldwide is a current topic of dispute. A particular issue is the choice of dating method: aminostratigraphy (using amino acid changes in fossils) may produce significantly different results from radioisotope dating methods (compare Belknap and Wehmiller [1982]'s aminostratigraphic dates to radioisotopes dates from McCartan et al. [1982a, b] for several Pliocene-Pleistocene units of the Atlantic Coastal Plain). The stratigraphy is further complicated by the use of marine terraces in the Atlantic Coastal Plain. Some of the terrace terms have also been used for formations. While this practice is now discouraged (Huddleston 1988), it is something to watch for in older publications.

The surface geology of FOMA is composed of deposits of the Anastasia Formation (Pleistocene) and Holocene sediments. These are also the lithological units exposed in the areas drained by waterways running through FOMA (Scott et al. 2001). Depositional settings of the units include beaches, swamps, and dunes (Scott et al. 1986). Underlying rocks in the shallow subsurface, down to about 30 m (100 ft), include undifferentiated sand, clay, shell, and limestone dating from the Upper Miocene to the Holocene, over similarly heterogeneous deposits from a Hawthorn Group unit (Readle 1983; Spechler and Hampson 1984; Odum et al. 1997). All of these units are known to produce fossils (Spechler and Hampson 1984; Huddleston 1988; Odum et al. 1997). FOMA has fossil material now curated as museum specimens, and paleontological resources in association with cultural resources, including Fort Matanzas itself, which is

built of fossil shell-laden rock from the Anastasia Formation. The Castillo de San Marcos (see CASA section of this report) is also constructed of the same material.

Sources of Paleontological Resources

The fossils of FOMA present opportunities for education, interpretation, and continued or future scientific research in the park. Aside from the material described in this section, a fossil from FOMA is stored at the Southeast Archeological Center (SEAC). This fossil is documented below, as part of the “Park Collections” section. Some fossils within FOMA are found in a cultural resource context, they are described below in the “Fossils found in cultural resource contexts” section.

Anastasia Formation (Upper Pleistocene)

The Anastasia Formation is a sandy coquina, exposed along the east coast of Florida from Anastasia Island to Palm Beach (Stauble and McNeill 1985). Coquina is a type of poorly-consolidated limestone made up of shell fragments (Kenworthy and Santucci 2006). In the Anastasia Formation, mollusk shells are common, from whole specimens to fragments to molds. Both gastropods and bivalves are present, with the donacid clam *Donax* dominant (Stauble and McNeill 1985). Donacid clams are colloquially known as coquina, and the geological term “coquina” is derived from this name (Kenworthy and Santucci 2006). Anastasia Formation coquina was used to construct Fort Matanzas (Bryne 1990). Thus, the Anastasia Formation coquina, and by extension Fort Matanzas, are composed of the archetypical coquina clam (Kenworthy and Santucci 2006). As mentioned above, this is the same building material used at Castillo de San Marcos (see CASA section).

The Anastasia Formation is interpreted as very shallow marine, deposited in settings from beach foreshore zones to barrier bars. The major period of deposition is dated to about 110,000 years ago (Stauble and McNeill 1985), although some deposition may have been substantially younger, as young as about 7,000 years ago for dunes and barrier islands (Portell et al. 2002). Successions of cemented and uncemented beds in this formation may represent beachrock on prograding shorelines (Missimer and McNeill 1992). Aside from mollusks, Anastasia Formation fossils include foraminifera (Cole 1931), coral (Lovejoy 1998), ghost crabs and their burrows (Portell et al. 2002), echinoids (Oyen and Portell 2001), and vertebrates (Stauble and McNeill 1985; Lovejoy 1998). One Anastasia Formation site that has produced vertebrate remains in St. Johns County is Wilson Coquina Quarry (now called Lakeview Dirt Company Quarry), about 8 km (5 miles) southwest of St. Augustine (R. Hulbert, collections manager, Division of Vertebrate Paleontology, Florida Museum of Natural History, pers. comm., November 2008; R. Portell, collections manager, Division of Invertebrate Paleontology, Florida Museum of Natural History, pers. comm., January 2009). Vertebrates known from this site include sharks, rays, bony fish, frogs, salamanders, turtles, lizards, snakes, alligators, grebes, rails, armadillos, cricetid rodents, lagomorphs, camelids, deer, and gomphotheriid proboscideans (Florida Museum of Natural History 2008).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following formations within FOMA, most of which would be found 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.

Mixed and undetermined formations (Upper Miocene to Holocene)

The underlying geology of St. Johns County has been described in several publications (Readle 1983; Spechler and Hampson 1984; Brown et al. 1986; Odum et al. 1997). Because the sediments nearest to the surface are most likely to be sampled, the following discussion will be confined to the sediments from the surface to 30 m (100 ft) below sea level. The components of the upper subsurface are an upper heterogeneous layer thought to be Late Miocene to Quaternary in age, over a heterogeneous unit identified as the Miocene-age Hawthorn Formation (now Hawthorn Group). Shells are known

throughout the shallow subsurface (Readle 1983; Spechler and Hampson 1984; Brown et al. 1986; Odum et al. 1997).

The division between the two units varies by author. Odum et al. (1997) found the upper subsurface of St. Johns County to consist of 7 to 36 m (23 to 118 ft) of undifferentiated surficial deposits over 30 to 152 m (100 to 500 ft) of Miocene-age Hawthorn Group (Hawthorn Formation of this reference) deposits. Spechler and Hampson (1984) found the upper subsurface to consist of 12 to 58 m (40 to 190 ft) of surficial deposits over 15 to 69 m (50 to 225 ft) of Miocene-age Hawthorn Group (Hawthorn Formation of this reference) deposits. Spechler and Hampson (1984) further split the surficial deposits into two subunits. The upper 6 to 27 m (20 to 90 ft) of the surficial deposits are from the Pleistocene and Holocene, and are made up of sand, clay, shells, and coquina. The Anastasia Formation is included in the upper section. The lower 6 to 30 m (20 to 100 ft) of the surficial deposits date from the Late Miocene and Pliocene, and are composed of sand, shell, and silty clay over limestone beds. In the St. Augustine area, there are about 9 m (30 ft) of undifferentiated Upper Miocene-Holocene deposits. Below this are roughly 43 m (140 ft) of Hawthorn Group (Formation of this reference) deposits (Spechler and Hampson 1984).

Hawthorn Group subsurface deposits in St. Johns County are composed of phosphatic sand, sandy clays, clayey sands, marl, sandy limestone (Spechler and Hampson 1984), silt, and dolomite, with some shell beds (Odum et al. 1997). Per Scott et al. (2001), the Hawthorn Group formation nearest to FOMA is the Coosawhatchie Formation. The Coosawhatchie Formation is mostly made up of sand with some clay and phosphate and occasional beds of dolomite or limestone (Scott 2001), and dates to the Middle Miocene (about 13.8 to 11.6 Ma). The Coosawhatchie Formation includes several members that differ in composition. The Meigs Member is the lowest member in the west and the Tybee Phosphorite Member is the lowest in the east. The Berryville Clay Member is next highest, followed by the Ebenezer Member and finally, in some locations, the Charlton Member (formerly Charlton Formation). Of the five subunits, the Meigs Member and Tybee Phosphorite Member are the least likely to be present in the FOMA area (Huddlestun 1988).

Of the other three Coosawhatchie Formation members, each is fossiliferous, but to different degrees. The Berryville Clay Member is the most clay-rich, and has a fossil fauna including nannofossils, silicoflagellates, diatoms, radiolarians, foraminifera, ostracodes, fish scales, and rare shelly material and barnacles. It is interpreted as a continental shelf deposit from the inner to probably middle neritic zone. The Ebenezer Member is sandy and generally unfossiliferous, except for molds and casts of bivalves and other mollusks, and fine vertebrate debris like fish scales. It is regarded as a nearshore (but not coastal) marine deposit from the inner neritic part of a continental shelf, under relatively cool conditions (Huddlestun 1988). The Charlton Member (formerly Charlton Formation) is made up of carbonate-rich silty to sandy clays. It is locally fossiliferous (Scott 2001), and is known to produce foraminifera, gastropods and other mollusks, barnacles, and echinoids (Jones and Portell 1988). Shells are often preserved as internal or external molds (Auffenberg and Portell 1990).

Other fossils that are known from Miocene or Pliocene deposits in the area include sirenian rib fragments, which are common in shallow-water and estuarine deposits from the Miocene (particularly the Hawthorn Group) and Pliocene in Florida (Simpson 1932), and microfossils. In 1886, diatoms, foraminifera, polycystine radiolarians, and sponge spicules were recovered from clay layers at levels of 27 and 37 m (90 and 120 ft) in an artesian well sunk at a St. Augustine hotel. At the time, the deposits could only be dated to the Miocene or Pliocene (Boyer 1895).

Surficial Quaternary rocks and sediments (Pleistocene-Holocene)

The surficial deposits of FOMA have not been assigned to a formation, although the presence of Pamlico and Silver Bluff marine terraces indicates that the Satilla Formation nomenclature of Huddlestun (1988) would be applicable for at least some of the sediments. The Satilla Formation is composed of shoreline complex deposits from the Pamlico, Princess Anne, Silver Bluff, and Holocene marine terraces, and includes clay-rich back-barrier deposits, sandy barrier island deposits, and shelly sands and clays from

offshore continental coast settings. The four marine terraces formed at different times during the deposition of the Satilla Formation. The Satilla Formation is regarded as Late Pleistocene to Holocene in age (roughly 126,000 thousand years ago to the present). Typical fossils include burrows, foraminifera, bivalves and other mollusks (Huddlestun 1988; Pirkle et al. 2007), and vertebrates including fish, turtles, crocodilians, ground sloths, castorid rodents, tapirids, equids, deer, bovids, and proboscideans (Markewich et al. 1992). The term “Satilla Formation” was only brought into use in 1988, so most references use marine terrace names for identification of deposits, or do not assign the deposits to a formation.

Invertebrate fossils are common in the undifferentiated surficial Quaternary deposits in the vicinity of FOMA. FOMA is underlain by shelly sand and clay (Scott 1979), and shells have been mentioned in passing for Quaternary-age deposits in the vicinity of FOMA (Scott 1979; Spechler and Hampson 1984; Odum et al. 1997). FOMA soils come from marine sand with small quantities of shell materials. Matanzas Inlet is composed of perched Pleistocene-age barrier islands overlain by mixed Holocene sands (Bryne 1990). Beaches in the vicinity of FOMA are known to produce shells ranging in age from the Pleistocene to the modern (Martens 1931, 1935; Scott et al. 1986). Crustacean burrows are known in other Pleistocene and Holocene coastal sediments, particularly those from high-energy littoral and shallow neritic settings (Weimer and Hoyt 1964), so may be present at FOMA as well.

Vertebrate remains are also known from the deposits in the area. Remains of Pleistocene animals including deer, bison, mastodon, and mammoth are known from Allen’s Farm, a site over 6 km (4 miles) south of FOMA on the Intracoastal Waterway. Mammals from this site include ground sloths, cetaceans, horses, mastodons, and mammoths (Simpson 1929). Fossils of the ground sloth *Paramylodon* (*Myiodon* at the time) are mentioned in passing from the Pleistocene of St. Johns County, although the location is not certain. The location was given as Sarasota, St. John County (Holmes and Simpson 1931), but there does not appear to be a Sarasota in St. Johns County. Sirenian rib fragments, while not as common as in Miocene and Pliocene deposits, are present in marine and river deposits of the Pleistocene (Simpson 1932).

Quaternary and older offshore deposits

There is also the potential for reworked offshore fossils to wash up on the beaches at FOMA. The continental shelf outside of FOMA is known to produce mollusk and barnacle fossils (Milliman et al. 1972). A variety of other fossils may also be present, including those of algae, foraminifera, corals, bryozoans, polychaete worm tubes, ostracodes, barnacles, and echinoids (Macintyre and Milliman 1970). Black staining of mollusks is one of the characteristics of Quaternary fossil mollusks, and may indicate deposition in low energy coastal swamps during a time of lower sea level (Milliman et al. 1972). Boring by other invertebrates (Pilkey et al. 1969), abrasion, and trace element composition can also be used to distinguish modern from fossil shells (Wehmiller et al. 2003). The more worn, damaged, and bored a specimen is, the older it probably is. Terrestrial remains such as peat and proboscidean teeth may also wash up, as the coast had been farther east at the last glacial maximum, leading to now-drowned offshore terrestrial deposits (Milliman et al. 1972).

Park Collections

There is one FOMA fossil specimen reposit at the Southeast Archeological Center (SEAC). FOMA 793 came from a trench at the North Midden, Fort Matanzas Complex, and consists of a *Diodon* (porcupinefish or balloonfish) specimen (B. Carter, SEAC supervisory museum specialist, pers. comm., August 2008). No definite fossils are housed at FOMA, although younger shells, bones, and bone fragments are known (A. Rich, FOMA resource program manager, pers. comm., October 2008).

Fossils Found in Cultural Resource Contexts

FOMA is archeologically rich, with multiple periods of human habitation. Because of this, fossils may be found associated with cultural resources, such as fossils altered or modified by humans. Remains of the biota that was contemporaneous with these archeological resources are also of paleontological interest. Artifacts from the Orange Period (4,000 to 3,000 years ago), St. Johns I Period (2,500 to 1,200 years ago) and early Spanish Period (after 1565) are present at FOMA, as well as perhaps the end of the Transitional Period between the Orange and St. Johns I periods. All of these periods are represented at the Visitor Center Midden Site. From the remains at the Visitor Center Midden Site, the Orange Period people processed oysters (oyster shells make up 85% to 90% of animal remains by weight), and also utilized clam (5% to 10%), *Donax* (coquina clam, less than 1%), crabs, sharks, catfish, flounder, and deer (less than 1% together). The St. Johns I people also exploited oysters (98%), clams, and vertebrates including fish, snakes, turtles, birds, and mammals. Few St. Johns artifacts are present, suggesting that the people used the site for collecting and processing shellfish rather than habitation (Bryne 1990). People from the St. Johns periods also made ceramics with sponge spicule paste (Hammersten 1988).

Another source of fossils in cultural resource contexts is the fort itself, as mentioned above: Fort Matanzas is a coquina fort (Bryne 1990), composed of the archetypical “coquina clam” that lent its name to the geological term coquina (Kenworthy and Santucci 2006). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts, including the similarly constructed Castillo de San Marcos.

Aside from their archeological value, coquina clams from shell middens are also utilized for stable isotope studies. Shells from two midden sites in the vicinity of FOMA, among several other sites in northeastern Florida, have been used for stable isotope analyses intended to examine Holocene climate. The Guana Shell Ring about 43 km (27 miles) north of FOMA, has shells from the Orange Period, about $3,600 \pm 50$ radiocarbon years before present (ybp), or $3,516 \pm 128$ calendar ybp (radiocarbon years must be calibrated to yield calendar years; this calibration was made using Calib 5.0.2 [<http://calib.qub.ac.uk/calib/>]). The SAUFL Station at Crescent Beach, about 2 km (1.25 miles) north of FOMA, has shells from about $4,240 \pm 60$ radiocarbon ybp, or $4,342 \pm 226$ calendar ybp. One *Donax* shell was used from each site. Additionally, a modern *Donax* shell was taken from the Anastasia Island portion of FOMA. High warm season temperatures, as interpreted from stable oxygen isotope ratios, may indicate greater seasonality at the time the organisms in the shells were alive (Jones et al. 2005).

Other archeological sites in the region also have vertebrates. Fossils of the tortoise *Gopherus* are known from sites at Crescent Beach and Summer Haven, about 1 km (0.6 miles) southeast of FOMA; specimens at both of these sites are about 5,000 to 2,500 years old (Franz and Quitmyer 2005).

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division has not yet conducted a geologic resource scoping session for FOMA.
- SECN parks such as CAHA, CALO, CANA, CASA, CUIS, FOCA, FOFR, FOMA, FOPU, FOSU, and TIMU are geologically very young, making it difficult to determine what material is a “fossil” and what would be considered “modern.” The National Park Service defines a fossil as any remains of life preserved in a geologic context. This definition does not include an arbitrary date where older specimens are considered fossils, and younger specimens are not. The “geologic context” phrase is intended to imply some level of antiquity, however. Generally, specimens dating back to the late Pleistocene are considered fossils. Late Holocene (last few hundred or thousand years, “Recent”) specimens are usually considered modern and not fossils. Pleistocene remains may differ from younger remains by having dark staining and being heavily worn and bored, but this does not always hold true. Surface and subsurface specimens collected at FOMA span this range between Pleistocene and Holocene. Regardless of what label is assigned to them, these specimens are important natural resources and valuable pieces of the history of life on earth.

- Some coastal park units in the NPS experience unauthorized casual collecting of fossils (beach-combing) from beach areas. This activity is not well documented in the SECN. Further investigation into casual collecting could lead to development of a park or regional policy related to such collecting.
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Southeast Archeology Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Future increases in sea level may impact paleontological (as well as archeological) sites within the park via inundation or increased erosion.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at FOMA.

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Data Sets

Fort Matanzas National Monument Paleontological Archives

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

Southeast Archeological Center (SEAC)

1924–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by SEAC staff; status: Active.

Fort Pulaski National Monument

Fort Pulaski National Monument (FOPU) preserves Fort Pulaski, a brick fortification constructed mostly between 1833 and 1847. Fort Pulaski was the site of a Civil War battle that featured the first significant use of rifled cannons. In April 1862, Confederate-held Fort Pulaski was surrendered to Union forces after it was heavily damaged by the new rifled cannons, signaling a significant change for future warfare. FOPU was proclaimed October 15, 1924 and was transferred from the War Department to the National Park Service August 10, 1933. Its boundaries were changed June 26, 1936 and May 25, 1959. Today FOPU encompasses 2,275.59 ha (5,623.10 acres), of which all but 104.40 ha (257.97 acres) are under Federal administration.

Geologic Background

FOPU is located in northeastern Chatham County, Georgia, just south of the Georgia-South Carolina border. It includes most of Cockspur Island (the location of the fort), all of adjoining McQueens Island, Cockspur Island Lighthouse Reservation just east of Cockspur Island, and Daymark Island, a small shell reef just north of Cockspur Island. Cockspur Island is found in the mouth of the Savannah River, and with Long Island and others splits the river into two channels as it drains into the Atlantic Ocean. McQueens Island to the south is bounded by the South Channel of the Savannah River on its north side; Lazaretto Creek to the east, separating it from Tybee Island and Little Tybee Island; and the Buff River to the south and west, separating it from Wilmington Island, Oatland Island, and the mainland. The city of Savannah is just to the northwest. Geological aspects of FOPU have been described by Howell and Alexander (2004).

In general, the east coast of the United States, including the Savannah region, has had relatively little tectonic activity since the events surrounding the formation and subsequent rifting of the supercontinent Pangaea. In the area of the Southeast Coast Network, this activity involved Africa and North America. The collision of these two continents was the culmination of a long series of events during the Paleozoic, with multiple deformations recorded in the Appalachian Mountains (see Figure 2 for a geologic time scale). North America and Africa rifted apart during the Late Triassic and Jurassic, and are still moving apart. The modern southeastern portion of Georgia developed during and after the rifting. Before the events leading to the North American-African collision, the southeastern coast of North America had been closer to the Appalachian Mountains. During the collision, several smaller intervening landmasses were welded onto North America. Some slivers of Africa were also added to southeastern North America (Hatcher 2001).

Rocks from the period of rifting and just afterward are relatively well-known in the Charleston area, about 130 km (80 miles) northeast of Savannah, where they have been studied via deep cores as part of larger efforts to understand the 1886 Charleston earthquake. As Charleston has a comparable geologic setting to Savannah, it is worth briefly mentioning the findings. The pre-rift geology is known only from eroded fragments recovered within younger sedimentary rocks; such fragments include granodiorites and other intrusive igneous rocks, basalts, and metamorphic rocks (Gohn 1983). Rocks from the rift period and shortly after are represented by basalts and sedimentary red beds. The sedimentary red beds are probably of river and alluvial fan environments, and are found below the basalts (Gohn et al. 1983). Basalts are found at depths of 750 to 775 m (2,460 to 2,540 ft) (Gottfried et al. 1983). The age of at least some of the basalts is about 184 Ma (million years) (Lanphere 1983). It appears that these rocks were deposited or extruded into fault-bounded basins (Gottfried et al. 1977; Gohn et al. 1983). The entire Charleston-area basement forms its own distinct geologic block, perhaps as a zone of Mesozoic crustal extension analogous to but much larger than exposed Triassic and Jurassic basins (Popenoe and Zietz 1977).

During the time following the rifting, there has been deposition of sedimentary rocks in environments varying from open marine to coastal plain settings in eastern Georgia, depending on sea level. The

geology of the Georgia Coastal Plain features a seaward-thickening wedge of Early Cretaceous and younger sedimentary rocks and deposits over a basement of older Triassic to Precambrian rocks (Herrick and Vorhis 1963). The basement is deeply buried at the coast. In Glynn County, over 100 km (60 miles) south of FOPU, the rocks are only as old as the Eocene at a depth of 530 m (1,740 ft) (Wait 1965). Just across the border from FOPU, in southeasternmost South Carolina, Cenozoic rocks and deposits alone are at least 1,068 m (3,504 ft) thick (Colquhoun and Johnson 1968).

The Coastal Plain sediments of the Savannah area were laid down along a minor structural feature of the East Georgia Basin known as the Beaufort Arch (Colquhoun and Johnson 1968), within the Southeast Georgia Embayment (or Okefenokee Embayment). The embayment and counterpart Cape Fear Arch (or Great Carolina Arch) to the north developed in the Miocene, resulting in existing formations undergoing differential erosion across their extent, depending on proximity to the evolving features (Colquhoun 1969). Additional sporadic episodes of movement also affected deposition (Huddlestun 1988). The Georgia Coastal Plain also had some faulting shortly before this, in the Oligocene, with southeast-trending faults that lowered eastern blocks, northeast-trending faults forming basins, and small north-south running faults. These faults appear to be responses to tension (Cramer and Arden 1978). The modern, relatively narrow shelf offshore from Georgia and northern Florida was formed in the Eocene. There had been a broader shelf before, including what is now the Blake Plateau, but the plateau submerged after the Middle Cretaceous (Dillon et al. 1978).

An important feature of Atlantic Coastal Plain geology is the well-developed set of marine terraces, which document of ancient shorelines. Over time, terraces formed progressively closer to the modern shore, in distance and elevation. There is a set of named terraces that are used in geologic descriptions. In Georgia, from oldest to most recent, these include the Hazelhurst, Pearson, Claxton, Argyle, Waycross, Okefenokee, "Wicomico," Penholoway, "Talbot," Pamlico, Princess Anne, Silver Bluff, and Recent terraces (Huddlestun 1988; names in quotation marks had originally been used for formations, but adequate reference locations in Georgia that could be used to give alternate names were unavailable). These terraces were formed between the Pleistocene and the present in response to sea level fluctuations over a long period of marine regression (Colquhoun 1969; Richards et al. 1971). The terraces typically have a marine layer at the base with a thicker sequence of coastal terrestrial sediments above, such as beach sands, barrier island sands, estuarine or back-barrier sands and clays, and floodplain deposits left behind by receding shorelines (Thornberry-Ehrlich 2006). Pleistocene-age Georgia Coastal Plain terrace deposits include two major lithologies: linear sand ridges from old barrier islands, and clayey sand plains that represent back-barrier tidal lagoons or marshes (Radtko 1985). Heights of marine terraces on the lower Georgia Coastal Plain are 1.4 m (4.5 ft; Silver Bluff), 4.0 m (13 ft; Princess Anne), and 7.3 m (24 ft; Pamlico) (Carver and Waters 1984). Skidaway Island, source of many Pleistocene fossils, is composed in part of Princess Anne-age barrier island sediments probably deposited sometime between 80,000 and 40,000 years ago (Booth et al. 2003).

The coastal islands of Georgia were built by Piedmont rivers draining into the Atlantic, as landward-migrating washover terraces. These terraces stabilized about 4,500 years ago (Hayes 1988). Archeological evidence indicates that there are 3 to 6 relict shoreline positions dated between roughly 4,500 and 100 years ago for Georgia's coastal islands, with most of the islands' current shorelines dating to about 1,600 years old. The oldest shoreline positions were about 1.5 to 2.0 m (4.9 to 6.6 ft) below the present sea level. Local sea level reached a lowstand of 3.0 to 4.0 m (9.8 to 13.1 ft) below the present sea level between 3,100 and 2,400 years ago, and then rose rapidly, leading to extensive erosion (Howard and DePratter 1978).

The Cenozoic formations of Georgia, particularly those from the Neogene and Quaternary, have complex histories, with different correlations, ages, and names proposed for the rock units. Geologic dating can be problematic for several reasons. For example, the dating of the Pliocene-Pleistocene boundary worldwide is a current topic of dispute. A particular issue for the Coastal Plain setting is the choice of dating method: aminostratigraphy (using amino acid changes in fossils) may produce significantly different results from radioisotope dating methods (compare Belknap and Wehmiller [1982]'s aminostratigraphic dates to radioisotopes dates from McCartan et al. [1982a, b] for several Pliocene-

Pleistocene units of the Atlantic Coastal Plain). The stratigraphy is further complicated by the use of marine terraces in the Atlantic Coastal Plain. Some of the terrace terms have also been used for formations. While this practice is now discouraged (Huddlestun 1988), it is something to watch for in older publications. This chapter will use Huddlestun (1988) as first source for stratigraphy.

FOPU has marsh and lagoonal material left behind from Pleistocene-age Silver Bluff and Holocene-age shorelines at its surface (Kellam 1986), and possibly some Holocene beach sand (Colquhoun et al. 1987). Barrier island deposits from the Pamlico, Princess Anne, Silver Bluff, and Recent shoreline complexes, and Princess Anne marsh and lagoonal deposits, make up the immediate vicinity (Lawton et al. 1976). These various Late Pleistocene shoreline complexes are included in the Satilla Formation. The units present in the immediate subsurface near FOPU, from the surface down, include the Satilla Formation, the Early Pliocene-age Wabasso beds, the Tybee Phosphorite Member of the Middle Miocene-age Coosawhatchie Formation, and the Early Miocene-age Marks Head Formation, all of which may produce fossils (Huddlestun 1988). To date, fossil foraminifera (amoeba-like organisms that secrete shells) are known in subsurface Wabasso bed deposits from FOPU, and fossil diatoms (algae that secrete shells) and other microfossils were recovered from earth moved in the construction of Fort Pulaski that would correspond to the Satilla Formation (see below).

Sources of Paleontological Resources

The fossils of FOPU present opportunities for education, interpretation, and continued or future scientific research in the park.

Wabasso beds (Lower Pliocene)

The Wabasso beds are an informally-designated package of sediments from the Lower Pliocene (about 5.3 to 4 Ma), and are part of the Hawthorn Group. The beds are composed of fine to very fine grained sand with some clay, phosphate, and calcareous material. Macrofossils are not known from this unit, but foraminifera and other calcareous microfossils are present. The Wabasso beds are interpreted as representing open marine continental shelf deposits, from a deeper and more open marine setting than any other Hawthorn Group depositional unit (Huddlestun 1988).

At FOPU, there is one record of fossils from the Wabasso beds. The find consists of foraminifera from a core designated Georgia Geological Survey (GGs) 772; the fossils were found at a depth of 18.3 to 19.8 m (60 to 65 ft). Similar foraminifera were found at adjoining Tybee Island, in core GGS 381, from a depth of 18.0 m to 24.1 m (59 to 79 ft). Both floating (planktonic) and bottom-dwelling (benthic) foraminifera were recovered. The specimens were identified as Pliocene foraminifera, from a shallow, warm shelf setting (Herrick 1976). Herrick (1976) identified the deposits that contained the fossils as belonging to the Duplin Marl. More recent publications, following Huddlestun (1988), have restricted the name “Duplin Formation” to South Carolina and North Carolina (south of the Neuse River; see Carter et al. 1988). Previous usages of the Duplin Formation can correspond to different units; the Georgian equivalent of the Duplin Formation is the Raysor Formation, but, as Huddlestun (1988) notes, the Duplin name had been applied to Hawthorn Group rocks, which is a Miocene-Pliocene unit. Huddlestun (1988) specifically identified the FOPU and Tybee Island finds of Herrick (1976) as coming from the Wabasso beds, an informal upper unit of the Hawthorn Group.

Satilla Formation and other Quaternary deposits (Pleistocene-Holocene)

The Satilla Formation is composed of shoreline complex deposits from the Pamlico, Princess Anne, Silver Bluff, and Holocene marine terraces, and includes clay-rich back-barrier deposits, sandy barrier island deposits, and shelly sands and clays from offshore continental coast settings. The four marine terraces formed at different times during the deposition of the Satilla Formation. The Satilla Formation is regarded as Late Pleistocene to Holocene in age (roughly 126,000 thousand years ago to the present). Typical fossils include burrows, foraminifera, bivalves and other mollusks (Huddlestun 1988; Pirkle et al. 2007), and vertebrates including fish, turtles, crocodilians, ground sloths, castorid rodents, tapirids,

equids, deer, bovids, and proboscideans (Markewich et al. 1992). The term “Satilla Formation” was only brought into use in 1988, so most references use marine terrace names for identification of deposits, or do not assign the deposits to a formation. Silver Bluff and Holocene shoreline complex deposits are present at FOPU, and Pamlico and Princess Anne shoreline complex deposits are present in the immediate vicinity (Lawton et al. 1976; Kellam 1986; Colquhoun et al. 1987). Other, older Pleistocene units are found west of the Pamlico terrace.

Quaternary deposits of the Savannah area are best known for their fossil mammals, but FOPU has different fossils. Jacob Whitman Bailey observed microfossils including diatoms, phytoliths (microscopic mineralized hard parts in plants), and bits of sponges and sea slugs in sediment removed during the construction of foundations and ditches at Fort Pulaski. The fossiliferous layer was found at depths of 4.6 to 6.1 m (15-20 ft). The diatoms are comparable to extant estuarine taxa from the Atlantic coast (Bailey 1851). Bailey was in the Savannah area in December 1849. This is shortly after the early 1847 completion of the dikes and ditches of the fort (Meader and Binkley 2003).

Shells may also be present at FOPU. Fossil shells and shark teeth are collected from the north beach of Tybee Island (Pearce and DeVivo Marketing 1997-2008 [<http://www.tybeeisland.com/tybee-bird-watching.shtml>]), bordering FOPU. Detrital Cenozoic-age mollusk shells are locally common along Georgia estuaries and nearshore settings; fragments of worm tubes may also be present (Salazar et al. 1982). Shell material is mentioned in passing by Verross (1983) and Compton et al. (2007) as present in Wassaw Sound, south of Tybee and Wilmington islands, by Martens (1935) as present on Tybee Island, and by Veatch and Stephenson (1911) from several Pleistocene-age deposits in the Savannah area, and fossil shells were described as common on Wilmington Island in 1839 (Anonymous 1839). More recent material may be mixed in as well (Salazar et al. 1982); for example, there is a modern oyster shell bank off of the north boundary of FOPU, in the Savannah River (Howell and Alexander 2004), FOPU's Daymark Island is a shell reef, and an island to the north of FOPU is called Oysterbed Island. Another potential invertebrate find in Pleistocene and Holocene coastal sediments, particularly those from high-energy littoral and shallow neritic settings, is crustacean burrows (Weimer and Hoyt 1964).

Quaternary vertebrate remains may be present at FOPU, as they are common in the Savannah area, but have not been found yet from the park. Quaternary vertebrate remains have been known from the Savannah area since at least 1823, when they were noticed on Skidaway Island, at a locality roughly 20 km (12 miles) southwest of FOPU (Hulbert and Pratt 1998). Skidaway Island is where the holotype of giant ground sloth *Megatherium mirabile*, now synonymized with *Eremotherium laurillardi*, was found (Sanders 2002). Savannah was an early source of Pleistocene mammal fossils, such as a nearly complete mastodon skeleton removed from a salt marsh in the 1830, but the region became forgotten toward the end of the 19th century. Systematic exploration resumed in the 1980s, and there are now several published sites in the Savannah area (Hulbert and Pratt 1998). Aside from Skidaway Island sites like the Fossilosa Site and Jones Girls Site, both about 20 km (12 miles) southwest of FOPU (Hulbert and Pratt 1998), several other sites are known, including: Elba Island to the north and northwest of FOPU across the south channel of the Savannah River (D. Bohaska, collections manager, Vertebrate Paleontology, National Museum of Natural History, pers. comm., January 2009); Isle of Hope and Mayfair, roughly 12 km (7 miles) to the west of FOPU; and the Porters Pit Site, 20 km (12 miles) to the northwest. The Isle of Hope site preserves the most diverse fossil vertebrate fauna known from the Georgia Coastal Plain (Hulbert and Pratt 1998). Isolated reports of mammal specimens from Pleistocene deposits in the Savannah area include a specimen of the Bearded Seal (*Erignathus*) collected by Ivan R. Tompkins in November 1937, material of the cricetid rodent *Neofiber*, and several specimens of the caviid *Hydrochoerus* (Sanders 2002). Quaternary deposition in the Savannah region probably occurred in environments similar to modern settings, such as barrier islands, back-barrier marshes, shallow marine, and channels (Hulbert and Pratt 1998).

The Savannah sites appear to include two discrete levels. Like FOPU, most of the sites are eastward of the Pamlico barrier island complex. These sites are found at or slightly below modern sea level, and most likely date to between 125,000 and 75,000 years ago (Hulbert and Pratt 1998). On Skidaway Island, corals in a shell layer have been dated to 80,000 years ago (Booth et al. 2003). Invertebrates from the sites east of

the Pamlico shoreline complex came from estuarine and neritic settings. The Jones Girls Site with its diverse mollusks resembles back-barrier and foreshore deposits of the Wando Formation (see the Fort Sumter National Monument chapter for a detailed discussion of the Wando Formation). Fish taxa were also largely from estuarine or shallow coastal settings. Most of the tetrapods came from barrier island, salt marsh, or quiet freshwater settings, with some upland animals, and a predominance of browsers over grazers. The Porters Pit Site and nearby gravel quarries are west of the Pamlico shoreline complex and represent fluvial deposits from a sea-level lowstand. Fossils from these sites are mixed from Miocene, Pliocene, and Pleistocene deposits, including the Raysor Formation, Coosawhatchie Formation, Marks Head Formation, and Parachucla Formation (Hulbert and Pratt 1998). Deposits east of the Pamlico shoreline complex fall under the definition of the Satilla Formation (Huddlestun 1988).

Pleistocene animals from the Savannah area east of the Pamlico shoreline complex include: corals; bryozoans; gastropods (8 taxa as of 1998); bivalves (11 taxa); barnacles; worms (represented by tubes); echinoids; sharks (9 taxa); rays (3 taxa); abundant actinopterygians (at least 25 taxa) from gars and eels to flounders and blowfish; salamanders (4 taxa); frogs (3 taxa); reptiles including turtles (12 taxa), colubrid (6 taxa) and croatlid snakes (2 taxa), and alligators; ducks; swans; turkeys; opossums; armadillos; ground sloths (3 taxa); moles (3 taxa); 5 taxa of carnivorans including ursids, raccoons, otters, and felids; a wide variety of rodents including sciurids (3 taxa), castorids (2 taxa), cricetids (8 taxa), geomyids, and caviids (2 taxa); lagomorphs (2 taxa); peccaries; camelids; tapirids; deer; bovids; equids; mastodons; and mammoths. Pleistocene, Holocene, and modern invertebrates (mostly mollusks and barnacles) are known to be mixed at the Isle of Hope site, raising the possibility that the vertebrates are also mixed, but it is thought that Holocene and modern vertebrates are not significant because preservation is uniform and introduced Old World taxa are not present (Hulbert and Pratt 1998). Animal fossils from west of the Pamlico shoreline complex are typically worn and include bivalves, sharks, crocodilians, dugongs, sperm whales, equids, and rhinocerotids, all of which are pre-Pleistocene, and isolated remains of Pleistocene vertebrates such as ground sloths, cervids, equids, mastodons, and mammoths (Hulbert and Pratt 1998).

Quaternary plant fossils are less well-known in the Savannah area, but are present. For example, peat debris dated to $36,830 \pm 340$ radiocarbon years before present (ybp) (radiocarbon dates require calibration to yield calendar dates) is known from an ancient channel deposit on Skidaway Island, and includes pollen, pine needles, and testate (shelled) amoebae from a relatively warm Coastal Plain setting (Booth et al. 2003). There are also the Fort Pulaski phytoliths (Bailey 1851) discussed above.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following formations or resource settings within FOPU, some of which would be found 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.

Marks Head Formation (Lower Miocene)

The Marks Head Formation is a Lower Miocene rock unit included in the Hawthorn Group (Huddlestun 1988). The base of the formation is burrowed, with shell fragments and phosphate pebbles just above the base. The rest of the Marks Head Formation has two major lithologies: clay and fine-grained phosphate-rich quartz sand (McCartan 1990). Its depositional environment is interpreted as marine, from nearshore to the inner continental shelf, and its marine fossils suggest a late Early Miocene age (20 to 16 Ma) (Huddlestun 1988). The name had fallen out of general usage for several decades until it was reintroduced in 1988 by Huddlestun, so its deposits may also be described as part of the Hawthorn Formation or as Miocene deposits.

Fossils of the Marks Head Formation include nannofossils (Bybell 1990), dinoflagellates (Edwards 1990), spores, pollen (Weems and McCartan 1990), foraminifera (Abbott and Huddlestun 1980), gastropods, bivalves, barnacles (Gardner 1925), and a variety of vertebrates (Prett and Petkewich 1989). It is typically

unfossiliferous, though, except at its type location and in the subsurface south of Savannah (Huddleston 1988). An important site for Marks Head Formation vertebrate fossils is near Porters Landing, on the Savannah River in Effingham County, GA, but this site is over 64 km (40 miles) northwest of Savannah. Most of the vertebrates found here are marine, including 11 species of sharks and rays, at least 10 species of teleost fish, turtles, marine crocodilians, and toothed whales, suggesting a nearshore subtropical setting. A few terrestrial vertebrates are also known, including lizards, insectivores, heteromyid and cricetid rodents, and mule deer (Prett and Petkewich 1989).

Coosawhatchie Formation (Tybee Phosphorite Member, Middle Miocene)

The Coosawhatchie Formation is another formation of the Hawthorn Group, and is of Serravallian age (about 13.8 to 11.6 Ma). It includes several members that differ in composition. The Meigs Member is the lowest member in the west and the Tybee Phosphorite Member is the lowest in the east. The Berryville Clay Member is next highest, followed by the Ebenezer Member and finally, in some locations, the Charlton Member. The member present under FOPU is the Tybee Phosphorite Member. The Tybee Phosphorite Member is made up of quartz sand and phosphate, with some clay and dolomite. It is regarded as a marine unit that was deposited over a shallow continental shelf distant from shore. Fossils include burrows and other trace fossils, molds and impressions of mollusks, and abundant fine vertebrate debris, like fish scales and teeth, small bones, and vertebrae (Huddleston 1988). Deposits identified as Coosawhatchie Formation clay in the Savannah area have yielded nannofossils, silicoflagellates, diatoms, terrestrial pollen (oak, hickory, and prairie grass), radiolarians, foraminifera, and fish teeth (Abbott and Andrews 1979).

Quaternary offshore deposits

There is some potential for reworked offshore fossils to wash up at FOPU, but this is reduced by the geography of the park: McQueens Island, the largest part of FOPU, is blocked from the ocean, although Cockspur Island and the small associated Cockspur Island Lighthouse Reservation and Daymark Island properties are not blocked. The continental shelf outside of Savannah is known to produce mollusk fossils (Milliman et al. 1972). A variety of other fossils may also be present, including those of algae, foraminifera, corals, bryozoans, polychaete worm tubes, ostracodes, barnacles, and echinoids (Macintyre and Milliman 1970). Black staining of mollusks is one of the characteristics of Quaternary fossil mollusks, and may indicate deposition in low energy coastal swamps during a time of lower sea level (Milliman et al. 1972). Boring by other invertebrates (Pilkey et al. 1969), abrasion, and trace element composition can also be used to distinguish modern from fossil shells (Wehmiller et al. 2003). The more worn, damaged, and bored a specimen is, the older it probably is.

Terrestrial remains may also wash up, as the coast had been farther east at the last glacial maximum. For example, wood, shell, bones, and a bone or antler tool are known from Gray's Reef National Marine Sanctuary and nearby J-Reef, presently under 17-20 m (56-66 ft) of water roughly 32 km (20 miles) out to sea and about 80 km (50 miles) south of FOPU. These remains date from between about 40,000 and 8,000 years ago (Garrison 2006).

Park Collections

There are no known FOPU specimens in the collections database of the Southeast Archeological Center (SEAC).

Fossils Found in Cultural Resource Contexts

There is also the possibility of finding fossils associated with cultural resources, such as fossils altered or modified by humans. Remains of the biota that was contemporaneous with archeological resources are also of paleontological interest. As noted by Howard and DePratter (1980), there are thousands of archeological sites on the Georgia coast, including shell ridges, villages, and burial mounds. Archeological sites are abundant on the Sea Islands (DePratter and Howard 1976); although FOPU properties are not

technically included in the Sea Islands, Tybee Island (just seaward of FOPU) is. Dating of archeological sites is often accomplished by chronologies using ceramics found in shell middens (DePratter and Howard 1976). Middens younger than about 3,200 years old can be dated in this way (the first fiber-tempered ceramics appear at the end of the Late Archaic period, about this age; Keel et al. 1996). People were living just across from the southeastern tip of FOPU between about 4,000 and 3,000 years ago (Howard and DePratter 1984). People were present in the area of Fort Frederica National Monument, a similar setting roughly 105 km (65 miles) south of FOPU, by 5,000 years ago, and they were using bone and shell tools and leaving shell middens (Hovarth et al. 1991). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division has not yet conducted a geologic resource scoping session for FOPU.
- SECN parks such as CAHA, CALO, CANA, CASA, CUIS, FOCA, FOFR, FOMA, FOPU, FOSU, and TIMU are geologically very young, making it difficult to determine what material is a “fossil” and what would be considered “modern.” The National Park Service defines a fossil as any remains of life preserved in a geologic context. This definition does not include an arbitrary date where older specimens are considered fossils, and younger specimens are not. The “geologic context” phrase is intended to imply some level of antiquity, however. Generally, specimens dating back to the late Pleistocene are considered fossils. Late Holocene (last few hundred or thousand years, “Recent”) specimens are usually considered modern and not fossils. Pleistocene remains may differ from younger remains by having dark staining and being heavily worn and bored, but this does not always hold true. Surface and subsurface specimens collected at FOPU span this range between Pleistocene and Holocene. Regardless of what label is assigned to them, these specimens are important natural resources and valuable pieces of the history of life on earth.
- Some coastal park units in the NPS experience unauthorized casual collecting of fossils (beach-combing) from beach areas. This activity is not well documented in the SECN. Further investigation into casual collecting could lead to development of a park or regional policy related to such collecting.
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Southeast Archeology Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at FOPU.

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Data Sets

Fort Pulaski National Monument Paleontological Archives

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

Fort Pulaski National Monument Museum Collections

1924–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by FOPU staff; status: Active.

Georgia Geological Survey

1976–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by GGS staff; status: Active.

Fort Sumter National Monument

Fort Sumter National Monument (FOSU) encompasses three sites in Charleston Harbor, South Carolina, including two historic forts. Fort Sumter, the titular site, is the location of the opening battle of the Civil War, April 12, 1861. Fort Moultrie (FOMO) is the scene of a battle from the Revolutionary War, where Patriot forces defeated the British June 28, 1776. Finally, there is the Fort Sumter Visitor Education Center and dock site at Liberty Square. FOSU was authorized April 28, 1948. It encompasses 80.76 ha (199.57 acres), all of which are under Federal administration.

Charles Pinckney National Historic Site (CHPI) was authorized September 8, 1988 to preserve part of the farm of Charles Pinckney, one of the framers of the Constitution. CHPI is about 6.1 km (3.8 miles) northeast of Fort Sumter, and has an area of 11.51 ha (28.45 acres), all under Federal administration. CHPI is not officially included in the Southeast Coast Network, but it is mentioned here due to its proximity to FOSU and overall geologic similarity.

Geologic Background

FOSU's various properties are located in the harbor of the city of Charleston, along the coast of Charleston County in southeastern South Carolina. Three rivers flow into the harbor; from west to east, they are the Ashley, Cooper, and Wando rivers. To the east is the Atlantic Ocean. The general setting of the area is that of the Atlantic Coastal Plain Province. Fort Sumter is on an artificial island at the mouth of the harbor. Fort Moultrie is about 1.6 km (1.0 miles) to the northeast, on the southwestern tip of Sullivan's Island. The visitor education center is about 6.5 km (4.0 miles) northwest of Fort Sumter, on a peninsula south of Drum Island and the junction of the Cooper and Wando rivers. The geology of the visitor education center at FOSU has been discussed in one publication (Campbell et al. 1996). This document has a confusing conclusion, as it implies the presence of the entire Charleston-area geologic column under the visitor education center, when only the upper 30 m (100 ft) were studied and several units that would be present in the idealized column are not present.

A strong earthquake occurred in the Charleston area in 1886, its epicenter just northwest of the city. This event has led to a great deal of study of the underlying geology of the region. The east coast of the United States, including the Charleston area, has been distant from well-known generators of seismic and tectonic activity for over a hundred and fifty million years, since the African continent rifted from the North American continent during the Late Triassic and Jurassic (see Figure 2 for a geologic time scale). The rifting was set up by the collision of the two continents during the formation of the supercontinent Pangaea in the Paleozoic. Multiple episodes of deformation in the Appalachian Mountains document the long process of this collision. In western South Carolina, at least four episodes of deformation occurred from before 315 Ma (million years ago) to about 267 Ma. Associated with these deformations were metamorphism and intrusion of igneous rocks (rocks formed from molten material emplaced underground) (Secor et al. 1986). Rocks from this time and earlier, before the Triassic, have not been observed in the Charleston area except as eroded fragments recovered within younger sedimentary rocks from deep drill holes. Such fragments include granodiorites and other intrusive igneous rocks, basalts, and metamorphic rocks (Gohn 1983).

The rifting that separated Africa and North America occurred during the Early and Middle Jurassic, and rocks that formed at this time have been sampled by deep cores in the Charleston area. Cores from Clubhouse Crossroads about 32 km (20 miles) northwest of Charleston first encounter rocks from this time in the form of basalts, at depths of 750 to 775 m (2,460 to 2,540 ft) (Gottfried et al. 1983). Below these are sedimentary red beds, probably of river and alluvial fan environments (Gohn et al. 1983). The age of at least some of the basalts is about 184 Ma (Lanphere 1983). It appears that these rocks were deposited or extruded into fault-bounded basins during the rifting (Gottfried et al. 1977; Gohn et al. 1983). In fact, the entire Charleston-area basement forms its own distinct geologic block, perhaps as a zone of Mesozoic crustal extension analogous to but much larger than exposed Triassic and Jurassic basins (Popenoe and

Zietz 1977). The 1886 Charleston earthquake occurred in a relict Late Triassic-Early Jurassic rift, running east-northeast and containing sedimentary rocks and igneous intrusions (Rankin et al. 1978). Several other large earthquakes are thought to have occurred in the area over the past 12,000 years (Nuttli et al. 1986).

In general, the earthquake of 1886 notwithstanding, the east coast of the United States has had relatively little tectonic activity since North America and Africa rifted apart. During the time following the rifting, there has been deposition of sedimentary rocks in environments varying from open marine to coastal plain settings in eastern South Carolina, depending on sea level. The Coastal Plain sediments of South Carolina form a wedge-shaped package of rocks, over 1.6 km (1 mile) thick near the coast in southeastern South Carolina but disappearing at the Fall Line to the west (Rankin 1977). The Coastal Plain sediments of the Charleston area were laid down in the East Georgia Basin (Colquhoun and Johnson 1968), between the Cape Fear Arch (or Great Carolina Arch) to the northeast and the Southeast Georgia Embayment (or Okefenokee Embayment) to the southwest. The arch and embayment developed in the Miocene, resulting in existing formations undergoing differential erosion across their extent, depending on proximity to the evolving features (Colquhoun 1969). Additional sporadic episodes of movement also affected deposition (Huddlestun 1988).

An important feature of Atlantic Coastal Plain geology is the well-developed set of marine terraces, which document ancient shorelines. Over time, terraces formed progressively closer to the modern shore, in distance and elevation. There is a set of named terraces that are used in geologic descriptions. From oldest to most recent, these include the Capitol, Hazelhurst, Cohaire, Sunderland, Okefenokee, Wicomico, Penholoway, Talbot, Pamlico, Princess Anne, Silver Bluff, and Recent terraces (Colquhoun and Johnson 1968; Colquhoun 1969). These terraces were formed between the Pleistocene and the present in response to sea level fluctuations over a long period of marine regression (Colquhoun 1969; Richards et al. 1971). The Charleston area is crossed by the Talbot, Pamlico, Princess Anne, Silver Bluff, and Recent terraces (Campbell et al. 1996). The terraces typically have a marine layer at the base with a thicker sequence of coastal terrestrial sediments above, such as beach sands, barrier sands, estuarine or back-barrier sands and clays, and floodplain deposits left behind by receding shorelines (Thornberry-Ehrlich 2006).

The Cenozoic formations of South Carolina, particularly those from the Neogene and Quaternary, have complex histories, with different correlations, ages, and names proposed for the rock units. Geologic dating can be problematic for several reasons. For example, the dating of the Pliocene-Pleistocene boundary worldwide is a current topic of dispute. A particular issue for the Coastal Plain setting is the choice of dating method: aminostratigraphy (using amino acid changes in fossils) may produce significantly different results from radioisotope dating methods (compare Belknap and Wehmiller [1982]'s aminostratigraphic dates to radioisotopes dates from McCartan et al. [1982a, b] for several Pliocene-Pleistocene units of the Atlantic Coastal Plain). Charleston is one area where aminostratigraphic dates are problematic (Wehmiller and Belknap 1982). The stratigraphy is further complicated by the use of marine terraces in the Atlantic Coastal Plain. Some of the terrace terms have also been used for formations. While this practice is now discouraged (Huddlestun 1988), it is something to watch for in older publications. Additionally, dredged material is common in the Charleston area, disrupting stratigraphy (B. Erickson, curator of vertebrate paleontology, Science Museum of Minnesota, pers. comm., October 2008).

The units of FOSU differ somewhat in terms of shallow subsurface geology (less than 30 m or 100 ft). Fort Sumter is an artificial island, with a foundation of granite, cement, and shells of unknown local provenance (Barnes 1952). Fort Moultrie is found over a combination of artificial fill and Quaternary beach, barrier island, and estuarine deposits (Weems and Lemon 1993). The visitor education center is also built on fill (Campbell et al. 1996). Both Fort Moultrie and Fort Sumter have Quaternary beach and barrier island sand immediately below their surficial material. Fort Sumter is underlain by Early Miocene-age rocks of the Marks Head Formation and then Late Oligocene-age Ashley Formation rocks in its near subsurface. Fort Moultrie has a more complicated immediate subsurface, with Quaternary tidal marsh

deposits over Pleistocene-age shelf sand and clayey sand of the Wando Formation, Marks Head Formation rocks, and Ashley Formation rocks (Weems and Lemon 1993). The visitor education center's artificial fill is underlain by Holocene deposits, the Wando Formation, and the Ashley Formation (Campbell et al. 1996). Other formations are present below the Ashley Formation, but because the shallowest rocks would be encountered most frequently, the descriptions are restricted to rock units known to about 30 m (100 ft) below sea level. See Weems and Lemon (1993) and Campbell et al. (1996) for descriptions of deeper subsurface units. All of these may produce fossils, and nannofossils (the remains of extremely tiny planktonic organisms) are known from Wando Formation deposits at Fort Moultrie (see below).

Sources of Paleontological Resources

The fossils of FOSU present opportunities for education, interpretation, and continued or future scientific research in the park. Aside from the material described in this section, a fossil from FOSU is repositied in the CHPI Museum. This specimen is documented below, as part of the "Park Collections" section following "Potential Sources of Paleontological Resources."

David Bohaska (collections manager, Vertebrate Paleontology, National Museum of Natural History, pers. comm., January 2009) notes that divers recover fossils from the Ashley and Cooper rivers. Given the fossiliferous nature of most Charleston-area formations, these could pertain to formations known to produce fossils at FOSU, formations that are known at FOSU but have not yet produced fossils there, or both.

Wando Formation (Upper Pleistocene)

The Wando Formation (some references may identify as the Socastee Formation at least in part) is largely made up of sand and clay, deposited between about 130,000 and 70,000 years ago (Weems and Lemon 1993). It was deposited in environments from both the terrestrial and marine sides of coasts, from rivers and estuaries to shallow shelves (Campbell et al. 1996). A thick lag deposit of phosphate nodules is found at the base of the Wando Formation, derived from the middle of the formation. The phosphate was mined from the late 19th century to the early 20th century in the Charleston area, when it was known as the "Ashley River phosphate beds" (Sanders 2002). Six subunits from three Pleistocene sea-level highstands are included in the Wando Formation, with sandy beach and barrier sand layers alternating with clay-rich lagoonal layers (Weems and Lemon 1993; Campbell et al. 1996). The Wando Formation can be so shell-rich as to form a coquina (Weems and McCartan 1990). Although the Wando Formation is completely buried at FOSU, this formation is exposed at the surface elsewhere.

In the Charleston area, the Wando Formation has produced trace fossils (Erickson and Sanders 1991), nannofossils (Bybell 1990), diatoms, spores, pollen (Weems and McCartan 1990), wood (Weems and Lemon 1993), foraminifera (Weems and McCartan 1990), corals (Campbell et al. 1996), gastropods, bivalves (Weems and McCartan 1990), ostracodes (Cronin 1990), and vertebrates (Weems and Lemon 1993). Wando Formation mammals include ground sloths, canids, ursids, felids, walrus, rodents (castorids, cricetids, and caviids), camelids, deer, and mastodont and gomphotherid proboscideans. Most Wando Formation vertebrate remains come from the lower lag deposit, are very dark grey or black, and are probably reworked from more terrestrial middle Wando Formation deposits, whereas *in-situ* Wando Formation vertebrate remains from above the lag are light gray in color and are very light, having had most of their calcium leached out (Sanders 2002).

The Wando Formation is present beneath both the visitor education center (Campbell et al. 1996) and Fort Moultrie, but not under Fort Sumter. Under Fort Moultrie, two distinct types of Wando Formation deposits are known: a shelf sand that is typically fossiliferous, with mollusks as well as worn bones and teeth at its base; and clayey sand and clay below. The latter type of deposit is known to produce wood and vertebrate fossils, probably from a river to estuarine setting (Weems and Lemon 1993). Both sand and clay layers of the Wando Formation are present beneath the visitor education center (Campbell et al.

1996). A Wando Formation sampling locality from near the west end of Fort Moultrie was discussed in Bybell (1990) and Weems and McCartan (1990). This site, number 73 (also identified as X-FM-4, XFM4, and J5), produced calcareous nannofossils at a depth of 10.5 to 11 m (35-36 ft) below sea level. Per Campbell et al. (1996), this level is probably close to the contact between Wando Formation deposits and overlying Holocene deposits.

Shell-bearing rocks and other fill contributors, local but unknown provenance (Cenozoic)

As noted by Barnes (1952), the construction of Fort Sumter required “hundreds of thousands of bushels of shells... for concrete, for the foundation of the first-tier casemate floors, and for use in the parade fill next to the enrockment.” Barnes notes that these were obtained locally. Because of the long-term coastal marine setting of the Charleston area, shells can be found in practically any local formation, except where they have been lost due to leaching (as in the lower Pleistocene Waccamaw Formation). Formations in the area that are particularly mollusk-rich include the Pliocene-age Raysor Formation and the Pleistocene-age Penholoway Formation, Ten Mile Hill Beds, and Wando Formation (Weems and McCartan 1990), the latter of which is also known to be present in the shallow subsurface of FOSU units (Weems and Lemon 1993).

Of the four well logs described by Campbell et al. (1996) for the visitor education center property, the only reported possible macrofossils are wood debris from the upper 2.4 m (8 ft). The associated deposits are made up of artificial fill, so the specimens could be modern instead.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following formations or resource settings within FOSU, some of which would be found 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.

Ashley Formation (Upper Oligocene)

The Ashley Formation, uppermost formation of the Cooper Group, is an extensive fossiliferous calcarenite (a rock type that is a combination of sand and calcareous material, typically shells) from the Upper Oligocene. It is encountered between 21.3 to 24.4 m (70 to 80 ft) below sea level at the visitor education center (Campbell et al. 1996) and is as shallow as 3 m (10 ft) below the surface south of Charleston Harbor (Katuna and Fields 1998). The depositional environment is interpreted as an open marine shelf (Campbell et al. 1996). It was deposited between about 28 and 23 Ma (Koretsky and Sanders 2002). Ashley Formation fossils include nannofossils, dinoflagellates, pollen, foraminifera, bryozoans (DuBar et al. 1980), mollusks (Giddens and Katuna 1989), ostracodes, echinoids (DuBar et al. 1980), sharks, bony fishes, sea turtles, nonmarine turtles, estuarine crocodilians, marine birds, pinnipeds (Koretsky and Sanders 2002), baleen whales (Barnes and Sanders 1996; Sanders and Barnes 2002a, b), toothed whales (Koretsky and Sanders 2002; Geisler and Sanders 2006), and sirenians (manatees and dugongs) (Domning 1997). The fossil record of the Ashley Formation is somewhat problematic, as the overlying Chandler Bridge Formation is also very fossiliferous with a similar fauna (Koretsky and Sanders 2002), and fossils assigned to the Ashley Formation are often found without tight stratigraphic context, for example found in the course of mining or washed from beds (Sanders 1980). Black magnetic spherules are also present, thought to be of extraterrestrial origin (i.e., an asteroid or other bolide; Taylor et al. 1996). The Ashley Formation is present under all three FOSU units (Weems and Lemon 1993; Campbell et al. 1996).

Marks Head Formation (Lower Miocene)

The Marks Head Formation is a Lower Miocene rock unit included in the Hawthorn Group (Huddleston 1988). The base of the formation is burrowed, with shell fragments and phosphate pebbles just above the base. The rest of the Marks Head Formation has two major lithologies: clay and fine-grained phosphate-

rich quartz sand. It is only found in the subsurface in South Carolina, but is exposed at the surface in Georgia (McCartan 1990). Its depositional environment is interpreted as marine, from nearshore to the inner continental shelf, and its marine fossils suggest a late Early Miocene age (20 to 16 Ma) (Huddleston 1988). The name had fallen out of general usage for several decades until it was reintroduced in 1988 by Huddleston, so its deposits may also be described as part of the Hawthorn Formation or as Miocene deposits.

Fossils of the Marks Head Formation include nannofossils (Bybell 1990), dinoflagellates (Edwards 1990), spores, pollen (Weems and McCartan 1990), foraminifera (Abbott and Huddleston 1980), gastropods, bivalves, barnacles (Gardner 1925), and a variety of vertebrates (Prett and Petkewich 1989). It is typically unfossiliferous, though, except at its type location and in the subsurface south of Savannah, about 130 km (80 miles) southwest of Charleston (Huddleston 1988). An important site for Marks Head Formation vertebrate fossils is near Porters Landing, on the Savannah River in Effingham County, GA, but this site is over 137 km (85 miles) west of FOSU. Most of the vertebrates found here are marine, including 11 species of sharks and rays, at least 10 species of teleost fish, turtles, marine crocodilians, and toothed whales, suggesting a nearshore subtropical setting. A few terrestrial vertebrates are also known, including lizards, insectivores, heteromyid and cricetid rodents, and mule deer (Prett and Petkewich 1989). The Marks Head Formation is present under all three FOSU units (Weems and Lemon 1993; Campbell et al. 1996).

Quaternary offshore deposits

Both Fort Sumter and Fort Moultrie have some exposure to ocean waves, and with them the possibility of reworked fossils washing up. The continental shelf outside of Charleston is known to produce mollusk fossils (Milliman et al. 1972). A variety of other fossils may also be present, including those of algae, foraminifera, corals, bryozoans, polychaete worm tubes, ostracodes, barnacles, and echinoids (Macintyre and Milliman 1970). Black staining of mollusks is one of the characteristics of Quaternary fossil mollusks, and may indicate deposition in low energy coastal swamps during a time of lower sea level (Milliman et al. 1972). Vertebrate remains may also wash up, as has happened for years at Edisto Island, over 36 km (22 mi) to the southwest of Fort Sumter. Both marine and terrestrial vertebrate fossils have washed up, indicating the presence of two distinct faunas. The remains are thought to be about 50,000 to 10,000 years old, and come from groups including turtles, armadillos, ground sloths, raccoons, ursids, canids, felids, seals, lagomorphs, porcupine and caviid rodents, tapirids, equids, oceanic dolphins and other toothed whales, deer, bovids, and proboscideans (Sanders 2002).

Holocene deposits

The Holocene deposits of the Charleston area were laid down in several depositional environments over the last 85,000 years, including tidal marshes, beaches and barrier islands, estuaries, streams, and swamps. The deposits under Fort Sumter are largely beach and barrier island sand, probably less than 10,000 years old. Fort Moultrie also has beach and barrier island sand, but is also has tidal marsh clay and sand over the beach and barrier sand. The tidal marsh deposits are probably less than 5,000 years old (Weems and Lemon 1993). The visitor education center has both sand and clay under it (Campbell et al. 1996). Per Weems and Lemon (1993), the tidal marsh deposits of the area are organic-rich, and the beach and barrier island sands have shells.

There is also the possibility of finding fossils associated with cultural resources, such as fossils altered or modified by humans. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Park Collections

There is one FOSU-associated specimen on record. FOSU 8034, from an unidentified animal, came from Fort Moultrie and is in storage at CHPI. Further identification of this specimen and its provenance is needed.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division has not yet conducted a geologic resource scoping session for FOSU.
- Further identification of the FOSU fossil specimen housed at SEAC is required.
- SECN parks such as CAHA, CALO, CANA, CASA, CUIS, FOCA, FOFR, FOMA, FOPU, FOSU, and TIMU are geologically very young, making it difficult to determine what material is a “fossil” and what would be considered “modern.” The National Park Service defines a fossil as any remains of life preserved in a geologic context. This definition does not include an arbitrary date where older specimens are considered fossils, and younger specimens are not. The “geologic context” phrase is intended to imply some level of antiquity, however. Generally, specimens dating back to the late Pleistocene are considered fossils. Late Holocene (last few hundred or thousand years, “Recent”) specimens are usually considered modern and not fossils. Pleistocene remains may differ from younger remains by having dark staining and being heavily worn and bored, but this does not always hold true. Subsurface specimens collected at FOSU span this range between Pleistocene and Holocene. Regardless of what label is assigned to them, these specimens are important natural resources and valuable pieces of the history of life on earth.
- Some coastal park units in the NPS experience unauthorized casual collecting of fossils (beach-combing) from beach areas. This activity is not well documented in the SECN. Further investigation into casual collecting could lead to development of a park or regional policy related to such collecting. FOSU does not have a policy or procedure to deal with the public collecting fossils that wash onto the beaches (R. Dorrance, FOSU resource program manager, pers. comm., November 2008).
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Southeast Archeology Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at FOSU.

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Data Sets

Fort Sumter National Monument Paleontological Archives

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

Fort Sumter National Monument Collections at the Charles Pinckney National Historic Site Museum

1988–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by CHPI staff; status: Active.

Horseshoe Bend National Military Park

Horseshoe Bend National Military Park (HOBE) was established to protect the site of the decisive battle of the 1813-1814 Creek War. On this site March 27, 1814, United States forces under Andrew Jackson defeated the Upper Creek Indian Confederacy. HOBE was authorized July 25, 1956, and encompasses 826 ha (2,040 acres), all of which are under Federal administration.

Geologic Background

HOBE is located in north-central Tallapoosa County, eastern Alabama. The namesake Horseshoe Bend pertains to the Tallapoosa River that runs through HOBE, draining into Martin Lake a few kilometers downstream to the southwest. Montgomery is about 90 km (55 miles) to the southwest. The geologic setting of HOBE was briefly described by Henderson (2000).

HOBE is in the region where the eastern Blue Ridge physiographic province meets the Piedmont physiographic province in Alabama, in the immediate vicinity of the Brevard Zone, a large strike-slip fault zone last active about 300 Ma (millions of years ago) (see Figure 2 for a geologic time scale) (McConnell and Costello 1980). The Brevard Zone in the HOBE area is thought to separate North American continental material on the northwest side from land added during the formation of Pangaea in the Paleozoic (Sterling et al. 2005), but the Brevard Zone has proved difficult to define, with 23 different interpretations by 2003 (Sterling and Steltenpohl 2003). The Blue Ridge is on the northwest side of the Brevard Zone, and the Piedmont is on the southeast side. HOBE itself is on the northwest side, and includes rocks from the Blue Ridge and Brevard Zone. The HOBE area is underlain by Paleozoic metamorphic and igneous rocks. This area is crossed by numerous faults, running in a general southwest-northeast orientation. These faults formed in the Paleozoic during the events that led to the assembly of the supercontinent Pangaea. Some faults represent boundaries between small landmasses that were added to North America (Drummond et al. 1997).

Most of HOBE is found along the southeastern margin of the Tallapoosa Block, a large unit of land bounded by faults (Stow et al. 1984). The portion of HOBE in the Tallapoosa Block is found in the southeastern subunit known as the Kowaliga Block (Bieler and Deininger 1984). The Tallapoosa Block is mostly made up of metamorphosed sedimentary rocks, with significant quantities of granitic rocks in the southwest. The metasedimentary rocks are at least as old as the Cambrian (Stow et al. 1984). Slightly later, during the Middle Ordovician, there had been a broad tidal flat complex in the region (Ward and Benson 1981), although the rocks that were deposited during this time in the HOBE area have been heavily metamorphosed, folded, and faulted.

Part of the HOBE area was added to North America during the events that led to the formation of the supercontinent Pangaea, in the Paleozoic. This was a long, complicated process, with several periods of mountain building that metamorphosed, folded, faulted, and otherwise disrupted and changed the rocks that had been present before. During these mountain-building events, called orogenies, landmasses ranging in size from island arcs to a partial supercontinent collided with what is now the southeastern United States. Important orogenies in the southeastern United States include the Taconic Orogeny, which took place during the Ordovician, the Acadian Orogeny, which took place during the Late Silurian and Early Devonian, and the Alleghenian Orogeny, which took place during the Pennsylvanian. When Pangaea later rifted apart, North America had become larger than it was before the assembly of the supercontinent, through the addition of the various small landmasses that had collided with it or been separated from the other components of Pangaea (Levin 1999; Hatcher 2001). North America and Africa rifted apart during the Late Triassic and Jurassic, and are still moving apart today.

The rocks present at HOBE include, roughly from oldest to youngest, undifferentiated rocks of the Emuckfaw Group (Lower Paleozoic, pre-Middle Ordovician per Guthrie and Dean 1989), the Kowaliga Gneiss (Ordovician, 460 ± 19 Ma, per Russell et al. 1987), and rocks of the Jacksons Gap Group (originally

deposited sometime from the Precambrian to the Paleozoic). The deposits of these rocks cut diagonally across the park in a southwest-northeast orientation, with the Emuckfaw Group present in the northwest corner and the Jacksons Gap Group present along the southeast boundary (Osborne et al. 1992). None of these are known to produce fossils, and are all unlikely to do so: the Emuckfaw Group is composed of schists and gneisses (Guthrie and Dean 1989), the Kowaliga Gneiss is a gneiss, and the Jacksons Gap Group is made up of a variety of metamorphic rocks (Steltenpohl et al. 1990). There is also undoubtedly Quaternary sedimentation from the Tallapoosa River running through HOBE. These Quaternary deposits are the only units likely to have fossils at HOBE. Fossils associated with cultural resources are also possible.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following formations or cultural resource settings within HOBE. However, these units are known to preserve fossils elsewhere, and future field investigations within the park may recover fossils from one or both (or none) of them. The cultural resource fossil potential is discussed in the “Fossils found in cultural resource contexts” section.

Quaternary rocks and deposits (Pleistocene-Holocene)

Quaternary deposits from streams running through HOBE and soils are the most likely sources to produce fossil resources in the park. Quaternary fossils such as algal cysts, pollen, leaves, and wood may be present in the deposits. Fossils like these are found in former marshy areas at Congaree National Park (CONG), another Southeast Coast Network park with active rivers (see the CONG chapter for a detailed discussion). If present, such fossils could be useful for paleoclimatological and paleoecological studies. Because the local bedrock contains no fossils, there will be no reworked fossils from these units in the Quaternary deposits.

Park Collections

There are no known HOBE specimens in the collections database of the Southeast Archeological Center.

Fossils Found in Cultural Resource Contexts

There is the potential for fossil resources to be found with cultural resources, although none are known to date (D. Colley, HOBE resource program manager, pers. comm., September 2008; J. Cahill, HOBE supervisory park ranger, pers. comm., September 2008). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division has not yet conducted a geologic resource scoping session for HOBE.
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Southeast Archeology Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at HOBE.

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Data Sets

Horseshoe Bend National Military Park Paleontological Archives

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

Kennesaw Mountain National Battlefield Park

Kennesaw Mountain National Battlefield Park (KEMO) was established to protect sites related to two Civil War battles fought during General William T. Sherman's Atlanta campaign. Union and Confederate earthworks from the battles of Kolb's Farm (June 22, 1864) and Kennesaw Mountain (June 27, 1864), where Confederate forces temporarily halted the Union advance, are included at KEMO. KEMO was authorized as a national battlefield site February 8, 1917. It was transferred from the War Department to the National Park Service August 10, 1933, and was redesignated June 26, 1935. Its boundaries were changed August 9, 1939. KEMO encompasses 1,167.17 ha (2,884.14 acres), all but 1.84 ha (4.54 acres) of which are under Federal administration.

Geologic Background

KEMO is located in north-central Cobb County, Georgia, about 26 km (16 miles) northwest of the center of Atlanta. Several creeks pass through this park. Based upon the configuration of Federal and private lands, KEMO has the shape of a stretched "Figure 8." KEMO is found in the northern Piedmont, north of the Brevard Zone (McConnell and Abrams 1984), a large strike-slip fault zone last active about 300 Ma (millions of years ago) (see Figure 2 for a geologic time scale) (McConnell and Costello 1980). Geologic resources of KEMO are described in publications (Rogers and Lester 1953; Hurst 1956; Conn and Neiheisel 1963; Leslie and Burbank 1979) and unpublished theses (Hurst 1952), although these publications are devoted to topics other than paleontology.

The Atlanta area lies mostly within the Piedmont physiographic province, divided into northern and southern components by the Brevard Zone (McConnell and Abrams 1984, although note that the Brevard Zone is sometimes used to divide the eastern Blue Ridge physiographic province from the Piedmont). Kennesaw Mountain is found within the northern Piedmont (McConnell and Abrams 1984), and is made up of gneisses of various compositions that probably formed from intense metamorphism of igneous rocks (Conn and Neiheisel 1963). Pegmatites (coarsely crystalline igneous rocks, with hydrothermal activity permitting the growth of oversized crystals) are also present (Rogers and Lester 1953).

The Atlanta area was added to North America during the events that led to the formation of the supercontinent Pangaea, during the Paleozoic. The Allatoona and Hayesville faults, northwest of the metro region, mark the boundary between an old North American margin on the northwest side and accreted lands on the southeast side (Holm and Farmer 2002; Eckert and Hatcher 2003). The accreted lands included slivers of oceanic crust and Ordovician-age volcanic island arcs (Eckert and Hatcher 2003). These terranes were added about 460 Ma as the basin between the arc and North America was subducted, during a mountain-building event known as the Taconic Orogeny (Hatcher 2001).

In the Georgia Piedmont, extensive deformations of the existing rock took place throughout most of the Paleozoic. Metamorphism peaked about 370 to 360 Ma (Dallmeyer 1978), and igneous rocks intruded at the same time or slightly before (McConnell and Abrams 1984). Another episode of igneous intrusion around 300 Ma was responsible for the formation of the granites of several Atlanta-area landmarks, such as Panola Mountain (Atkins and Griffin 1977) and Stone Mountain, dated to approximately 291 Ma (Whitney and Jones 1976). These igneous bodies are related to the Pennsylvanian-age Alleghenian Orogeny, the final stage of the formation of Pangaea, when Africa and North America collided. North America and Africa then rifted apart during the Late Triassic and Jurassic, and are still moving apart today. Deposition younger than the Paleozoic is not recorded in the Atlanta area, except as Quaternary surficial soil and river deposits. Crystalline rocks (igneous, or previously molten) persist at or near the surface until the Fall Line (about 110 km or 70 miles southeast of the metro area) (Lawton et al. 1976).

Much of KEMO is underlain by metamorphic rock units. These rocks have complicated structural geology and are difficult to interpret, with multiple naming schemes and interpretations since the late 1970s (Higgins and McConnell 1978; Abrams and McConnell 1984; McConnell and Abrams 1984;

Higgins et al. 1988; Crawford et al. 1999). Therefore, terminology will vary by source. Higgins et al. (2003) is used for this report. The rocks present at KEMO include, roughly from oldest to youngest: several units from sometime between the Precambrian and Ordovician, including an amphibolite, the Crider Gneiss, migmatite (partially melted and recrystallized metamorphic rock) of Kennesaw Mountain, magnetite-rich quartzite, the Ropes Creek Metabasalt, the Stonewall Gneiss, and altered silica-poor igneous rock; the Crawfish Creek Formation (Cambrian); schist of the Bill Arp Formation (Cambrian-Ordovician), altered rocks similar to those from Garnet Hill, from sometime between the Late Ordovician and Permian; and heavily weathered fragments of all of the above (Quaternary) (Higgins et al. 2003). There are also undoubtedly some Quaternary soils and sedimentation from local drainage in the small streams running through KEMO. These Quaternary deposits are the only potentially fossiliferous units at KEMO. Fossils associated with cultural resources are another possibility.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following formations or cultural resource settings within KEMO. However, these units are known to preserve fossils elsewhere, and future field investigations within the park may recover fossils from one or both (or none) of them. The cultural resource fossil potential is discussed in the “Fossils found in cultural resource contexts” section.

Quaternary rocks and deposits (Pleistocene-Holocene)

Quaternary-age deposits from streams running through KEMO and soils are the most likely places to find fossil resources in the park. Quaternary fossils such as algal cysts, pollen, leaves, and wood may be present in the deposits. Fossils like these are found in former marshy areas at Congaree National Park (CONG), another Southeast Coast Network park with active rivers (see the CONG chapter for a detailed discussion). If present, such fossils could be useful for paleoclimatological and paleoecological studies. Because the local bedrock contains no fossils, there will be no reworked fossils from these units in the Quaternary deposits.

Park Collections

There are no known KEMO specimens in the collections database of the Southeast Archeological Center. Willie Johnson (KEMO resource program manager, pers. comm., September 2008) reported that there were no paleontological specimens in KEMO collections.

Fossils Found in Cultural Resource Contexts

Small rock mounds around Kennesaw Mountain suggest the presence of people of the Mound Builder culture in the vicinity of KEMO around 1,100 years ago (Capp 1994). Nearby Chattahoochee River National Recreation Area (CHAT) is rich in archeological resources, although neither KEMO nor CHAT are yet known to have associated paleontological resources. People are known to have been present at CHAT from about 10,000 to 8,000 years ago to the present. As of 1982, 70 archeological sites were known in CHAT. 47 of these pertain to prehistoric Indians and the other 23 are historic. The heaviest usage of sites occurred during the Woodland Period, from about 3,000 to 1,000 years ago. Sites are also known from the Archaic (10,000 to 8,000 years ago) and Mississippian (1,000 to 350 years ago) periods. The inhabitants left behind rock shelters, fish weirs, special-use areas, villages, and camps (Ehrenhard 1982). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division has not yet conducted a geologic resource scoping session for KEMO.

- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Southeast Archeology Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at KEMO.

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Data Sets

Kennesaw Mountain National Battlefield Park Paleontological Archives

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

Moore's Creek National Battlefield

Moore's Creek National Battlefield (MOCR) was established to commemorate an American Revolutionary War battle fought on the site February 12, 1776. The battle was waged between North Carolina Patriots and Loyalists, and the Patriots emerged victorious. MOCR was established as a national military park June 2, 1926 and was transferred from the War Department to the National Park Service August 10, 1933. Its boundaries were changed September 27, 1944 and October 26, 1974. Today MOCR encompasses 35.51 ha (87.75 acres), all of which are under Federal administration.

Geologic Background

MOCR is located in southeastern North Carolina, in southwestern Pender County near the town of Currie. Moore's Creek, which leads into the Black River and then the Cape Fear River, runs through MOCR. The setting is a Coastal Plain marshy lowland, with much vegetative cover. The geology of MOCR has been the subject of an internal National Park Service report (Thornberry-Ehrlich 2006). MOCR's general geology consists of deposits of unconsolidated to partially consolidated sands, silts, and clays from the Appalachian Mountains (Thornberry-Ehrlich 2006).

In general, the east coast of the United States has had relatively little tectonic activity since North America and Africa rifted apart during the Late Triassic and Jurassic (see Figure 2 for a geologic time scale), although there are occasional earthquakes (one caused slump deposits of 100 cubic kilometers in the Hatteras Abyssal Plain about 16,000 years ago [Elmore 2003]). A few features are tectonically active in the MOCR area. The Cape Fear Arch, a broad, deep-seated tectonic feature underlying the area of the Cape Fear River, has been active over at least the last 65 million years. Uplift and warping of this arch has shifted the Cape Fear River's course to the southwest, creating differential preservation of river terraces. River terraces northeast of the river have been preserved, while those to the southwest have been destroyed. There also are fewer large tributaries on the southwest side (Thornberry-Ehrlich 2006). Periods of movement include the Upper Cretaceous and some time pre-Pliocene (Bonini and Woollard 1960), probably during the Miocene (Colquhoun 1969). A smaller fold roughly perpendicular to the Cape Fear Arch has been active in the past 750,000 years, uplifting the upper part of the river valley. The Cape Fear Arch, with its ancient crystalline basement rocks, is found 457 m (1,500 ft) below sea level near Wilmington (about 32 km or 20 miles southeast of MOCR) (Thornberry-Ehrlich 2006). The presence of the arch brings relatively older Cretaceous rocks near the surface and causes post-Cretaceous deposits to be thinner or absent above it (Wehmiller et al. 1992; Thornberry-Ehrlich 2006); there are only a few Pliocene and younger rock units over Upper Cretaceous rocks in the area of MOCR (Owens 1989).

During the time following the Jurassic rifting, there has been deposition of sedimentary rocks in environments varying from open marine to coastal plain settings in eastern North Carolina, depending on sea level. Extensive submergence of eastern North Carolina occurred during the Cretaceous, Paleocene, Eocene, late Miocene, and parts of the Pliocene and Pleistocene (Richards 1968; Carter et al. 1988). An important feature of Atlantic Coastal Plain geology is the well-developed set of marine terraces, which document ancient shorelines. Over time, terraces formed progressively closer to the modern shore, in distance and elevation. There is a set of named terraces that are used in geologic descriptions. From oldest to most recent, these include the Capitol, Hazelhurst, Cohaire, Sunderland, Okefenokee, Wicomico, Penholoway, Talbot, Pamlico, Princess Anne, Silver Bluff, and Recent terraces (Colquhoun and Johnson 1968; Colquhoun 1969). These terraces were formed between the Pleistocene and the present in response to sea level fluctuations over a long period of general marine regression (Colquhoun 1969; Richards et al. 1971). In the Moore's Creek area, the terraces typically have a marine layer at the base with a thicker sequence of coastal terrestrial sediments above, such as beach sands, barrier sands, estuarine or back-barrier sands and clays, and floodplain deposits left behind by receding shorelines (Thornberry-Ehrlich 2006).

The Cenozoic formations of North Carolina, particularly those from the Neogene and Quaternary, have complex histories, with different correlations, ages, and names proposed for the rock units. From the Pliocene to the Holocene, there are several periods of deposition that are known under multiple names. One reason for this is the presence of structural highs, such as the Cape Lookout High that divided Miocene sedimentation (Snyder and Riggs 1989), and the Cape Fear Arch described above. Geologic dating can be problematic for several reasons. For example, the dating of the Pliocene-Pleistocene boundary worldwide is a current topic of dispute. A particular issue for the Coastal Plain setting is the choice of dating method: aminostratigraphy (using amino acid changes in fossils) may produce significantly different results from radioisotope dating methods (compare Belknap and Wehmiller [1982]'s aminostratigraphic dates to radioisotopes dates from McCartan et al. [1982a, b] for several Pliocene-Pleistocene units of the Atlantic Coastal Plain). The stratigraphy is further complicated by the use of marine terraces in the Atlantic Coastal Plain. Some of the terrace terms have also been used for formations. In North Carolina, this is particularly true for the Pamlico Formation/Terrace. While this practice is now discouraged (Huddlestun 1988), it is something to watch for in older publications. This chapter uses Thornberry-Ehrlich (2006) and its composite map (after Soller 1988 and Owens 1989) for stratigraphy, with the 1985 North Carolina state geologic map (found at <http://www.geology.enr.state.nc.us/usgs/geomap.htm>) and North Carolina Geologic Survey Bulletin 89 (Carter et al. 1988) to complement it.

Two rock units are known to underlie MOCR: the Pleistocene-age Socastee Formation, and Holocene deposits (Owens 1989). The Pleistocene-age Wando Formation, younger than the Socastee Formation but older than the Holocene deposits, may also be present (Thornberry-Ehrlich 2006). River drainage may also have introduced material from nearby exposures of the Penholoway Formation (Pleistocene, older than the Socastee Formation) and Bladen Formation (Upper Cretaceous). All of these units are fossiliferous to some extent, but the only unit that may have contributed fossil resources to MOCR is the nearby Peedee Formation: fossiliferous Peedee Formation rocks have reportedly been used as building material or riprap at MOCR (see “Fossils found in cultural resource contexts” section below).

Sources of Paleontological Resources

The fossils of MOCR present opportunities for education, interpretation, and continued or future scientific research in the park. Because the fossils within the park are found in a cultural resource context, they are described below in the “Fossils found in cultural resource contexts” section.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following formations or resource settings within MOCR, some of which are only found outside of the park but are near enough to contribute eroded material to the drainage running through the park. 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.

Bladen Formation (Upper Cretaceous)

The Bladen Formation is one of three formations designated from the old Black Creek Formation, which has been raised to group status (Owens 1989; Sohl and Owens 1991). It underlies the Donoho Formation and overlies the Tar Heel Formation (Sohl and Owens 1991). The Bladen Formation is mostly composed of sand and clay (Thornberry-Ehrlich 2006). The drainage that runs through MOCR has cut through the Penholoway Formation north of the park, exposing rocks of the Bladen Formation about 4.0 km (2.5 miles) away (Owens 1989), making it possible for eroded Bladen Formation material to have been transported into MOCR. The Tar Heel Formation was deposited sometime between 78.5 and 77.1 Ma (Self-Trail et al. 2004), so the Bladen Formation is somewhat younger.

The division of the Black Creek Formation was published relatively recently, so references older than 1990 likely include everything as the Black Creek Formation. The Black Creek Group is older than the

Peedee Formation, and there is a time gap between the two in at least some locations (Sohl and Christopher 1983; Carter et al. 1988), perhaps on the order of 5 million years (Self-Trail 2000). Fossils from the older Black Creek Group rocks were sometimes eroded out and redeposited during deposition of the Peedee Formation (Self-Trail et al. 2002). As a whole, the Black Creek Group represents shallower deposition than the Peedee Formation (Sohl and Christopher 1983), including settings like deltas (Straight et al. 1997; Ross and Cuffey 2003), tidal flats and channels, estuaries, and shallow marine bays (Carter et al. 1988).

Fossils of the Black Creek Group include pollen (Robb 1989b), diverse fossil plants, wood, amber, trace fossils, marine invertebrates, sharks, bony fishes, turtles, marine reptiles, crocodilians, several types of dinosaurs (Carter et al. 1988; Robb 1989b; note that *Hypsibema*, cited by Carter et al. as a “brontosaurus”-like herbivore, is now known to be an exceptionally large duckbilled dinosaur [Weishampel and Horner 1990]), and birds (Straight et al. 1997). The best-known locality for collecting vertebrate remains from the Black Creek Group is at Phoebus Landing near Elizabethtown, Bladen County, about 48 km (30 miles) northwest of MOCR (Carter et al. 1988); these rocks are from the slightly older Tar Heel Formation (Self-Trail et al. 2004). Fossils of the Bladen Formation include wood and logs, trace fossils (Thornberry-Ehrlich 2006), foraminifera (Mason et al. 2006), and bivalves (Thornberry-Ehrlich 2006).

Peedee Formation (Upper Cretaceous)

The Peedee Formation is a heterogeneous, extremely fossiliferous unit composed mostly of sand, clayey sand, and clay, with some clayey or sandy limestone. It was mostly deposited in open marine settings (Carter et al. 1988) with some shallower shelf deposits (Cunliff and Textoris 1969; Hattner and Wise 1979). The Peedee Formation was deposited during the late Maastrichtian faunal stage, between 68.5 and 65.5 Ma (Self-Trail et al. 2002). The upper portion of the Peedee Formation, composed of quartz sand and sandy limestone, is known as either the Rocky Point Member (Wheeler and Curran 1974) or the Scotts Hill Member (a replacement name proposed because the name Rocky Point is in use elsewhere [Ward and Blackwelder 1979]). A further division has designated the Island Creek Member above the Scotts Hill/Rocky Point Member, deposited under normal marine settings below storm wave base (Dockal et al. 1998).

Fossils from the Peedee Formation include plants, trace fossils (Carter et al. 1988), nannofossils (Hattner and Wise 1979), foraminifera (Thornberry-Ehrlich 2006), cephalopods, gastropods, bivalves, scaphopods (Carter et al. 1988), ostracodes (Van Nieuwenhuise and Kanes 1976), echinoderms (Carter et al. 1988), sharks, rays, other bony fishes (Robb 1989a), and indeterminate vertebrate teeth and bones. The Scotts Hill Member, thought to be from a shallower marine setting that winnowed out fine material and left shell beds (Carter et al. 1988), has fossils of crustacean burrows (Carter et al. 1988), foraminifera, cephalopods (Blake and Sturgeon 1995), gastropods, bivalves, echinoids (Carter et al. 1988), starfish, and mosasaurs (Blake and Sturgeon 1995). It may include a cape-shoal complex (Blake and Sturgeon 1995). The Island Creek Member has algae, nannofossils, foraminifera, bryozoans, brachiopods, bivalves, ostracodes, and echinoids (Dockal et al. 1998). Peedee Formation fossils are particularly notable in that the hard part of a Peedee Formation belemnite (an extinct type of cephalopod) from South Carolina was used to establish the PDB (Peedee Belemnite) standard for stable oxygen isotopes (Boggs 2001).

Although the Peedee Formation is not present in MOCR, and exposures large enough to have been mapped by Owens (1989) are not present in the drainage leading to MOCR, it nevertheless is reported to have contributed fossil resources to MOCR as described in the “Fossils found in cultural resources” section.

Penholoway Formation (Pleistocene)

The Penholoway Formation is a sandy-clayey unit that represents a barrier/back-barrier setting (Thornberry-Ehrlich 2006). It is dated to more than approximately 750,000 years ago (Soller 1988). Exposures of the Penholoway Formation have been cut by drainage north of MOCR that eventually runs through the park. These exposures are only 2.7 km (1.7 miles) away (Owens 1989), so it is reasonable to

expect that Penholoway Formation sediments have been transported into the park. Penholoway Formation fossils include wood, shells, shark teeth, and other vertebrate remains (Thornberry-Ehrlich 2006).

The Penholoway Formation may just be an upper unit of the Waccamaw Formation (Thornberry-Ehrlich 2006). The Waccamaw Formation, a sandy shelly unit found south of the Cape Fear River (Carter et al. 1988), was deposited about 1.75 million years ago during a marine transgression (Thornberry-Ehrlich 2006). It had a diverse fauna, including nannofossils, foraminifera (Bybell and Poore 1981), corals, bryozoans, mollusks, barnacles (Carter et al. 1988), ostracodes (Howard 1974), echinoids, and sharks (Carter et al. 1988).

Socastee Formation (Pleistocene)

The Socastee Formation is a heterogeneous sand-dominated unit, with both marine and nonmarine deposition. Coarser material tends to be found at the base, with finer material like clay toward the top. The base has gravel, coarse sand, and reworked shells (Thornberry-Ehrlich 2006). Fossils found in the Socastee Formation include pollen, organic matter like peat (DuBar et al. 1974), wood, tree trunks, trace fossils, gastropods, bivalves (Thornberry-Ehrlich 2006), and ostracodes (Cronin 1979). Mastodon bones are known from the roughly equivalent Pamlico Formation, at a locality about 53 km (33 miles) southeast of MOCR near Carolina Beach in New Hanover County (Richards 1936). The overlying Wando Formation is sometimes associated with upper Socastee Formation deposits (Thornberry-Ehrlich 2006). Socastee Formation material is present in the east part of MOCR (Owens 1989). As an example of the complicated stratigraphy of the southeastern Coastal Plain, the Socastee Formation is thought to correlate to the Flanner Beach Formation (Belknap and Wehmiller 1982; McCartan et al. 1982; also known as the Neuse Formation) and by extension the upper Canepatch Formation and (in part) the Croatan and Pamlico formations (Carter et al. 1988). Any of these names may be found in publications, depending on the stratigrapher, location being described, and year of publication. The Socastee Formation was deposited about 200,000 years ago (Soller 1988).

Wando Formation (Upper Pleistocene)

The Wando Formation (some references may identify as the Socastee Formation at least in part) is the youngest river terrace recognized in the MOCR area. River terraces form because of changes in river base level, and thus roughly correspond to marine terraces, as both types of terraces track changes in erosion. The Wando Formation is largely made up of sand and clay, deposited between about 130,000 and 70,000 years ago (Weems and Lemon 1993). It was deposited in environments from both the terrestrial and marine sides of coasts, from rivers and estuaries to shallow shelves (Campbell et al. 1996). Its surface does not exceed 5 m (16 ft) above sea level (Soller 1988; Thornberry 2006). Deposits of the Wando Formation are often found in the same valleys as Holocene rocks and sediments, underlying the younger deposits (Owens 1989). Per Thornberry-Ehrlich (2006), there may be a contact between the Wando and Socastee Formations in MOCR boundaries. Wando Formation fossils include wood, foraminifera, bivalves, and other shells (Thornberry-Ehrlich 2006).

Holocene deposits

Much of MOCR is underlain by Holocene deposits. Such deposits are composed of river-transported alluvium, made up of clay and sand with some gravelly layers and organic-rich deposits like buried bogs. The most likely fossils in the Holocene deposits are woody debris and logs. Wetlands and former wetlands are present throughout MOCR (Thornberry-Ehrlich 2006), but remains found in them may be recent or younger because of the relative youth of the depositional environments.

Park Collections

There are no known MOCR specimens in the collections database of the Southeast Archeological Center.

Fossils Found in Cultural Resource Contexts

Christy Visaggi (former Geologist in the Park, now doctoral student at the University of North Carolina-Wilmington, pers. comm. to J. Kenworthy, February 2009) has reported fossiliferous Peedee Formation rocks used inconspicuously as building material or riprap at MOCR. According to Visaggi, blocks of fossiliferous rocks are found beneath footbridges in the park (perhaps used as riprap), and in some instances, the blocks line trails leading to and from the bridges. The fossiliferous blocks are most likely from the Late Cretaceous-aged Peedee Formation (Rocky Point Member) as they display characteristic oyster fossils in addition to molds (impressions) of other marine invertebrates. Visaggi indicated that the stone is commonly quarried locally near Castle Hayne and Rocky Point. Timothy Boyd (MOCR resource program manager, pers. comm., October 2008) could not confirm the presence of this material.

There is also the possibility of finding fossils associated with cultural resources, such as fossils altered or modified by humans. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division coordinated geologic scoping for MOCR during April 2000, and produced a geologic resources evaluation report July 2006 (Thornberry-Ehrlich 2006). The participants developed a series of recommendations for future work.
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Southeast Archeology Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at MOCR.

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Data Sets

Moore's Creek National Battlefield Paleontological Archives

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

Moore's Creek National Battlefield Museum Collections

1926–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by MOCR staff; status: Active.

Ocmulgee National Monument

Ocmulgee National Monument (OCMU) preserves remains of 12,000 years of human habitation. The most visible such remnants are temple mounds from a Mississippian Indian ceremonial complex built between about 1,100 and 900 years ago. OCMU was authorized June 14, 1934. Its boundaries were changed June 13, 1941 and July 8, 1991. OCMU encompasses 283.90 ha (701.54 acres), all of which are under Federal administration.

Geologic Background

OCMU is located in eastern Bibb County, central Georgia. Most of the monument is adjacent to and east of the city of Macon. The Lamar Mounds and Village Unit (also the Lamar Mounds Unit or just Lamar Unit) is a small detached unit, located about 2.2 km (1.4 miles) southeast of the main unit of OCMU. The Ocmulgee River forms the southwestern border of the main unit, and Walnut Creek forms the southeastern border. As OCMU adjoins a major metropolitan center, several highways and railroads run through the monument. The Norfolk Southern Railroad bisects OCMU into northern and southern portions, Interstate 16 runs through OCMU parallel to the Ocmulgee River, and combined U.S. Routes 23 and 80 run through the north and northeastern area. The Macon area sits on the Fall Line, which separates Georgia's Coastal Plain on the southeast from the Piedmont to the northwest. Geologic maps (Lawton et al. 1976) show a distinct change from variably deformed Paleozoic (see Figure 2 for a geologic time scale) igneous and metamorphic rocks in the Piedmont to Cretaceous and Lower Cenozoic sedimentary rocks in the upper Coastal Plain. Geologic features of OCMU are described in Schmitt (1943) and Cosner (1973).

The area underlying OCMU and Macon was added to North America during the events that led to the formation of the supercontinent Pangaea, during the Paleozoic. The Ocmulgee and Dean Creek faults, as near as 24 km (15 miles) northwest of Macon, form part of the western boundary of the Avalon or Carolina Terrane (Hooper and Hatcher 1986; Hooper and Hatcher 1990; Hanley et al. 1997), a small landmass that collided with North America about 360 Ma (million years ago) (Hatcher 2001). By that point, the evolving southern Appalachian Mountains had been undergoing episodes of metamorphism, igneous activity, folding, and faulting for 200 million years.

Mountain building and rock deformation persisted throughout the collision of North America and Africa in the Pennsylvanian. Besides the Avalon Terrane, several other small landmasses and slivers of Africa were added to southeastern North America (Hatcher 2001). North America and Africa then rifted apart during the Late Triassic and Jurassic, and are still moving apart today. Rifting occurred during the Early and Middle Jurassic, creating basins by faulting (Gottfried et al. 1977; Gohn et al. 1983), and promoting basalt flows (Gottfried et al. 1983). During the time following the rifting, there has been deposition of sedimentary rocks in environments varying from open marine to coastal plain settings in Georgia seaward of the Fall Line, depending on sea level. The geology of the Georgia Coastal Plain features a seaward-thickening wedge of Early Cretaceous and younger sedimentary rocks and deposits over a basement of older Triassic to Precambrian rocks (Herrick and Vorhis 1963). Rock units of the Atlantic Coastal Plain become younger toward the coast, and distinct marine terraces left behind by ancient shorelines are present in the youngest units (Colquhoun and Johnson 1968; Colquhoun 1969; Richards et al. 1971). Such terraces are not seen in the Macon area, which is mostly underlain by Cretaceous and Eocene rocks and deposits seaward of the Fall Line (Lawton et al. 1976).

In general, the east coast of the United States, including the Macon region, has had relatively little tectonic activity since the events surrounding the formation and subsequent rifting of the supercontinent Pangaea. Tectonic activity in the Cenozoic of Georgia's Coastal Plain has included faulting southwest of Macon, with vertical movement on the order of 30 to 60 m (100 to 200 ft) (Cocker 2007), and Oligocene faulting in the southeast part of the state (Cramer and Arden 1978).

OCMU and its surroundings come from the southern tip of a “red hill” made up of soils from the Upper Eocene Barnwell Formation over sands and clays of the Upper Cretaceous Tuscaloosa Formation (Fairbanks 1956). The surface geology of OCMU is made up of Quaternary alluvium (Cosner 1973; Lawton et al. 1976). Units present beneath the Quaternary deposits of the main OCMU unit include Upper Cretaceous rocks of the Tuscaloosa Formation (Fairbanks 1956; Cosner 1973) and red soils from the Upper Eocene Barnwell Formation (Fairbanks 1956), and an unnamed relict Eocene clay is present in the subsurface of the Lamar Unit (Jennings 1939; Schmitt 1943), probably also pertaining to the Barnwell Formation. Drainage from the Ocmulgee River/Walnut Creek system through OCMU could also introduce eroded material from mica-rich and granitic gneisses and undifferentiated Cretaceous and Lower Cenozoic sedimentary rocks. Nearby formations that could be present in the undifferentiated deposits include, from oldest to youngest, the Tuscaloosa Formation, Eutaw Formation, Blufftown Formation, Cusseta Sand, and Ripley Formation of the Upper Cretaceous, and the Twiggs Clay and Irwinton Sand of the Upper Eocene Barnwell Formation (Lawton et al. 1976). All of the units present at the surface or in the shallow subsurface of OCMU (Tuscaloosa Formation, Barnwell Formation, and Quaternary alluvium) are potentially fossiliferous, as well as the formations that may be present in the undifferentiated Cretaceous-Lower Cenozoic rocks eroded by OCMU’s drainage system. To date, several paleontological specimens from OCMU are in the collections of the Southeast Archeological Center.

Sources of Paleontological Resources

The fossils of OCMU present opportunities for education, interpretation, and continued or future scientific research in the park. Because the fossils within OCMU are found in a cultural resource context, they are described below in the “Fossils found in cultural resource contexts” section. Aside from the material described in this section, fossils from OCMU are stored at the Southeast Archeological Center (SEAC). These fossils are documented below, as part of the “Park Collections” section following “Potential Sources of Paleontological Resources.”

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following formations or resource settings within OCMU, most of which are found 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.

Tuscaloosa Formation (Upper Cretaceous)

The Tuscaloosa Formation dates to the early Late Cretaceous (roughly 100 to 94 Ma) (Reinhardt 1980). It is a coarse or gravelly sandy unit with clay and silt (Eargle 1955), fining upward from conglomeratic sand to silty clay. This unit is usually interpreted as composed of river deposits. An extensive coastal plain was present at the time of deposition (Reinhardt 1981). In Georgia, outcrops are nonmarine, but marine fossils found in wells indicate that marine deposition also took place (Richards 1956), for example in western Alabama (Reinhardt 1981). The Tuscaloosa Formation has been a source of some confusion. Researchers studying microfossils recognized in the 1970s that beds of Paleocene and Eocene age had been assigned to the Tuscaloosa Formation in the kaolin district east of OCMU, and that Upper Cretaceous fossils had been reworked into the younger units (Cousminer and Terris 1972, 1974; Cousminer 1973; Tschudy and Patterson 1975). The best-known fossils from the Tuscaloosa Formation are burrows, leaves, and wood (Reinhardt 1981); its fossil plants have been studied since the 19th century (Smith 1892), and at least 19 plant species are known (Richards 1956). Some plant fossils preserve evidence of arthropods feeding and forming galls (Daubner and Martin 1995). Plant pollen is also known (Tschudy 1966). Subsurface marine deposits have produced foraminifera and mollusks (Richards 1956). In the Macon area, it extends for an unknown depth to crystalline basement rocks (Cosner 1973).

Undifferentiated formations (Upper Cretaceous)

Four Upper Cretaceous formations that may be present in nearby undifferentiated Cretaceous-lower Cenozoic deposits are described here briefly. They are of interest because they are fossiliferous and the Ocmulgee River and Walnut Creek pass through them before reaching OCMU, potentially moving eroded material including fossils from them through the monument. Flooding is possible at both OCMU units, and is recorded in the Quaternary sediments (Schmitt 1943; Cosner 1973). The units described here, from oldest to youngest, are the Eutaw Formation, Blufftown Formation, Cusseta Sand, and Ripley Formation. These formations were all deposited more recently than the Tuscaloosa Formation. One reason why the formations are lumped together in the Macon area is the difficulty in distinguishing them (e.g. LeGrand 1962). To date, fossil finds in these Upper Cretaceous formations are better known in the vicinity of the Alabama-Georgia border portion of the Chattahoochee River Valley than in the Macon area. The potential Eocene rock units known by name are described under the Barnwell Formation, which is present at OCMU.

The Eutaw Formation is a fossiliferous sand unit (Eargle 1955) from a marine (Richards 1956) to estuarine setting (Savrda and Nanson 2003). It is dated to the middle Late Cretaceous (between about 86 and 83 Ma) (Case and Schwimmer 1988). It includes the Tombigbee Sand Member, a structureless glauconitic sand (greensand), as its upper division (Schwimmer et al. 1985). The Tombigbee Sand Member is interpreted as an inner to middle shelf setting (Kiernan 2002). Trace fossils (including crustacean burrows), leaves, logs (Eargle 1955), nannofossils (Liu 2004), foraminifera (Herrick and Vorhis 1963), sponges, cephalopods, gastropods, bivalves, polychaete worm tubes (Markewich and Christopher 1982), sharks, bony fish, pterosaurs (Schwimmer et al. 1985), and duckbilled dinosaurs (Weishampel et al. 2004) are known from the Eutaw Formation. Trace fossils in estuarine storm beds were thought to represent opportunist colonizers, but may instead have been made by storm-transported animals (Savrda and Nanson 2003). Nannofossils (Liu 2004), cephalopods, bivalves, sharks, bony fish, and pterosaurs have been found in the lower part of the Eutaw Formation, in open marine deposits (Schwimmer et al. 1985). 27 species of plants are known from the Tombigbee Sand Member (Berry 1914), along with nannofossils, foraminifera, cephalopods, bivalves (Kiernan 2002), sharks (Schwimmer et al. 2002), bony fish (Hooks et al. 1999), and mosasaurs (Kiernan 2002). The Eutaw Formation may not be exposed in the Macon area (LeGrand 1962).

The Blufftown Formation grades from sand at its base to a clayey fossiliferous sand and silty shale above (Eargle 1955). It dates to the late Late Cretaceous (roughly 83 to 77 Ma) (Case and Schwimmer 1988). Both nonmarine and marine settings are represented (Schwimmer 1986). In Georgia, deposits are reworked and represent detrital estuarine settings, unlike the more marine deposits of the formation in Alabama (Schwimmer et al. 1988). The lower Blufftown Formation is a sandy marginal marine unit. The middle of the formation is a fossiliferous clay deposited in the middle neritic zone of an encroaching sea. The top of the formation is silty and represents deposition under a retreating sea (Rosen 1985). The fossil fauna of the Blufftown Formation includes organic fragments, crustacean burrows, logs and other plant fossils (Eargle 1955), nannofossils (Schwimmer et al. 1993), foraminifera (Rosen 1985), bryozoans (Schwimmer 1986), cephalopods, gastropods, bivalves (including oyster reefs) (Schwimmer 1981), scaphopods, ostracodes (Rosen 1985), crabs, sharks, bony fish, turtles, mosasaurs, crocodilians (Schwimmer 1986), carnivorous dinosaurs (including tyrannosaurids and ostrich dinosaurs), and duckbilled dinosaurs (Schwimmer et al. 1993). In general, the vertebrate finds closest to Macon are about 135 km (85 miles) to the southwest, near the Georgia-Alabama border south of Columbus, Georgia (Schwimmer et al. 1993). Foraminifera are only present in the middle and upper parts of the formation, and are most diverse in the middle, which also has bivalves, scaphopods, and ostracodes (Rosen 1985). Fish are diverse toward the top and bridge Atlantic Coastal Plain and Gulf of Mexico Coastal Plain faunas. At least fifteen taxa of cartilaginous fish and eight taxa of bony fish are known (Case and Schwimmer 1988). The Blufftown Formation may not be exposed in the Macon area (LeGrand 1962).

The Cusseta Sand is a coarse sand unit with some clay (Eargle 1955). Its depositional setting is interpreted as ranging from an inner shelf to barrier islands, back-barriers, and tidal inlets (Skotnicki and King 1989).

It is dated to the late Late Cretaceous (about 77 to 71 Ma) (Case and Schwimmer 1988), and was regarded as a member of the Ripley Formation (Berry 1914) until 1938 (Cooke and Munyon 1938). At least six species of plants are known from the Cusseta Sand (Berry 1914), along with crustacean burrows, lignite (Eargle 1955), foraminifera (Herrick and Vorhis 1963), cephalopods, bivalves (Eargle 1955), cartilaginous fish, bony fish, and mosasaurs (Skotnicki and King 1989). This unit may not be exposed in Bibb County (LeGrand 1962).

The Ripley Formation is made up of calcareous (calcium carbonate-rich) sand and clay (Eargle 1955). It is dated to the late Late Cretaceous (about 71 to 69 Ma) (Case and Schwimmer 1988). The depositional environment is interpreted as nearshore subtidal shallow marine (Ray 2008). It has produced fossils of crustacean burrows (Eargle 1955) and other traces, plants (Ray 2008), nannofossils (Kiernan 2002), foraminifera, mollusks (Eargle 1955), crabs, echinoids (Ray 2008), fish (Hall and Savrda 2005), and possible duckbilled dinosaurs (Weishampel et al. 2004), with most specimens being bivalve mollusks (Ray 2008). Like the others units, its contribution to the undifferentiated Cretaceous deposits is uncertain; it was described by LeGrand (1962) as not definitely known east of the divide between the Flint and Ocmulgee Rivers, which is west of OCMU, in Crawford County.

Barnwell Formation (Upper Eocene)

Fairbanks (1956) has identified the Eocene clay of the OCMU units as pertaining to the Barnwell Formation. This clay is a sandy red clay that is also known as Greenville Sandy Loam (Schmitt 1943). Other deposits of the Barnwell Formation in the area include green or gray clay and limestone (LeGrand 1962). The Barnwell Formation is an Upper Eocene rock unit (roughly 40 to 34 Ma), and represents a period of sea withdrawal, with deposits going from littoral to continental (Carver 1966). It includes two members in the Macon area: the Twiggs Clay Member, which is most prominent (LeGrand 1962), and the overlying Irwinton Sand Member (Lawton et al. 1976). The members may be elevated to formations, or the Barnwell Formation elevated to a group, depending on the stratigrapher. For example, Huddlestun and Hetrick (1982) regarded the Barnwell Formation as the Barnwell Group, with the Twiggs Clay as the lower member of the Dry Branch Formation and the Irwinton Sand as the upper member. Based on the description of the clay, and the prevalence of the Twiggs Clay Member in the area (LeGrand 1962), the OCMU deposit likely pertains to the Twiggs Clay Member. Deposits of the Twiggs Clay Member in the Macon area are usually less than 18 m (60 ft) thick (LeGrand 1962).

The Twiggs Clay Member is known to be fossiliferous. It has produced dinoflagellates, angiosperm pollen (but no gymnosperms), foraminifera (Darrell 1974), shells (Carver 1980), 23 species of sharks (Case 1981), frogs, snakes (Holman 1977), early whales (Kesler 1956), and terrestrial mammals (Domning et al. 1982). Opalized shell hash is known in the Twiggs Clay Member of Jones County, adjoining Bibb County to the northeast (Carver 1980). One frog taxon, two sea snakes, two terrestrial snakes (Holman 1977), and terrestrial mammals including an entelodont (“terminator pig”) have been recovered from a Twiggs Clay Member locality in Twiggs County, Georgia (Domning et al. 1982), about 14 km (9 miles) southeast of Macon. The land mammals suggest an age of about 40 to 37 Ma (Holman 1977). A vertebra of the early whale *Basilosaurus* was recovered from the Twiggs Clay Member in the vicinity of Macon at Crawford Creek, 32 km (20 miles) southwest of the city (Kesler 1956). The Irwinton Sand Member is less known for fossils, but has shark and ray teeth and sawfish spines (Case and Borodin 2000). Additionally, echinoids are known from unspecified Barnwell Formation deposits (Herrick and Vorhis 1963).

Quaternary rocks and sediments (Pleistocene-Holocene)

The upper 12 m (40 ft) or so of deposits along the Ocmulgee River and larger tributaries are composed of unsorted clay, sand, and gravel from the Pleistocene and Holocene (LeGrand 1962). Along the Ocmulgee River, terrestrial deposits are related to flooding. Sedimentation can be quite rapid on the floodplain; more than 3 m (10 ft) of sedimentation occurred along the Ocmulgee River at the main unit of OCMU between the 18th century and the middle of the 20th century. Cosner (1973) defined eight informal members in Ocmulgee River floodplain deposits at the main OCMU unit, including artificial fill. The other seven include sandy, silty, and clay-rich layers, deposited in a variety of settings such as levee, point

bar, and overbank locations. These layers are all thought to be Late Pleistocene or younger. Older deposits, but still probably Pleistocene, are preserved above the floodplain at OCMU (Cosner 1973).

Because of the floodplain and wetland geography of OCMU, it is possible that Quaternary climate indicators like pollen are present in old marshy areas (see the Congaree National Park chapter of this report for a discussion of such resources at CONG). Back swamp deposits at OCMU are known to include grass, leaves and twigs (Cosner 1973). Plant macrofossils are known from an Ocmulgee River wetland deposits about 135 km (85 miles) south of Macon, near Coffee Bluff in Telfair County, Georgia. These plants date from $38,690 \pm 420$ radiocarbon years before present (ybp) (radiocarbon years must be calibrated to yield calendar dates) and are comparable to the modern flora (Thieme et al. 2007).

Park Collections

SEAC has several fossils or potential fossils from OCMU. Five are listed as fossils, one is a lot of six cores, and one is a flake from a fossiliferous flint conglomerate. Catalog number OCMU 16867 is identified as an arciid (a type of bivalve) from the Lamar Unit. OCMU 56658 is an unidentified fossil from the Ocmulgee Mound Complex. OCMU 58331 is a piece of petrified wood from Mound D. OCMU 61709 and 63950 are also from Mound D, but are otherwise unidentified. OCMU 66133 is a lot of 6 cores from Mound D. Finally, OCMU 69084 is the fossiliferous flint conglomerate flake mentioned above. All of the above have only SEAC listed as their present location, except for OCMU 16867, which is further identified to storage box 0192 L1Q1 (B. Carter, SEAC supervisory museum specialist, pers. comm., August 2008). Further identification of several of these specimens and their provenance is needed.

Fossils Found in Cultural Resource Contexts

OCMU is very rich in archeological resources, including associated potential paleontological resources. There were three major periods of occupation in the Macon Plateau area: a late Archaic to Woodland Period occupation, 2,500 to 1,100 years ago; a period about 1,100 to 900 years ago when the OCMU mounds were built; and about 650 to 315 years ago (Fairbanks 1956). A charred roof timber from the Mound D earthlodge has been dated by radiocarbon to the year 1015 (Wilson 1964). Shell beads, shell ornaments, bone pins, shell-temper sherds, a conch cup, and wood used for building are all known from OCMU. One particularly notable piece is a puma jaw with copper plating. Food refuse is rare at the main OCMU unit, but evidence suggests that deer were eaten (Fairbanks 1956). Bone refuse, again dominated by deer, is present in a dump at the Lamar Unit (Williams 1999). Additionally, charcoal from human-induced burns for clearing land may be present in the soil (Cosner 1973). The Lamar Unit artifacts, are at the Southeast Archeological Center (SEAC) (Williams 1999), although at least some of the main unit artifacts remain at OCMU, such as the puma jaw (on display at the visitor center). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division has not yet conducted a geologic resource scoping session for OCMU.
- Further identification of several of the OCMU fossil specimens housed at SEAC is required.
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g.

subject to NAGPRA) and should be regarded as such until otherwise established. The Southeast Archeology Center and the Geologic Resources Division can coordinate additional documentation/research of such material.

- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at OCMU.

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Data Sets

Ocmulgee National Monument Paleontological Archives

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

Ocmulgee National Monument Museum Collections

1934–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by OCMU staff; status: Active.

Southeast Archeological Center (SEAC)

1934–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by SEAC staff; status: Active.

Timucuan Ecological and Historic Preserve and Fort Caroline National Memorial

Timucuan Ecological and Historic Preserve (TIMU) and Fort Caroline National Memorial (FOCA) are closely intertwined. FOCA is surrounded on three sides by TIMU, the two units are administered together, and they have the same geological history. For these reasons, the two are covered together.

Timucuan Ecological and Historic Preserve (TIMU) protects natural resources and remains of thousands of years of human habitation. People from groups ranging from the Timucua, to Spanish, French, and English colonists, to 19th century Americans left traces of their presence. TIMU was authorized February 16, 1988, and had a boundary change October 5, 2004. It encompasses 18,731.91 ha (46,286.91 acres), of which 3,618.36 ha (8,941.15 acres) are under Federal administration. TIMU as a whole is operated under a partnership including the National Park Service, the Florida State Park System, the City of Jacksonville, and over 300 private and corporate landowners. Several state parks and other administrative areas are found within its boundaries, including Big Talbot Island State Park, Fort George Island Cultural State Park, Kingsley Plantation (once a state park under the Florida Park Service, but transferred to the National Park Service in 1989), and Huguenot Memorial Park.

Fort Caroline National Memorial (FOCA) memorializes the site of a short-lived (1564-65) French Huguenot settlement that marked the beginning of two centuries of French and Spanish colonial rivalry in North America. FOCA was authorized September 21, 1950, and had boundary changes April 11, 1972, November 10, 1978, and November 19, 1979. It encompasses 56.00 ha (138.39 acres), all but 2.12 ha (5.24 acres) of which are under Federal administration.

Geologic Background

TIMU and FOCA are located in northeastern Duval County, northeastern Florida, with the northern border of TIMU only about 19 km (12 miles) south of Georgia. The center of Jacksonville is about 12.3 km (9.5 miles) southwest of TIMU. TIMU's northern boundary is delineated by the Nassau River and Thomas Creek. The Atlantic Ocean is to the east, with Little Talbot Island interposed between TIMU and the ocean on most of TIMU's eastern border. Amelia Island is north of the Nassau River. The St. Johns River runs through TIMU on its way to the Atlantic Ocean, with a small portion of the park including the Theodore Roosevelt Area on the south side of the river. FOCA is found adjacent to the part of TIMU that is south of the river, surrounded by TIMU on all sides but the west.

In general, the east coast of the United States, including the Jacksonville region, has had relatively little tectonic activity since the events surrounding the formation and subsequent rifting of the supercontinent Pangaea. In the area of the Southeast Coast Network, this activity involved the African and North American continents. The collision of these two continents was the culmination of a long series of events, with multiple deformations recorded in the Appalachian Mountains. North America and Africa rifted apart during the Late Triassic and Jurassic, and are still moving apart today (see Figure 2 for a geologic time scale).

The land beneath the Jacksonville area has only been part of North America since Pangaea rifted apart. What is now the east coast of North America was assembled from small landmasses that collided with the continent during the assembly of Pangaea during the Paleozoic (Hatcher 2001). The final portion that was added was the landmass that now underlies Florida and parts of southern Alabama and Georgia. This landmass, called the Suwannee Terrane, had been part of the much larger landmass known as Gondwana, which included most of today's southern continents and India. The Suwannee Terrane had been attached to Gondwana near the northern junction of South America and Africa, but was incorporated into North America during the breakup of Pangaea (Scotese et al. 1979; Horton et al. 1989). Sedimentary rocks of the Suwannee Terrane, deposited in the hundred million years before the North American-African collision,

resemble those of similar age in Guinea and Senegal of western Africa (Horton et al. 1989). Rifting occurred during the Early and Middle Jurassic, creating basins by faulting (Gottfried et al. 1977; Gohn et al. 1983), and promoting basalt flows (Gottfried et al. 1983). During the time following the rifting, there has been deposition of sedimentary rocks in environments varying from open marine to coastal plain settings in northeastern Florida, depending on sea level. Rocks older than the Cenozoic are deeply buried in Duval County; at 610 m (2,000 ft) below sea level, the rocks are only as old as the Paleocene (Phelps 1994). Just across the state border in Camden County, Georgia, there are about 1,675 m (5,500 ft) of Cretaceous to Holocene rocks and deposits over Proterozoic quartz-rich volcanic rocks or Paleozoic metamorphic rocks (Leeth 1999).

The sediments of the Jacksonville area were laid down in the Southeast Georgia Embayment (or Okefenokee Embayment), east of the Peninsular Arch (Puri and Vernon 1964); the area is known as the Jacksonville Basin (Lane 1994). Sporadic movements of the embayment affected the quantity of deposition during various periods, for example leading to very thick Miocene deposits (Huddleston 1988). The modern, relatively narrow shelf offshore from Georgia and northern Florida was formed during the Eocene. There had been a broader shelf before, including what is now the Blake Plateau, but the plateau submerged after the Middle Cretaceous (Dillon et al. 1978). Florida was generally under water in the Paleogene, with a shallow-water setting like the present-day Bahama Banks. These conditions led to thick fossiliferous limestone deposits. Rock fragments are uncommon in these deposits because the sources (the Appalachian Mountains) were distant and a powerful current running in the Gulf Trough, in the vicinity of the Florida-Georgia border, swept away what was delivered to the area. Near the end of the Paleogene, the Appalachian Mountains were uplifted and shed enough material to fill in the trough. Combined with falling sea levels beginning in the Late Oligocene, more and more of the state was above sea level for longer and longer periods. Terrestrial exposure and deposition moved from north to south (Lane 1994).

An important feature of Atlantic Coastal Plain geology is the well-developed set of marine terraces, which document ancient shorelines. Over time, terraces formed progressively closer to the modern shore, in distance and elevation. There is a set of named terraces that are used in geologic descriptions. In Florida, from oldest to most recent, these include the Hazelhurst, Cohaire, Sunderland, Wicomico, Penholoway, Talbot, Pamlico, and Silver Bluff terraces (Healy 1975). These terraces were formed between the Pleistocene and the present in response to sea level fluctuations over a long period of marine regression (Colquhoun 1969; Richards et al. 1971). Deposits from the Penholoway, Talbot, Pamlico, and Silver Bluff terraces are found in the FOCA-TIMU area (Phelps 1994). Terraces typically have a marine layer at the base with a thicker sequence of coastal terrestrial sediments above, such as beach sands, barrier island sands, estuarine or back-barrier sands and clays, and floodplain deposits left behind by receding shorelines (Thornberry-Ehrlich 2006). The terrace deposits are probably similar to those of Georgia's Coastal Plain, which include two major lithologies: linear sand ridges from old barrier islands, and clayey sand plains that represent back-barrier tidal lagoons or marshes (Radtko 1985). The respective heights of marine terraces above sea level in Duval County are 0-3.0 m (0-10 ft; Silver Bluff), 3.0-7.5 m (10-25 ft; Pamlico), 7.5-13.0 m (25-42 ft, Talbot), and 13.0-21.0 m (42-70 ft; Penholoway) (Phelps 1994). The youngest of these terraces, the Silver Bluff terrace, is over 40,000 years old (Booth et al. 1999).

Chronologically interspersed with the terraces are marine lowstands, some with sea levels significantly lower than the present as water was taken up into ice sheets during major ice advances in the Pleistocene ("Ice Age"). During the last maximum ice advance, 25,000 years ago, sea level dropped to about 122 m (400 ft) below the modern level. It began to rise again about 11,000 years ago, and rose rapidly until about 5,000 years ago, after which it then slowly rose to its present level (Griffin 1982), with fluctuations. Local sea level reached a lowstand of 3.0 to 4.0 m (9.8 to 13.1 ft) below the present sea level between 3,100 and 2,400 years ago, and then rose rapidly, leading to extensive erosion (Howard and DePratter 1978).

The Cenozoic formations of Florida, particularly those from the Neogene and Quaternary, have complex histories, with different correlations, ages, and names proposed for the rock units. Geologic dating can be problematic for several reasons. For example, the dating of the Pliocene-Pleistocene boundary

worldwide is a current topic of dispute. A particular issue is the choice of dating method: aminostratigraphy (using amino acid changes in fossils) may produce significantly different results from radioisotope dating methods (compare Belknap and Wehmiller [1982]'s aminostratigraphic dates to radioisotopes dates from McCartan et al. [1982a, b] for several Pliocene-Pleistocene units of the Atlantic Coastal Plain). The stratigraphy is further complicated by the use of marine terraces in the Atlantic Coastal Plain. Some of the terrace terms have also been used for formations. While this practice is now discouraged (Huddleston 1988), it is something to watch for in older publications.

The surface geology of TIMU and FOCA is composed of beach ridge and dune deposits (Pleistocene-Holocene), undifferentiated deposits (Pleistocene-Holocene), and Holocene sediments. These are also the lithological units exposed in the areas drained by waterways running through TIMU and FOCA (Scott et al. 2001). Depositional settings include salt marsh, beach, marine, and lagoon (Scott et al. 1986). Underlying rocks in the shallow subsurface, down to about 30 m (100 ft), include Quaternary sands, clay-rich and limestone layers from the Upper Miocene or Pliocene, and mixed deposits from a Hawthorn Group unit (Fairchild 1972; Causey and Phelps 1978; Stern et al. 1978; Johnson 1986; Watts 1991; Phelps 1994), perhaps the Coosawhatchie Formation (Johnson 1986). All of these units are known to produce fossils (Fairchild 1972; Johnson 1986; Huddleston 1988; Phelps 1994). FOCA is not known to have produced any fossils, but TIMU has produced paleontological resources in association with cultural resources.

Sources of Paleontological Resources

Fossils are only known at TIMU to date. Because the fossils within FOFR are found in a cultural resource context, they are described below in the "Fossils found in cultural resource contexts" section. The fossils of TIMU present opportunities for education, interpretation, and continued or future scientific research in the park.

Potential Sources of Paleontological Resources

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

Mixed and undetermined formations (Miocene to Pliocene?)

The underlying geology of Duval and Nassau counties has been described in several publications (Fairchild 1972; Causey and Phelps 1978; Stern et al. 1978; Brown 1980; Spechler 1982; Johnson 1986; Watts 1991; Phelps 1994; Scott et al. 2001). Because it is the sediments nearest to the surface that are most likely to be sampled, the following discussion will be confined to the sediments from the surface to 30 m (100 ft) below sea level. The typical components of the upper subsurface are an upper sandy layer from the Quaternary, then a clay-rich layer, then a limestone layer thinning to the east, and then a unit usually identified as the Miocene-age Hawthorn Formation or as a Hawthorn Group subunit (Fairchild 1972; Causey and Phelps 1978; Stern et al. 1978; Johnson 1986; Watts 1991; Phelps 1994). The major differences lie in how the authors interpret these components. The report that goes into the most detail regarding the names of the units is Johnson (1986). This report lumps the upper sand and clay layers, identifies the limestone layer with the Charlton Member of the Coosawhatchie Formation (Hawthorn Group), and the lowest unit as undifferentiated Coosawhatchie Formation deposits. Identification of the Hawthorn Group unit as the Coosawhatchie Formation corresponds with the stratigraphic findings of Huddleston (1988) for the Cumberland Island National Seashore (CUIS) area about 19 km (12 miles) north of TIMU. However, more recent reports (Watts 1991; Phelps 1994; Scott et al. 2001) have not attempted to differentiate the deposits beyond the Hawthorn Group or Hawthorn Formation.

The most detailed report on the subsurface closest to TIMU and FOCA is Fairchild (1972). This report finds the uppermost layer to be approximately 3 to 5 m (10 to 16 ft) of Pleistocene-Holocene medium to fine sand with shells and minor clay. Below this are 15 to 20 m (50 to 67 ft) of Upper Miocene or Pliocene deposits. In Duval County, these deposits have an upper section composed of fine to coarse sand, sandy clay, clayey sand, and shell beds, and a lower part made up of sandy and occasionally cavernous limestone. The FOCA-TIMU area is dominated by the clay-sand-shell upper portion. Below the Upper Miocene or Pliocene deposits are Hawthorn Group (Formation of this reference) deposits of Middle Miocene-age clay, sandy clay, and sandy limestone, often phosphatic and known to produce shark teeth and molds and casts of mollusk shells. Neither the Upper Miocene-Pliocene unit nor the Hawthorn Group are known to be exposed at the surface in Duval County, although the younger unit may be present in local river valleys. The Hawthorn Group of Duval County is interpreted as a delta deposit (Fairchild 1972).

For reference, the Coosawhatchie Formation of the Hawthorn Group is mostly made up of sand with some clay and phosphate and occasional beds of dolomite or limestone (Scott 2001), and dates to the Middle Miocene (about 13.8 to 11.6 Ma). The Coosawhatchie Formation includes several members that differ in composition. The Meigs Member is the lowest member in the west and the Tybee Phosphorite Member is the lowest in the east. The Berryville Clay Member is next highest, followed by the Ebenezer Member and finally, in some locations, the Charlton Member. Johnson (1986) assigned the unnamed Upper Miocene or Pliocene limestone deposits to the Charlton Member, and based on the geology of CUIS, other potential members under TIMU and FOCA are the Tybee Phosphorite Member, Berryville Clay Member, and Ebenezer Member (Huddlestun 1988).

The Tybee Phosphorite Member is made up of quartz sand and phosphate, with some clay and dolomite. It is regarded as a marine unit that was deposited over a shallow continental shelf distant from shore. Fossils include burrows and other trace fossils, molds and impressions of mollusks, and abundant fine vertebrate debris, like fish scales and teeth, small bones, and vertebrae (Huddlestun 1988).

The Berryville Clay Member is the most clay-rich of the Coosawhatchie Formation members, and has a fossil fauna including nannofossils, silicoflagellates, diatoms, radiolarians, foraminifera, ostracodes, fish scales, and rare shelly material and barnacles. It is interpreted as a continental shelf deposit from the inner to probably middle neritic zone (Huddlestun 1988).

The Ebenezer Member is sandy and generally unfossiliferous, except for molds and casts of bivalves and other mollusks, and fine vertebrate debris like fish scales. It is regarded as a nearshore (but not coastal) marine deposit from the inner neritic part of a continental shelf, under relatively cool conditions (Huddlestun 1988).

The Charlton Member (formerly Charlton Formation) is made up of carbonate-rich silty to sandy clays (Scott 2001). It is locally fossiliferous (Scott 2001), and is known to produce foraminifera, gastropods and other mollusks, barnacles, and echinoids (Jones and Portell 1988). Shells are often preserved as internal or external molds (Auffenberg and Portell 1990). Wilson et al. (1991) identified a fossiliferous dolomite layer encountered between about 20 to 27 m (65 to 90 ft) beneath CUIS as a Charlton Formation deposit, with both actual shell fossils and molds and casts. This corresponds reasonably well to Johnson (1986)'s description of the potential Duval County Charlton Member as limestone and dolomite with mollusk molds.

Other fossils that are known from Miocene or Pliocene deposits in the area include sirenian rib fragments, which are common in shallow-water and estuarine deposits from the Miocene (particularly the Hawthorn Group) and Pliocene in Florida (Simpson 1932), and microfossils. Diatoms, silicoflagellates (both types of silica-secreting algae), and foraminifera of Middle Miocene age, and diatoms and silicoflagellates of Early Pliocene age, are known from cores and cuttings from CUIS (Hoenstine and Wise 1982). Hoenstine and Wise did not specify the lithologic units from which the specimens were recovered.

Quaternary rocks and sediments (Pleistocene-Holocene)

The surficial deposits of TIMU and FOCA have not been assigned to a formation, although the presence of Pamlico and Silver Bluff marine terraces indicates that the Satilla Formation nomenclature of Huddlestun (1988) would be applicable for at least some of the sediments. The Satilla Formation is composed of shoreline complex deposits from the Pamlico, Princess Anne, Silver Bluff, and Holocene marine terraces, and includes clay-rich back-barrier deposits, sandy barrier island deposits, and shelly sands and clays from offshore continental coast settings. The four marine terraces formed at different times during the deposition of the Satilla Formation. The Satilla Formation is regarded as Late Pleistocene to Holocene in age (roughly 126,000 thousand years ago to the present). Typical fossils include burrows, foraminifera, bivalves and other mollusks (Huddlestun 1988; Pirkle et al. 2007), and vertebrates including fish, turtles, crocodilians, ground sloths, castorid rodents, tapirids, equids, deer, bovids, and proboscideans (Markewich et al. 1992). The term “Satilla Formation” was only brought into use in 1988, so most references use marine terrace names for identification of deposits, or do not assign the deposits to a formation.

Shells have been mentioned in passing for Quaternary-age deposits in the vicinity of TIMU and FOCA (Fairchild 1972; Phelps 1994). Beaches near the parks are known to produce shells ranging in age from the Pleistocene to the modern (Martens 1931, 1935; Scott et al. 1986). Brown (1980) reported fossils including shells and microfossils in the deposits from 0 to 42 m (0 to 139 ft) down in a well at Fernandina Beach, about 10.9 km (6.8 miles) north of TIMU. Crustacean burrows are known in other Pleistocene and Holocene coastal sediments, particularly those from high-energy littoral and shallow neritic settings (Weimer and Hoyt 1964), so may be present at TIMU and FOCA as well. Vertebrate remains are also known from the deposits in the area. Fossils of the turtles *Gopherus* and *Hesperotestudo* have been found at Jacksonville Beach, about 10.5 km (6.5 miles) south of TIMU (Franz and Quitmyer 2005). Remains of Pleistocene animals including the sea turtle *Trachemys* (Hay 1916), deer, bison, mastodon, and mammoth are known from Station 120, a site on the Intracoastal Waterway 23 km (14 miles) south of TIMU (Simpson 1929). A fossiliferous Pleistocene conglomerate about 40 km (25 miles) southwest of TIMU, at Stokes Ferry on the St. Mary’s River, has produced a shark tooth, a turtle shell fragment, whale ear bones, and horse and mammoth teeth (Matson and Clapp 1909). Sirenian rib fragments, while not as common as in Miocene and Pliocene deposits, are present in marine and river deposits of the Pleistocene (Simpson 1932).

Quaternary and older offshore deposits

There is also the potential for reworked offshore fossils to wash up on the beaches at TIMU, although this is limited by the relatively small seaward exposure of the park. The continental shelf outside of TIMU is known to produce mollusk fossils (Milliman et al. 1972). A variety of other fossils may also be present, including those of algae, foraminifera, corals, bryozoans, polychaete worm tubes, ostracodes, barnacles, and echinoids (Macintyre and Milliman 1970). Black staining of mollusks is one of the characteristics of Quaternary fossil mollusks, and may indicate deposition in low energy coastal swamps during a time of lower sea level (Milliman et al. 1972). Boring by other invertebrates (Pilkey et al. 1969), abrasion, and trace element composition can also be used to distinguish modern from fossil shells (Wehmiller et al. 2003). The more worn, damaged, and bored a specimen is, the older it probably is. Terrestrial remains such as peat and proboscidean teeth may also wash up, as the coast had been farther east at the last glacial maximum, leading to now-drowned offshore terrestrial deposits (Milliman et al. 1972).

Park Collections

TIMU specimens, found in archeological contexts, are currently in storage at the Florida Museum of Natural History and the Southeast Archeological Center (SEAC), as described above under “Fossils found in cultural resource contexts.”

Fossils Found in Cultural Resource Contexts

TIMU is archeologically rich. Because of this, fossils may be found associated with cultural resources, such as fossils altered or modified by humans. Remains of the biota that was contemporaneous with these archeological resources are also of paleontological interest. There were 125 archeological sites within or adjacent to TIMU at the time it was proposed. 80 of these sites are prehistoric: 63 within the proposed boundaries of TIMU, and 17 more than 100 m (30 ft) away. Human habitation goes back to at least approximately 6,000 years ago. People may have been in the area earlier, as there is evidence for humans in Florida 14,000 years ago, but because the coast was farther east at the time, human habitations in the Jacksonville area from before about 6,000 years ago may be offshore now. Settings available for exploitation included coastal marine, maritime, estuarine, riverine, and palustrine environments. Shell middens are by far the most common type of site at or near TIMU; 63 of the prehistoric sites are shell middens or include a shell midden component. Other common types of sites include burial mounds, sand mounds, and shell rings. Those sites that have been dated mostly come from the Orange Period (4,000 to 3,000 years ago), St. Johns I Period (2,500 to 1,500 years ago), and undifferentiated St. Johns II Period (1,200 years ago to 1513, when Europeans first made contact with the inhabitants of northern Florida) (Hammersten 1988). Dating of archeological sites is often accomplished by chronologies using ceramics found in shell middens (DePratter and Howard 1976). Middens younger than about 3,200 years old can be dated in this way (Keel et al. 1996). Orange Period people made middens of coquina clams (*Donax*), probably during the winter months. These people also hunted deer, bear, and small mammals, and made shell and bone tools. By the St. Johns I Period, people utilized oysters as the dominant shellfish. People from the St. Johns periods also made ceramics with sponge spicule paste (Hammersten 1988). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Aside from their archeological value, coquina clams from shell middens are also utilized for stable isotope studies. Shells from two midden sites at or near TIMU in the Jacksonville area, among several other sites in northeastern Florida, have been used for stable isotope analyses intended to examine Holocene climate. The Spencer's Midden site from Atlantic Beach, 3.9 km (2.4 miles) south of TIMU, has shells from the Archaic Period, about $5,570 \pm 80$ radiocarbon years before present (ybp), or $5,989 \pm 211$ calendar ybp (radiocarbon years must be calibrated to yield calendar years; this calibration was made using Calib 5.0.2 [<http://calib.qub.ac.uk/calib/>]). The Orange Period-age Rollins site, on Fort George Island within TIMU, has shells from about $3,760 \pm 60$ radiocarbon ybp, or $3,701 \pm 172$ calendar ybp. High warm season temperatures, as interpreted from stable oxygen isotope ratios, may indicate greater seasonality at the time the organisms in the shells were alive. One *Donax* shell was used from each site. These specimens are stored in the collections of the Environmental Archaeology Program at the Florida Museum of Natural History (FLMNH), of the University of Florida, at Gainesville (Jones et al. 2005).

In addition to the specimens at the Florida Museum of Natural History discussed above, there are eleven other specimens or parts of specimens from TIMU that were found in archeological contexts. These specimens are repositated at the Southeast Archeological Center (SEAC), and are unidentified to date. TIMU 5391 is a lot of two items from the Fitzpatrick Plantation. TIMU 6120, a lot of eight items, and TIMU 6213, a single item, come from the Kingsley Plantation (B. Carter, SEAC supervisory museum specialist, pers. comm., August 2008; A. Lewellen, TIMU museum curator, pers. comm., October 2008; R. Bryant, FOCA/TIMU resource program manager, pers. comm., December 2008). Further identification of these specimens and their provenance is needed.

There is one other human-potential fossil association worth noting. Construction at TIMU includes brick and tabby structures (such as at Kingsley Plantation), tabby being an oyster shell concrete. Given the ready accessibility of shell middens, it is likely that at least some of the shells used came from local middens; the midden shells were certainly mined for use elsewhere (Hammersten 1988). Because of this, it is possible that there are bones and prehistoric pottery in the remains of TIMU tabby structures, as

Denise Spear (Fort Frederica National Monument resource program manager, pers. comm., September 2008) proposes for FOFR tabby structures.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division has not yet conducted a geologic resource scoping session for TIMU or FOCA.
- Further identification of the TIMU fossil specimens housed at SEAC is required.
- SECN parks such as CAHA, CALO, CANA, CASA, CUIS, FOCA, FOFR, FOMA, FOPU, FOSU, and TIMU are geologically very young, making it difficult to determine what material is a “fossil” and what would be considered “modern.” The National Park Service defines a fossil as any remains of life preserved in a geologic context. This definition does not include an arbitrary date where older specimens are considered fossils, and younger specimens are not. The “geologic context” phrase is intended to imply some level of antiquity, however. Generally, specimens dating back to the late Pleistocene are considered fossils. Late Holocene (last few hundred or thousand years, “Recent”) specimens are usually considered modern and not fossils. Pleistocene remains may differ from younger remains by having dark staining and being heavily worn and bored, but this does not always hold true. Surface and subsurface specimens collected at TIMU span this range between Pleistocene and Holocene. Regardless of what label is assigned to them, these specimens are important natural resources and valuable pieces of the history of life on earth.
- Some coastal park units in the NPS experience unauthorized casual collecting of fossils (beach-combing) from beach areas. This activity is not well documented in the SECN. Further investigation into casual collecting could lead to development of a park or regional policy related to such collecting.
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Southeast Archeology Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Future increases in sea level may impact paleontological (as well as archeological) sites within the park via inundation or increased erosion.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at FOCA and/or TIMU.

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Data Sets

Fort Caroline National Memorial Paleontological Archives

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

Timucuan Ecological and Historic Preserve Paleontological Archives

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

Timucuan Ecological and Historic Preserve Collections at the Florida Museum of Natural History (FLMNH), Environmental Archaeology Program

1988–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by FLMNH staff; status: Active.

Timucuan Ecological and Historic Preserve Collections at the Southeast Archeological Center (SEAC)

1988–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by SEAC staff; status: Active.

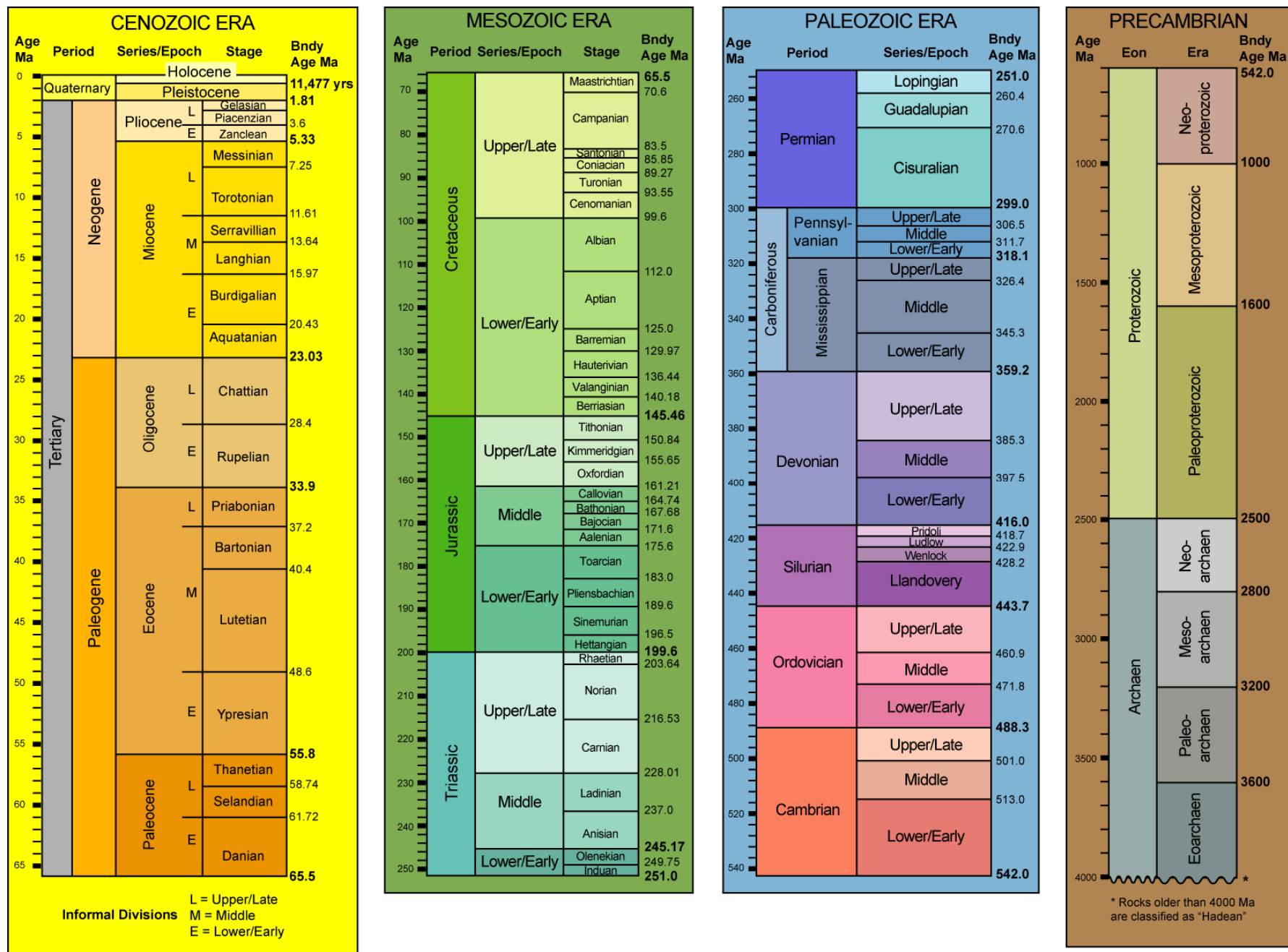


Figure 2. Geologic Time Scale. *Ma* = Millions of year old. *Bndy Age* = Boundary Age. Colors are USGS standard colors found on geologic maps. Modified from 1999 Geological Society of America Time scale (www.geosociety.org/science/timescale/timescl.pdf). Boundary dates and additional information from 2004 International Commission on Stratigraphy (www.stratigraphy.org/gssp.htm) and U.S. Geological Survey Fact Sheet 2007-3015 (<http://pubs.usgs.gov/fs/2007/3015/>).

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