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Natural Resource Program Center

Paleontological Resource Inventory and Monitoring
Sonoran Desert Network

Natural Resource Technical Report NPS/NRPC/NRTR—2008/130



ON THE COVER
Proboscidean footprint from “Elephant Hill,” Montezuma Castle National Monument. For more information refer to the MOCA section of the report. NPS Photo.

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Natural Resource Technical Report NPS/NRPC/NRTR—2008/130

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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 nearly 200 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 Sonoran Desert 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 21 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 Sonoran Desert Network come from the middle to late Paleozoic and late Cenozoic. Casa Grande Ruins National Monument (CAGR) and Tumacácori National Historical Park (TUMA) have fossils possibly associated with cultural resources. Chiricahua National Monument (CHIR) has Paleozoic marine invertebrates, Cretaceous petrified wood, and fossils that may have a cultural association. There may be algal structures and other Paleozoic fossils associated with caves at Coronado National Memorial (CORO). Mapping at Fort Bowie National Historic Site (FOBO) has uncovered Paleozoic marine invertebrates. Gila Cliff Dwellings National Monument (GICL) has unstudied Quaternary packrat middens. Montezuma Castle National Monument (MOCA) has plant and invertebrate body fossils and mammal tracks from the Miocene, and phytoplankton, plant, and invertebrate fossils in Montezuma Well, along with possible fossils from cultural settings. The Quaternary packrat middens of Organ Pipe Cactus National Monument (ORPI) are well-known and well-documented. Early Paleozoic marine invertebrates and Quaternary packrat middens have been reported from Saguaro National Park (SAGU). The oldest fossils in the SODN are known from Tonto National Monument (TONT), in the form of algal laminations from the Mesoproterozoic, over 1.1 billion years ago. Tuzigoot National Monument (TUZI), like nearby MOCA, has plant and invertebrate fossils from the Miocene-Pliocene. The Quaternary fossils of MOCA, ORPI, and SAGU are the best known of these fossils, and have been used to document changes in climate and ecology in the Sonoran Desert since the last glacial period.

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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 nearly 200 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 Sonoran Desert I&M Network (SODN).

The Sonoran Desert Network includes eleven National Park Service areas as shown in Figure 1, ten in central and southern Arizona and one in western New Mexico: Casa Grande Ruins National Monument (CAGR), Chiricahua National Monument (CHIR), Coronado National Monument (CORO), Fort Bowie National Historic Site (FOBO), Gila Cliff Dwellings National Monument (GICL), Montezuma Castle National Monument (MOCA), Organ Pipe Cactus National Monument (ORPI), Saguaro National Park (SAGU), Tonto National Monument (TONT), Tumacácori National Historical Park (TUMA), and Tuzigoot National Monument (TUZI).

The parks that comprise the Sonoran Desert Network vary in size from 146 ha (360 acres) (TUMA) to over 113,540 ha (330,000 acres) (ORPI), and protect resources ranging from human history and prehistory, to modern wildlife, to spectacular rocks. These parks are found across an area that changes in geographic setting from the southern extreme of the Colorado Plateau in the north, to the transitional zone of the Mogollon Rim, to Basin and Range topography in the south. The Sonoran Desert begins at the Mogollon Rim and extends into northwestern Mexico. A hot desert with winter and summer precipitation, it may have the greatest species diversity of any North American desert, due to factors including its climate and widely varying topography, and its geographic location. The Sonoran Desert is located between several other important physiographic regions which have influenced its modern flora and fauna. To the north is the Colorado Plateau, to the east is the Chihuahuan Desert, to the south are tropical and montane Mexican forests, and to the west is the Mohave Desert. A further driver of diversity is the "sky island" phenomenon: as overall climate in the Southwest became warmer and drier following the end of the last glacial period about 10,000 years ago, vegetation zones retreated up the many small mountain ranges, creating "sky islands" of endemic organisms. These factors have led to the presence of all globally recognized biomes except tundra within the Sonoran Desert. Over 2,000 species of plants, about 30 species of fish, 20 species of amphibians, 100 species of reptiles, 350 species of birds, and 60 species of mammals are known from the Sonoran Desert.

The geology of the Sonoran Desert Network (discussed in detail in the appropriate park chapters) combines lengthy periods of quiet with extensive volcanism and tectonic activity, and much of geologic history since at least 1.7 billion years ago is represented somewhere. Many of the parks and monuments of the SODN tell similar geologic stories, and together they present evidence of nearly every large-scale geologic event in the Sonoran Desert.

Igneous intrusions and now-metamorphosed underwater sediment flows mark the beginning of local geological history, in the Early Proterozoic (see Figure 2 for a geologic time scale). A mountain-building event known as the Mazatzal Orogeny occurred around 1.45 to 1.40 billion years ago, followed by the

deposition of formations that provide the oldest signs of life in the SODN. These rocks, in the Apache Group, include microfossils of uncertain derivation in the Dripping Spring Formation and prominent algal mats in the Mescal Limestone, and probably represent shallow marine environments, although some researchers have promoted the idea that some of the algal fossils actually came from terrestrial exposures. The Apache Group and overlying Troy Quartzite were deposited between about 1.3 and 1.05 billion years ago, and are followed by a long gap until the middle Cambrian, about 500 million years ago.

By the Middle Cambrian, the SODN would have been represented by a stable region in the vicinity of an ocean. At times, some or all of the area was inundated by this ocean. For the next 250 million or so years, this would be the general state of affairs. Sonoran Cambrian formations, representing tidal to shallow marine settings, are not known for their diverse fossils, with only trilobites, brachiopods (superficially clam-like shelled animals), and tracks and burrows being common finds. Most of the 70 or so million years following the Cambrian, representing most of the Ordovician, all of the Silurian, and most of the Devonian, are not recorded in SODN rocks. Shallow marine deposition returned in the Late Devonian and continued until the Middle Mississippian, between about 385 and 328 million years ago. This stretch of time is represented by the Martin Formation (Upper Devonian) and two Mississippian formations, the Escabrosa Limestone of southern Arizona and the Redwall Limestone of northern Arizona. All three are known for their marine invertebrate fossils. The shallow seas of Devonian-Mississippian Arizona were populated by a diverse flora and fauna including algae, foraminifera (single-celled animals that secrete a hard covering), sponges, stromatoporoids (reef-building sponges), corals, bryozoans (moss animals), brachiopods, cephalopods (squid and octopus-like animals), gastropods (snails), pelecypods (bivalves), annelid worms, trilobites, ostracodes (tiny shell-dwelling crustaceans), crinoids (sea lilies), blastoids (extinct crinoid-like echinoderms), holothurians (sea cucumbers), conodonts (extinct eel-like chordates), and fish (including placoderms and early lobe-fins).

As with the Mississippian, the next period of deposition, from about 310 to about 260 million years ago, has a north-south division. Southern Arizona has the Naco Group of formations, and northern Arizona has the Supai Group and a variety of younger formations best known from the walls of the Grand Canyon. In both areas, the formations represent shallow marine to various terrestrial settings, depending on time and geography. The marine formations have similar organisms to the earlier Devonian-Mississippian seas, with the addition or increase in prominence of fusulinid foraminifera (particularly large abundant foraminifera of the Pennsylvanian-Permian), scaphopods (tusk shells), echinoids (sand dollars), and cartilaginous fish. On land, terrestrial invertebrates and early tetrapods (including amphibians, early relatives of mammals, and early reptiles) left their tracks in river and dune settings.

The Mesozoic, famous for dinosaurs and other large prehistoric reptiles, is only partially known in the SODN region. Unlike northern Arizona and New Mexico, the Triassic and Early Jurassic are almost unknown in SODN parks. The Middle and Late Jurassic, however, are represented by extensive igneous and tectonic activity in the southern part of the SODN, particularly in the area of CORO, ORPI, SAGU, and TUMA. In many places, volcanoes vented so much lava that they collapsed into their emptied magma chambers, forming large circular basins called calderas. CORO itself is near three such Jurassic calderas, dating to about 170 million years ago. Volcanic activity began slightly later farther north, around 165-160 million years ago near TUMA, and 159 million years ago at SAGU, possibly in a continental volcanic arc like the modern Andes. Intrusions of igneous rocks and large scale faulting also occurred. As this volcanic activity subsided, deposition in terrestrial environments followed, with evidence of lizards and dinosaurs.

The Early Cretaceous was a time when the SODN region returned to the marine-terrestrial cycling of the Devonian to Permian, although instead of multiple cycles, the rocks record one large, long-term general episode of marine encroachment (sea level rise) and regression. The rocks of the widespread Bisbee Group are the primary source of data. Scattered occurrences of wood and dinosaur bones are known from the terrestrial formations. Fossils are much more abundant in the marine rocks; about 112 million years ago, the SODN region was a shallow platform with unusual reefs composed of algal mats, coral, and

rudist bivalves, and home to foraminifera, bryozoans, brachiopods, gastropods, pelecypods, ostracodes, and echinoids.

By the Late Cretaceous, the seas had retreated for the last time. Western North America was entering the Laramide Orogeny, a major mountain building event that led to the modern Rocky Mountains. This event, lasting roughly from 75 to 50 million years ago, brough another period of volcanism, igneous intrusions, metamorphism, and faulting to southern and central Arizona. Caldera-forming volcanism resumed, including one event about 73 million years ago that created much of what would become the Tucson Mountains of SAGU. A period of little deposition followed, ending about 30 million years ago with another tectonic event that left lava flows in the vicinity of many SODN units. Particularly prominent is volcanism at CHIR (29-26 million years ago), GICL (28 million years ago), ORPI (17.4-15.4 million years ago for the Ajo volcanic field) and SAGU (29-20 million years ago). This tectonic event led into Basin and Range faulting that created a distinctive topography of small narrow north-south mountain ranges and intervening basins as the Earth's crust was pulled apart. In the SODN, this topography is best developed at ORPI, and was usually formed between about 25 and 5 million years ago, largely in the Miocene.

The altered topography led to basin-filling sedimentary deposits, isolated basin lakes, and reorganization of drainage. Large shallow lakes formed in the vicinity of MOCA-TUZI and FOBO-CHIR. Gastropods, pelecypods, ostracodes, fish, amphibians, turtles, lizards, snakes, birds, and plants are known from some of these local deposits, but large mammals are more famous. A variety of large mammals including bears, canids, felids, equids, camelids, llamas, antelope, deer, bovids, and proboscideans inhabited the region, although most of them either left the area or went extinct as the last glacial period ended and humans entered the region 13,000 to 11,000 years ago. The last 20,000 or so years of SODN history are well-represented by fossil packrat middens, former rodent nests cemented by urine and now well-preserved by the arid climate in crevices and caves. These middens show changes in climate through vegetation, illustrating how the modern Sonoran vegetation developed as conditions changed. Before 9,000 years ago, the region was wetter and cooler, and woodlands flourished. There was then a transition lasting until about 4,000 years ago, when the modern hot, dry climate was fully entrenched, and desertscrub took over. Some of these middens are known from ORPI and SAGU.

Collectively, the paleontological resources of the SODN Network contribute to a greater understanding of the history of life on earth. Continued paleontological resource inventories will serve to expand this ever-widening base of paleontological knowledge represented throughout the National Park Service. Although nearly 200 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.

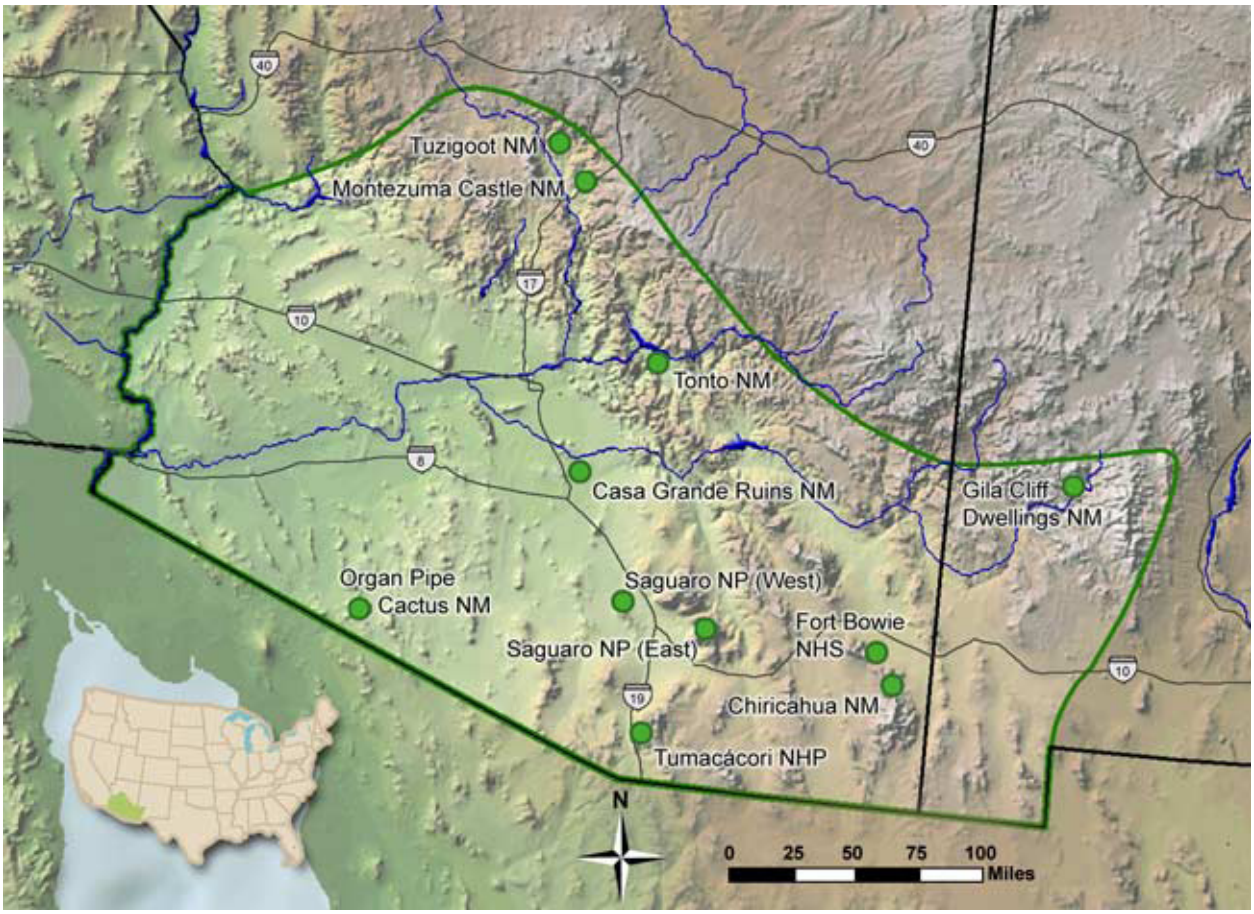


Figure 1. Map of SODN network parks. Map courtesy SODN staff. Coronado National Memorial is omitted; it is located southeast of Tumacácori National Historical Park on the international border.

Paleontological Resource Inventory Strategies and Methodology

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

Comprehensive Park-Specific Paleontological Resource Inventories

Comprehensive park inventories are designed to identify all known paleontological resources within a single park unit. A team of specialists from within the NPS and from educational institutions and cooperators work with the targeted park to identify and address all aspects of its paleontological resources, including resource management, museum curation, law enforcement, and interpretation. Paleontology-specific training for park staff is an important component of many comprehensive paleontological inventories. Park-specific comprehensive paleontological resource inventories have been completed at Yellowstone NP (first park to have inventory completed), Amistad NRA (in review October 2008), Arches NP, Bighorn Canyon NRA, Death Valley NP, Grand Teton NP, Santa Monica 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 October 2008, network-based inventories have been completed for 21 of the 32 I&M Networks including: the Appalachian Highlands, Chihuahuan Desert, Eastern Rivers and Mountains, Great Lakes, Greater Yellowstone, Gulf Coast, 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 (this report), Southern Plains, Southeastern Alaska, Southwestern Alaska, and Upper Columbia Basin networks. Research for summaries of the Arctic, Heartland, Northern Great Plains, South Florida/Caribbean and Southeast Coast networks is currently underway (October 2008). 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, or paleontological technicians 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 USGS Library in Reston, Virginia is a premier repository for geologic publications, and houses most of the publications obtained for the network-based paleontological resource inventories. 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 individual 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). In addition, the USGS National Geologic Map Database (NGMDB; see citation below in Additional References section) lists maps for a given geographic area or place name and provides information on where 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.

The information from these various sources for each park is then compiled and summarized in a written report and developed into individual datasets. 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.

The paleontological resource inventory reports synthesize information regarding the scope and significance of fossils documented from each 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 in 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 reports 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, nearly 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. The inventory reports include information on the history of paleontological research, descriptions of current cooperative projects, identification of any museums or universities serving as repositories for park fossils, and a comprehensive list of publications related to paleontological research associated with the park. 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 (References Cited) and other associated bibliographies (Additional References). The cooperative projects section highlights paleontological resources projects, if any, that the park has funded or supported. Formal datasets are established for known associated paleontological collections, research, or activities.

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 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 2008. 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.

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General SODN Information
SODN I&M Network: http://www.nature.nps.gov/im/units/sodn/sonoran.cfm

Geological Survey Websites
Arizona Geological Survey: http://www.azgs.az.gov/
New Mexico Bureau of Geology & Mineral Resources: http://geoinfo.nmt.edu/
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://igsrglib03.er.usgs.gov:8080/#focus
Smithsonian Institution Libraries Catalog: http://www.siris.si.edu/

Museums
Arizona Museum of Natural History: http://www.azmnh.org/Home.aspx
Arizona-Sonora Desert Museum: http://www.desertmuseum.org/
Arizona State Museum:http://www.statemuseum.arizona.edu/index.shtml
Museum of Northern Arizona: http://www.musnaz.org/
New Mexico Museum of Natural History and Science: http://www.nmnaturalhistory.org/
Robert S. Deitz Museum of Geology (Arizona State University): http://sese.asu.edu/museum/museum.php
Smithsonian National Museum of Natural History Dept. of Paleobiology: http://www.nmnh.si.edu/paleo/
University of Arizona Mineral Museum: http://www.uamineralmuseum.org/
University of Arizona Museum of Natural History: http://eebweb.arizona.edu/Collections/AboutUs.htm
Western Archeological and Conservation Center: http://www.museum.nps.gov/wacc/page.htm

Resource Management/Legislation Documents
NPS 2006 Management Policies (§1.4; Park Management): http://www.nps.gov/policy/mp/chapter1.htm
NPS 2006 Management Policies (§4.8.2.1; Paleontological Resources):
http://www.nps.gov/policy/mp/chapter4.htm
NPS 1998 Omnibus Management Act (paleontological resource summary):
http://www.nature.nps.gov/geology/paleontology/paleo_5_1/index.htm
NPS Natural Resource Management Reference Manual #77 (paleontology section):
http://www.nature.nps.gov/rm77/paleo.cfm
Assessment of Fossil Management on Federal & Indian Lands: http://www.fs.fed.us/geology/fossil.pdf

National Park Service Paleontology Program sites
NPS Geologic Resources Division: http://www.nature.nps.gov/geology/
NPS Paleontology Program: http://www.nature.nps.gov/geology/paleontology/
NPS Park Paleontology Newsletter: 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):
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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/
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, description of physiographic provinces: http://tapestry.usgs.gov/Default.html
U.S. Geological Survey/National Oceanographic and Atmospheric Administration North American Packrat Midden Database: http://esp.cr.usgs.gov/data/midden/

Casa Grande Ruins National Monument

Casa Grande Ruins National Monument (CAGR) was established to protect the large adobe Casa Grande, built by the Hohokam between about 1200 and 1450, and other ancient buildings and objects of prehistoric interest. It was designated as an archeological reserve by executive order on June 22, 1892, and proclaimed a National Monument and transferred to the National Park Service on August 3, 1918. Its boundaries have been changed twice to date, on December 10, 1909 and June 7, 1918, and park managers have proposed further expansion (Powell et al. 2006). Currently, CAGR encompasses 191.22 ha (472.50 acres), all of which are under Federal administration.

Hohokam Pima National Monument (PIMA) was proclaimed October 21, 1972 to protect the Hohokam village "Snaketown." The monument is located within the Gila River Indian Community reservation and is owned and managed by the tribe. It is not open to the public. Encompassing 684 ha (1,690 acres), PIMA is a few kilometers or miles west-northwest of CAGR, with essentially the same geology, so anything in this section that is not specifically attributed to CAGR (such as fossil specimens) is also relevant to PIMA. PIMA is not part of the Sonoran Desert Network, but is mentioned here due to its proximity and geologic similarity to CAGR.

Geologic Background

CAGR is located about 1.6 to 2.4 km (1.0 to 1.5 miles) south of the Gila River in northwestern Pinal County, in the region where the Basin and Range Province transitions into the Colorado Plateau. The mountains surrounding this area include the San Tans to the north, the Picacho to the southeast, the Casa Grande to the southwest, and the Sacaton to the west. The monument itself is located in Tertiary to Quaternary fluvial and lake deposits (see Figure 2 for a geologic time scale; Powell et al. 2006), atop a Pleistocene-age Gila River terrace (National Park Service 2006). CAGR has been the subject of a geologic report by the National Park Service (2006); this is an internal National Park Service document.

There are not a great deal of rocks older than the Tertiary exposed in the area of CAGR. Volcanism took place around 50 million years ago, followed by faulting that created Basin and Range topography 30 to 10 million years ago. The Gila River system began to form after 9 million years ago, with the Gila River depositing CAGR's river terrace between 100,000 and 10,000 years ago (National Park Service 2006).

There is essentially no chance of fossils eroding out of other formations and entering CAGR via the Gila River in the foreseeable future, barring significant changes to water management, drainage courses, and precipitation patterns. The Gila River today is usually dry downstream of Coolidge Dam except under occasional torrential monsoons (C. West, CAGR resource program manager, pers. commun., July 2008). CAGR is located up (6 to 9 m or 20 to 30 ft; National Park Service 2006) and away from the Gila River's current bed (Pearthree et al. 1996; Spencer et al 1996), and even if the Gila River was undammed and changed course to be flowing near enough to CAGR that it might deposit material there at times, but was not near enough to destroy it, nearby fossiliferous formations are lacking. Thus, potential fossils at CAGR are essentially limited to Pleistocene and younger river deposits of the Gila, or associated with cultural artifacts. Despite these limited sources, there are several specimens at the Western Archeological Conservation Center (WACC) associated with CAGR (R. Carr, CAGR Chief of Cultural Resources, pers. commun. to V. Santucci, 2008).

Potential Sources of Paleontological Resources

Quaternary rocks and sediments (Pleistocene-Holocene)

As with any park or monument in the SODN, any rocks or sediments of Quaternary age may contain isolated remains of the Quaternary fauna, such as testudinids, equids, camelids, and proboscideans (R. McCord, Arizona Museum of Natural History paleontologist, pers. commun., May 2008). Additionally,

the distribution of packrats (*Neotoma* spp.) suggests that ancient packrat middens could be present in caves or crevices, although the level topography of CAGR makes it less likely than other Sonoran Desert Network parks and monuments to have the necessary settings. Caves and karst, also sources for Quaternary fossils in Arizona, are not known at CAGR to date.

There is little known about the Quaternary paleontology of Pinal County and surrounding areas, or the rest of the Cenozoic for that matter; finds have been confined to the southern border and southeastern corner (Lindsay and Tessman 1974; Lindsay 1978; Nations and Landye 1984; Lucas and Morgan 2005; Morgan and White 2005). Agenbroad (1984) places a *Bison bison* locality, from within the last 12,000 years, in the vicinity of CAGR in Pinal County, but does not elaborate further. Along with the cultural setting of CAGR itself, and the possible worked antler, this suggests the possibility of additional fossils associated with humans. Kenworthy and Santucci (2006) provide an overview and a few examples of NPS fossils found in cultural resource contexts.

Park Collections

There are five specimens listed in the database of WACC as fossils or potential fossils that may be from CAGR (R. Carr, pers. commun. to V. Santucci, February 2008). One of them, a piece of possible petrified wood cataloged as CAGR-2651, is directly associated with CAGR. The other four (CAGR-2392, an antler or horn; and CAGR-2393, 2394, and 2395, each a possible tooth) are listed with a possible provenance from CAGR. The antler piece is listed as possibly worked, which could indicate a cultural use; unfortunately, they were not known in time for Kenworthy and Santucci's (2006) initial survey of fossils in cultural resources from National Park Service areas. Other provenance data or further identification in unavailable or unknown at this time, and would be a good topic for future research.

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division coordinated geologic scoping for CAGR during May 2006. The participants of the CAGR Geologic Scoping meeting developed a series of recommendations for future work. There is little potential for *in situ* fossil discovery within the park. Nevertheless five specimens within park collections at WACC are fossils and may have been originally discovered in a cultural context.
- Park staff should be encouraged to observe the Pleistocene river terrace deposits underlying CAGR 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 Western Archeology & Conservation Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Fossil packrat middens are typically found in dry rockshelters, and resemble piles or mounds of plant material with a dark glossy coating of crystallized packrat urine. Fossil middens can provide important paleoecological information. If one is located, there are several midden researchers in the Southwest who may be contacted. The GRD maintains a list of active researchers and can facilitate communication between the park and these researchers.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at CAGR.

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Data Sets

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

Casa Grande Ruins National Monument collections at the Western Archeological Conservation Center (WACC)
1958-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by WACC staff; status: Active

Chiricahua National Monument

Chiricahua National Monument (CHIR) was proclaimed April 18, 1924, and was transferred from the U.S. Forest Service to the National Park Service on August 10, 1933. The monument was established to protect unusual volcanic rock features, such as "pinnacles, columns, spires and balanced rocks" (National Park Service 2006). CHIR had boundary changes June 10, 1938, November 10, 1978, and August 28, 1984; today, it encompasses 4850.15 ha (11,984.73 acres), all but 0.95 ha (2.35 acres) of which are under Federal administration. Much of the monument (4164 ha or 10,290 acres) was designated wilderness in 1976.

Geologic Background

CHIR is located in Cochise County, Arizona, in the northern Chiricahua Mountains, surrounded by a unit of Coronado National Forest. The Dos Cabezas Mountains are found to the northwest, the San Simon Valley to the north and northwest, and the Sulphur Springs Valley to the west and southwest. Timber Mountain and Cochise Head abut the northeast corner; Sugarloaf Mountain at over 2228 m (7310 ft) tall is a prominent point of elevation within the monument. CHIR mostly overlies volcanic ash-flow tuff and rhyolitic lava flows, with several canyons and associated Quaternary alluvium (see Figure 2 for a geologic time scale). The northeast corner is composed of faulted Paleozoic and Mesozoic rocks. The geology of CHIR has been the subject of numerous reports, not including geologic publications on other aspects of, or locations in, the Chiricahua Mountains. CHIR geology has been documented in the published literature (Bezy 1998, 2001; Enlows 1951, 1955; Pallister, du Bray, and Hall 1993, 1997), maps (Drewes 1982; du Bray and Pallister 1993; Pallister and du Bray 1997), theses (Waller 1952), and internal National Park Service literature (Alberts 1940; Chaney 1971; Enlows n. d.; Gould 1937; Hall and Bezy 1974; Maxwell 1941; Ringenbach 1966; Smith 1940; Yetman 1974). Most recently, CHIR was the subject of a geologic report by the National Park Service (2006); this is an internal National Park Service document. Understandably, these reports have been primarily devoted to the volcanic units. The sedimentary rocks of CHIR, most of which were not part of the monument until recent boundary changes, are typically mentioned only briefly to establish the pre-volcanic geologic history of the area.

The geologic history of the Chiricahua-Dos Cabezas area is complex, with multiple episodes of sea level changes, folding, faulting, igneous intrusion, volcanism, metamorphism, and other tectonic activity. Precambrian time is represented by the Pinal Schist and igneous intrusions, and included a mountain-building event (Sabins 1957a). Cambrian sandstones (Bolsa Quartzite) and Ordovician limestones (El Paso Formation or Limestone) were followed by more mountain building. Subsequent to this was the deposition of a series of formations under varying marine to terrestrial conditions from the Upper Devonian to the Middle Permian. Deposition was interrupted by another period of uplift (Sabins 1957a) that ended by the Upper Jurassic with the deposition of the Bisbee Group's Glance Conglomerate (long assumed to be Lower Cretaceous in total, but with datable volcanics at 150 million years ago; Dickinson et al. 1989). The Lower Cretaceous Bisbee units, like the earlier Naco Group, show marine-terrestrial alternation from sea level changes. Bisbee deposition was ended by another episode of uplift, including volcanism and more faulting. This episode ended before the Pliocene, and was followed by the Basin and Range tectonics and associated basin fill sediments that gave the area its present geography (Sabins 1957a).

In CHIR itself, dramatic volcanics reshaped the surface during the Oligocene, about 29 to 26 million years ago. First came volcanic ash deposits and lava flows pertaining to the Faraway Ranch Formation and Jesse James Canyon Tuff, between about 28.6 and 27 million years ago (Pallister and du Bray 1997). These flows were followed by the formation of the Turkey Creek Caldera at 26.9 million years ago. At this time, what would become the Turkey Creek Caldera was a large magma chamber to the south of CHIR. This chamber ruptured and released more than 100 cubic miles of magma, burying the surrounding area in pumice and ash, and leaving a depression 19 km (12 miles) in diameter and 1,500 m (5,000 ft) deep (Pallister, du Bray, and Hall 1993) The resulting volcanic rocks are known as the Rhyolite Canyon Tuff. The caldera continued to produce lava flows until about 26.6 million years ago (Pallister and du Bray

1997), after which Basin and Range tectonic activity (roughly 25 to 5 million years ago; Bezy 1998) and erosion took over and sculpted the rocks of the monument into their present forms.

From oldest to youngest, the following rock units are exposed within CHIR boundaries: the Naco Group's Horquilla Limestone (Upper Pennsylvanian-?Lower Permian), Earp Formation (?Upper Pennsylvanian-Lower Permian), Colina Limestone and Epitaph Formation (undivided; Lower Permian), Scherrer Formation (Lower Permian), and Concha Limestone (Lower to Middle Permian); an unnamed Jurassic and Cretaceous mixed sedimentary and volcanic unit; the Bisbee Group's Glance Conglomerate (Upper Jurassic-Lower Cretaceous) and Morita Formation (upper Lower Cretaceous); unassigned Tertiary volcanic dikes and lava flows; sedimentary rocks of Bonita Park (Oligocene); volcanic rocks of the Faraway Ranch Formation (middle Oligocene); Jesse James Canyon Tuff (middle Oligocene); Rhyolite Canyon Tuff outflow from the Turkey Creek Caldera collapse (middle Oligocene); the lava atop Sugarloaf Mountain (middle Oligocene); Tertiary-Quaternary landslide deposits; and Quaternary gravels, sand, and silt (Pleistocene and Holocene) (Pallister and du Bray 1997).

Fossils have been reported from several of these units in CHIR or the surrounding area. The Horquilla Limestone, Colina/Epitaph, and Concha Limestone were described as producing fossils of various aquatic invertebrates by Pallister and du Bray (1997) in their map of CHIR. Their preliminary map (du Bray and Pallister 1993) reported the same formations as fossiliferous. Pallister, du Bray, and Hall (1993, 1997) described the Glance Conglomerate as including fossiliferous Paleozoic limestone debris, and also cited fossil wood in unnamed Cretaceous sandstones; the description is suggestive of the overlying Morita Formation. Pallister, du Bray, and Hall (1997) specifically mentioned corals, brachiopods, gastropods, and echinoids as abundant in the Paleozoic rocks, but did not state which formations they came from. Although the 1993 and 1997 publications did not directly state that fossils were known from CHIR, their presence is strongly implied. For the purposes of this report, it will be assumed that this implication is correct, as these publications make more sense when read that way. Drewes (1982), in an earlier map of the Cochise Head quadrangle and associated areas (including CHIR), mentioned fossils in the Horquilla, Earp, Colina, and Concha formations. Two invertebrate specimens of unknown provenance from Faraway Ranch at CHIR are in the collections of the Western Archeological Conservation Center (WACC) (A. Iverson, WACC, pers. commun., 2008). Finally, the Scherrer Formation (Butler 1971; Blodgett et al. 2002), and Morita Formation (Stoyanow 1949; Lindberg 1987) also have produced fossils, but from more distant locations.

Sources of Paleontological Resources

Horquilla Limestone (Upper Pennsylvanian-?Lower Permian)

The Horquilla Limestone is dominated by limestones with interbedded mudstones. The limestones are interpreted as representing shallow marine to shoreline deposition, and the mudstones more terrestrial deposition. Mudstones increase toward the top, where the Horquilla Limestone grades into the Earp Formation. The Horquilla Limestone typically ranges in age from about 311 to 304 million years ago, from the Middle to Upper Pennsylvanian, although in areas of extreme southeastern Arizona and southwestern New Mexico it ends in the Lower Permian (Blakey and Knepp 1989). Fossils in the Horquilla Limestone are typically found toward the base and top of the formation, within the limestone beds (Ross 1973). Organisms known from the Horquilla Limestone include algae, fusulinid foraminifera, corals, bryozoans, brachiopods (Ross and Sabins 1965), mollusks, crinoids (Blakey and Knepp 1989), conodonts (eel-like extinct chordates; Johnson et al. 1986), and rare echinoids and fish (Williams 1954), along with burrows and algal layering in the limestone (Blakey and Knepp 1989). Depending on rock unit correlation, there may be cartilaginous fish known from the Horquilla Limestone (Pennsylvanian Naco Formation of Elliott et al. 2004 and Elliott and Blakey 2005), and root traces in non-limestone beds (Kenny and Neet 1993). The fusulinid foraminifera in the Horquilla Limestone are useful for dating, and show that there are 9 to 11 fusulinid zones in the formation, separated by periods without deposition interpreted as the result of sea level fluctuation (Ross 1978).

Du Bray and Pallister (1993) and Pallister and du Bray (1997) both described the Horquilla Limestone of CHIR as fossiliferous. Drewes (1982) described the upper Horquilla Limestone of the Cochise Head quadrangle and associated areas as preserving fusulinids, corals, bryozoans, and brachiopods, and the lower as preserving fusulinids, corals, and brachiopods. He also marked locations where fusulinids are present; some are just outside current CHIR boundaries, to the northeast and east.

Colina Limestone/Epitaph Formation (Lower Permian)

The Colina Limestone and Epitaph Formation are regarded as two portions of the same unit, with the Epitaph in part having been chemically altered into dolomite, incorporating clastics and limestone toward its top (Sabins 1957b; Patch 1973; Blakey and Knepp 1989). The Earp Formation grades into the Colina/Epitaph, which in turn passes conformably into the overlying Scherrer Formation. The Colina/Epitaph ranges in age between sometime before 280 million years ago and sometime before 271 million years ago (Blakey and Knepp 1989). At CHIR, the two are regarded as undivided (du Bray and Pallister 1993; Pallister and du Bray 1997).

The Colina Limestone is a relatively uniform limestone unit that is interpreted as a shallow marine shelf deposit, from subtidal to intertidal. Typical Colina Limestone fossils include bryozoans, brachiopods, pelecypods, gastropods, and echinoids (Blakey and Knepp 1989). Just across the border in Sonora (Mexico), algae, trilobites, and conodonts have been documented (Blodgett et al. 2002). The Epitaph Formation has an uncertain depositional setting for its non-dolomite beds (Blakey and Knepp 1989), and is less fossiliferous; Butler (1971) reported corals, brachiopods, gastropods, and echinoids.

Du Bray and Pallister (1993) and Pallister and du Bray (1997) both described the Colina/Epitaph of CHIR as sparsely fossiliferous, with gastropods and echinoids. Drewes (1982) noted the presence of gastropods and echinoids in the Colina Limestone of the Cochise Head quadrangle and associated areas, but did not report fossils from the Epitaph Formation.

Concha Limestone (Lower-Middle Permian)

The Concha Limestone is a chert-rich fossiliferous limestone deposited under quiet open-water shelf conditions. It ranges in age from sometime before 271 million years ago to sometime before 260 million years ago (Leonardian to Wolfcampian stages, Lower to Middle Permian) (Blakey and Knepp 1989). It has a fossil assemblage including the remains of fusulinid foraminifera, sponges, corals, bryozoans, brachiopods, gastropods, scaphopods, pelecypods, ammonoid cephalopods, echinoids, and crinoids (Bryant and McClymonds 1961). A tooth and associated fin spine, both possibly from the petalodontid cartilaginous fish *Megactenopetalus*, have been reported from Concha Limestone rocks in Santa Cruz County (Hansen 1978; note though that the coordinates given actually lie just north of the county border, in Coronado National Forest land in Pima County).

Du Bray and Pallister (1993) and Pallister and du Bray (1997) both described the Concha Limestone of CHIR as fossiliferous, with large brachiopods common. Drewes (1982) also noted the presence of brachiopods in the Concha Limestone of the Cochise Head quadrangle and associated areas.

Glance Conglomerate (Upper Jurassic-Lower Cretaceous)

The Glance Conglomerate is a conglomerate of variable thickness and age, commonly incorporating Precambrian granite and schist, Paleozoic sedimentary rocks (notably limestone), and Jurassic igneous rocks, deposited as subaerial alluvial fans (Dickinson et al 1989). It does not have an *in situ* flora or fauna (Bilodeau 1978), but does include fossils from older units (Gilluly 1956), including Concha Limestone brachiopods (Lawton and Olmstead 1995).

Pallister, du Bray, and Hall (1997) noted the presence of fossiliferous Paleozoic limestone among the rock cobbles incorporated into the Glance Conglomerate at CHIR. Drewes (1982) did not report any fossils in the Glance Conglomerate of the Cochise Head quadrangle and associated areas, but did note the presence of Paleozoic rock fragments within the Glance.

Undesignated Cretaceous Sandstone

Pallister, du Bray, and Hall (1993, 1997) described sandstone beds above the Glance Conglomerate at CHIR as sometimes containing petrified wood. These rocks may belong to the Morita Formation, which overlies the Glance, includes sandstone beds, and is known to produce wood elsewhere (Stoyanow 1949; Jamison 1987). The unnamed Jurassic-Cretaceous volcaniclastics are less likely, but cannot be ruled out.

Potential Sources of Paleontological Resources

Earp Formation (?Upper Pennsylvanian-Lower Permian)

The Earp Formation is a heterogeneous rock unit with an arbitrary lower boundary with the Horquilla Limestone, defined as where clastic (rock fragment) beds begin to predominate over limestone beds. It typically ranges in age between about 304 million years ago and sometime around 280 million years ago, and is thought to represent a variety of environments from shallow marine to shoreline, estuarine, coastal plain, and river, as sea level fluctuated (Blakey and Knepp 1989). Fossils found in Earp Formation rocks in Arizona pertain to a "typical Pennsylvanian shallow marine fauna," particularly fusulinid foraminifera, brachiopods, mollusks, and echinoids, along with burrows (Blakey and Knepp 1989). Different fossils are known from more terrestrial Earp Formation beds in southwestern New Mexico, including plants, brachiopods, conchostracans (bivalve-like crustaceans), ostracodes, pelecypods, and the tracks of temnospondyl amphibians and early reptiles (Lucas and Hunt 1995). Du Bray and Pallister (1993) and Pallister and du Bray (1997) did not mention fossils in their descriptions of this formation at CHIR, but Drewes (1982) mentioned fusulinids in his description of the Earp Formation in the Cochise Head quadrangle and associated areas.

Fusulinids from the Earp Formation are known from the Dos Cabezas-Chiricahua area, and have been described by Sabins and Ross (1963) and Ross and Tyrrell (1965). The map in Sabins and Ross (1963; Text-Figure 2, p. 326) is misleading, as it suggests that collection actually took place within CHIR boundaries at what was the northeast corner. It appears that a measured section overlapped CHIR boundaries, but collection of Earp Formation fusulinids could not have taken place within CHIR boundaries, as there is no Earp Formation in the area in question (Drewes 1982; Pallister and du Bray 1997). Instead, collection must have occurred just outside of CHIR. However, this is important because it shows how close known occurrences of Earp Formation fossils are to CHIR. As with the Horquilla, Drewes (1982) identified fusulinid locations, some of which are just outside of CHIR.

Scherrer Formation (Lower Permian)

The Scherrer Formation is a heterogeneous unit of sandstone and carbonate rock (limestone or dolomite) beds, possibly deposited under marginal marine to mudflat conditions. Its age is not well known, but it was deposited after the Colina/Epitaph and before about 271 million years ago. The only abundant fossils belong to echinoids; "ghosts" of dissolved gastropod shells (Blakey and Knepp 1989), bryozoans, brachiopods, crinoids (Butler 1971), and burrows have also been found (Blodgett et al. 2002). No fossils were reported by Drewes (1982), Du Bray and Pallister (1993), or Pallister and du Bray (1997) for the Scherrer Formation of the Cochise Head quadrangle and associated areas.

Morita Formation (upper Lower Cretaceous)

The Morita Formation is mostly made up of sandstone and mudstone, with limestone beds appearing toward the top. The lower portion of the formation shows terrestrial to marine influence, with deposition in river and delta environments, and the upper portion has more of a marine influence, with lagoon and marginal marine deposition. It is not certain when deposition of the Morita Formation began, but deposition was over by the late Aptian, around 115 million years ago (Dickinson et al. 1989).

The Morita Formation is not known for its fossils; some sources have stated outright that it is unfossiliferous (Hayes and Drewes 1978; Bilodeau et al. 1987). Fossils are present, but uncommon and

mostly found in the upper limestone beds (Gilluly 1956; Hayes 1970). It has also been part of a confusing stratigraphic issue. Stoyanow (1949) elected to designate the lower portion of the overlying Mural Limestone its own formation, the Lowell Formation, but did not indicate that he was also including in the Lowell a substantial amount of upper Morita Formation. This was noticed by Hayes and Landis (1961), who rejected the Lowell Formation. Their recommendation has been adopted, but older sources may misinterpret the extent of the Morita Formation. This is important because Stoyanow described fossils from the lower Lowell Formation, which actually pertain to the upper Morita Formation. These fossils include gastropods, pelecypods, ammonites, echinoids, worm traces, and wood (Stoyanow 1949). Other burrows and pelecypods are found lower in the Morita Formation, in the lagoonal mudstone beds, and some algal limestone is also present (Lindberg 1987). Jamison (1987) remarked that fossil wood is relatively abundant in the formation. No fossils were reported by Drewes (1982), Du Bray and Pallister (1993), or Pallister and du Bray (1997) for the Morita Formation of the Cochise Head quadrangle and associated areas. The fossils described by Lindberg (1987) came from Rucker Canyon, 24-32 km (15-20 miles) south of CHIR.

Tertiary and Quaternary rocks and sediments (?Upper Oligocene-Holocene)

As with any park or monument in the SODN, any rocks or sediments of Quaternary age may contain isolated remains of the Quaternary fauna, such as testudinids, equids, camelids, and proboscideans (R. McCord, Arizona Museum of Natural History paleontologist, pers. commun., May 2008). Additionally, the distribution of packrats (*Neotoma* spp.) suggests that ancient packrat middens could be present in crevices. Caves and karst, also sources for Quaternary fossils in Arizona, are not known at CHIR to date (National Park Service 2006). No fossils were reported by Drewes (1982), Du Bray and Pallister (1993), or Pallister and du Bray (1997) in the Tertiary or Quaternary rocks of the Cochise Head quadrangle and associated areas.

There are a number of sites in Cochise County where Tertiary or Quaternary fossils have been found. To date, these are almost all from the western half of the county (Lindsay and Tessman 1974; Lindsay 1978; Nations and Landye 1984; Agenbroad 1984; Lucas and Morgan 2005; Morgan and White 2005). The nearest well-documented material comes from the Willcox (Wilcox in some sources) gravel pit and playa deposits to the west, but clearly the potential is there. Willcox Playa, representing the deposits of Lake Cochise, is about 48 km (30 miles) to the west of CHIR and has yielded pollen and Ice Age body fossils of turtles (Moodie and Van Devender 1978), equids, camelids, and proboscideans (Schreiber 1978; Bezy 1998). Another nearby site is at Mustang Mountain, which is listed as having Pleistocene invertebrates by Nations and Landye (1984). Fossils may be included among cultural artifacts as well, as may be the case with the Faraway Ranch specimens.

Park Collections

CHIR specimens are held at the Western Archeological Conservation Center (WACC), per Danielle Foster (CHIR resource program manager, pers. commun., June 2008). A check of the WACC database by Anne Iverson in June 2008 found seven specimens from CHIR within this collection. These are described as "bric-a-brac" from Faraway Ranch with no additional locality information, and Foster did not know if they came from CHIR or not (pers. commun., June 2008). As there are no appropriate rock formations in the area of the ranch, it is unlikely that they were found *in situ* in the immediate vicinity. However, the nearest appropriate rocks are the Paleozoic exposures of the northeast side of the monument, which have been described as fossiliferous. The specimens are CHIR 721, described as a "small stone [with] fossil embedded. Found in CHIR 704. Crate" and CHIR 8164, a lot of six fossil "sea shell" pieces thought perhaps to be calcium carbonate (A. Iverson, pers. commun., June 2008). Source candidates in the vicinity include the Horquilla Limestone, Earp Formation, Colina/Epitaph, Scherrer Formation, Concha Limestone, Morita Formation, and the upper Lower Cretaceous Mural Limestone, a unit which has produced appropriate fossils (Lindberg 1987; Dickinson et al. 1989) and is exposed nearby but not within CHIR (Drewes 1982, Pallister and du Bray 1997). Information concerning the exact association of these fossils and the Faraway Ranch cultural resources is not available and is a topic for future investigation.

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division coordinated geologic scoping for CHIR during April 2006. The participants of the CHIR Geologic Scoping meeting developed a series of recommendations for future work. Several formations are represented by publications and geologic maps as being fossiliferous in CHIR, but have not had detailed study. WACC houses seven fossil specimens from the park, possibly from the northeastern portion of the monument. There is good potential for future fossil discovery within the park.
- The park should consider future field inventories for paleontological resources to more fully document in situ occurrences of fossils, particularly invertebrates in the northeastern portion of CHIR. The park may consider a formal site documentation and condition assessment for significant fossil localities. Monitoring of significant sites should be undertaken at least once a year in the future.
- A forthcoming (late 2008 or early 2009) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management and monitoring.
- Park staff should be encouraged to observe exposed sedimentary rocks and associated eroded 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 Western Archeology & Conservation Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Fossil packrat middens are typically found in dry rockshelters, and resemble piles or mounds of plant material with a dark glossy coating of crystallized packrat urine. Fossil middens can provide important paleoecological information. If one is located, there are several midden researchers in the Southwest who may be contacted. The GRD maintains a list of active researchers and can facilitate communication between the park and these researchers.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at CHIR.

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Coronado National Memorial

Coronado National Memorial (CORO) was established to commemorate the expedition of Francisco Vásquez de Coronado, which entered the Southwest in the vicinity in 1540. CORO was authorized as an International Memorial on August 18, 1941. It was redesignated on July 9, 1952, and established November 5, 1952. Its boundaries were changed September 2, 1960, and November 10, 1978. CORO today encompasses 1922.38 ha (4,750.22 acres), all but 0.81 ha (2 acres) of which are under Federal administration.

Geologic Background

CORO is located at the southeastern end of the Huachuca Mountains along the U.S.-Mexico border in southwestern Cochise County, Arizona. The southern San Pedro Valley and San Pedro River are found to the east. The underlying geology of CORO is complex, due to volcanic and tectonic activity. Most of the rocks in CORO pertain to Jurassic volcanic units and the Upper Jurassic-Lower Cretaceous Glance Conglomerate (see Figure 2 for geologic time scale). Folding, faulting, and metamorphism are common (Hayes and Raup 1968; Lipman and Hagstrum 1992; National Park Service 2006). CORO geology has been documented by Hon et al. (1994) and in a geologic scoping summary by the National Park Service's Geologic Resources Division (2006); these are internal National Park Service documents.

The geologic history of CORO and the surrounding area has been heavily influenced by Jurassic volcanism. Before the Jurassic, several Paleozoic formations were deposited in the vicinity as conditions fluctuated between terrestrial and marine. These include the Bolsa Quartzite (Middle Cambrian), Abrigo Formation (Upper Cambrian), Martin Limestone (early Upper Devonian), Escabrosa Limestone (Lower-Middle Mississippian), Horquilla Limestone (Upper Pennsylvanian to possibly Lower Permian), Earp Formation (possibly Upper Pennsylvanian to Lower Permian), Colina Limestone (Lower Permian), Epitaph Formation (Lower Permian), Scherrer Formation (Lower Permian), Concha Limestone (Lower-Middle Permian), and Rainvalley Formation (Middle Permian) (Hayes and Raup 1968). During the Jurassic, there were no fewer than three large volcanic eruptions that led to magma chamber collapses and caldera formation.

The oldest caldera, the Montezuma Caldera, erupted around 170 million years ago (Hon et al. 1994), and produced lava that is dacitic in composition (made up mostly of plagioclase feldspar; Lipman and Hagstrum 1992). This caldera and its collapse structures underlie most of CORO (Denny and Peacock 2000). Montezuma Caldera was followed by the rhyolitic lavas (made up mostly of quartz) of the Turkey Creek Caldera and the welded ash layer (called tuff) of the Parker Canyon Caldera (Lipman and Hagstrum 1992). These three large eruptions may have been related to the emplacement of a single batholith, or mass of underground igneous rock (Hon and Lipman 1994). Igneous intrusion followed the volcanic eruptions at around 168 million years ago (Lipman and Hagstrum 1992). Sedimentary deposition resumed after this burst of activity, with several Jurassic and Cretaceous units deposited as the seas returned and withdrew multiple times, and finally receded from the area for the last time (Glance Conglomerate, Morita Formation, Mural Limestone, Cintura Formation, and Fort Crittenden Formation). Igneous and tectonic activity resumed at the end of the Cretaceous and continued through the Tertiary, with the Jones Mesa volcanics followed by intrusions (Hayes and Raup 1968). Thrust faults displaced sections of rock by at least 1 to 2 km (0.6 to 1.2 miles) at the end of the Cretaceous and beginning of the Tertiary, accompanied by folding. Further large-scale faulting occurred in the Miocene (Davis et al. 1996). The Huachuca Mountains probably appeared around 15 to 10 million years ago (Hon et al. 1994). The late Tertiary through the present has seen the deposition of valley fills and alluvial fans (Hayes and Raup 1968).

The nature and extent of volcanism in the Huachuca Mountains was not fully described until the 1990s, so older maps such as Hayes and Raup (1968) have different terminology than would be used today for some rock units. From oldest to youngest, the following rock units are exposed at CORO: an

undetermined Naco Group limestone (deposited sometime between the Upper Pennsylvanian to Middle Permian); Huachuca Mountain volcanics (Jurassic, pertaining to the Montezuma Caldera per Lipman and Hagstrum 1992); rhyolite lava from the Canelo Hills Volcanics (Jurassic, pertaining to the Turkey Creek Caldera per Lipman and Hagstrum 1992); tuff from the Canelo Hills Volcanics (Jurassic, pertaining to the Parker Canyon Caldera per Lipman and Hagstrum 1992); Huachuca Quartz Monzonite (Jurassic, 168 million years ago per Lipman and Hagstrum 1992); the Bisbee Group's Glance Conglomerate (Upper Jurassic-Lower Cretaceous) and Morita Formation (upper Lower Cretaceous); Tertiary intrusive and extrusive igneous rocks; and Quaternary pediment, terrace, and fan gravels (Hayes and Raup 1968). Fossils are likely present in the Paleozoic rocks that make up Coronado Cave (National Park Service 2006), and Coronado Cave and other caves at CORO have potential for other fossil resources (Santucci et al. 2001). Formations that are known to produce fossils elsewhere include the Glance Conglomerate, Morita Formation, and Quaternary rocks, although metamorphism and tectonic activity have probably destroyed most pre-Quaternary fossils in the fault zones of CORO.

Sources of Paleontological Resources

Naco Group limestone (Upper Pennsylvanian to Middle Permian)

CORO has at least ten limestone/gypsum caves. These caves presumably have developed within the Naco Group limestone units, because the Naco Group is the primary source of limestone within CORO boundaries, although exposures are small and dispersed (Hayes and Raup 1968). The National Park Service geologic scoping summary (2006) reported features resembling algal stromatolites on limestone and dolomite in the vicinity of Coronado Cave. Stromatolites are not body fossils, but layered structures formed by algal colonies. Algal mats would passively trap sediment, which would block algal access to sunlight and nutrients, forcing the algae to grow over the sediment. This process would lead to the formation of roughly concentric layers of sediment as long as the algal colony continued to grow and trap sediment. Today, stromatolites are only found in hypersaline tidal settings, such as Shark Bay, Australia, where prevailing conditions keep out animals that could feed on the algae building them (McConnell 1975).

In addition to the possible stromatolites, Santucci et al (2001) suggested five CORO caves as potentially having paleontological significance: Fly Cave, No Name #1 (Road Cave), No Name #2 (Joe's Canyon Trail Cave), Hairpin Cave, and George's Tank Cave (although this report did not indicate if Paleozoic fossils or Quaternary fossils, or both, were of concern). Santucci et al. (2001) put forward the Colina Limestone (a member of the Naco Group) and Martin Formation (Upper Devonian) as potential limestone sources, but further work has shown that the Martin does not outcrop within CORO boundaries (National Park Service 2006). The caves, other than Coronado, had not been evaluated as of 2006 (National Park Service 2006).

The Naco Group has several formations with significant limestone beds; all of these units are also fossiliferous, preserving marine fossils. From oldest to youngest, they are the Horquilla Limestone (Upper Pennsylvanian-?Lower Permian), Earp Formation (?Upper Pennsylvanian-Lower Permian), Colina Limestone/Epitaph Formation (in part chemically altered Colina Limestone per Patch 1973 and Blakey and Knepp 1989; Lower Permian), Scherrer Formation (Lower Permian), Concha Limestone (Lower to Middle Permian), and Rainvalley Formation (Middle Permian) (Blakey and Knepp 1989). These beds were laid down between about 311 and 260 million years ago, and record the fluctuations of sea level during a time when southern Arizona was sometimes covered by a shallow sea (Blakey and Knepp 1989).

The limestone beds of the various Naco Group units preserve similar suites of marine fossils. Organisms known from the Horquilla Limestone include algae, fusulinid foraminifera (amoeba-like single-celled protists that form shells called tests), corals, bryozoans, brachiopods (Ross and Sabins 1965), mollusks, crinoids (Blakey and Knepp 1989), conodonts (eel-like extinct chordates; Johnson et al. 1986), and rare echinoids and fish (Williams 1954), along with burrows and algal layering in the limestone (Blakey and

Knepp 1989). Earp Formation fossils include fusulinid foraminifera, brachiopods, mollusks, and echinoids, along with burrows (Blakey and Knepp 1989). Typical Colina Limestone fossils include bryozoans, brachiopods, gastropods, pelecypods, and echinoids (Blakey and Knepp 1989). Just across the border in Sonora (Mexico), algae, trilobites, and conodonts have been documented in the Colina Limestone (Blodgett et al. 2002). The Epitaph Formation is less fossiliferous; Butler (1971) reported corals, brachiopods, gastropods, and echinoids. In the Scherrer Formation, the only abundant fossils belong to echinoids; "ghosts" of dissolved gastropod shells (Blakey and Knepp 1989), bryozoans, brachiopods, crinoids (Butler 1971), and burrows have also been found (Blodgett et al. 2002). The Concha Limestone has yielded fusulinid foraminifera, sponges, corals, bryozoans, brachiopods, gastropods, scaphopods, pelecypods, ammonoid cephalopods, crinoids, and echinoids (Bryant and McClymonds 1961). Finally, the Rainvalley Formation preserves sponges, corals, bryozoans, brachiopods, gastropods, pelecypods, cephalopods, crinoids, and echinoids (Butler 1971). Although stromatolites are not specifically mentioned in connection with any of these formations, stromatolites can be easily overlooked if the observer is unfamiliar with them, and the Horquilla Limestone does have reports of algal laminations (Blakey and Knepp 1989). Fossils were not reported by Hayes and Raup (1968) for Naco Group formations in the area of CORO and the southern Huachuca Mountains.

Potential Sources of Paleontological Resources

Glance Conglomerate (Upper Jurassic-Lower Cretaceous)

The Glance Conglomerate is a conglomerate of variable thickness and age, commonly incorporating Precambrian granite and schist, Paleozoic sedimentary rocks, and Jurassic igneous rocks, deposited as subaerial alluvial fans. This unit was long assumed to be Lower Cretaceous in total, but has datable volcanics from 150 million years ago (Dickinson et al. 1989). It does not have an *in situ* flora or fauna (Bilodeau 1978), but does include fossils from older units (Gilluly 1956), including Concha Limestone brachiopods (Lawton and Olmstead 1995). Given the surroundings at CORO, the Glance Conglomerate there is likely to be made up largely of igneous rock fragments. This unit is found throughout much of the western third of the memorial (Hayes and Raup 1968).

Morita Formation (upper Lower Cretaceous)

The Morita Formation is mostly made up of sandstone and mudstone, with limestone beds appearing toward the top. The lower portion of the formation shows terrestrial to marine influence, with deposition in river and delta environments. The upper portion has more of a marine influence, with lagoon and marginal marine deposition. It is not certain when deposition of the Morita Formation began, but deposition was over by the late Aptian, around 115 million years ago (Dickinson et al. 1989). Exposures at CORO are found in the northeast corner and in a strip running northwest-southeast through the center.

The Morita Formation is not known for its fossils and some sources have stated outright that it is unfossiliferous (Hayes and Drewes 1978; Bilodeau et al. 1987). Fossils are present, but uncommon and mostly found in the upper limestone beds (Gilluly 1956; Hayes 1970). It has also been part of a confusing stratigraphic issue. Stoyanow (1949) elected to designate the lower portion of the overlying Mural Limestone its own formation, the Lowell Formation, but did not indicate that he was also including a substantial amount of upper Morita Formation in the Lowell. This was noticed by Hayes and Landis (1961), who rejected the Lowell Formation. Their recommendation has been adopted, but older sources may misinterpret the extent of the Morita Formation. This is important because Stoyanow described fossils from the lower Lowell Formation; these fossils actually pertain to the upper Morita Formation, and include gastropods, pelecypods, ammonites, echinoids, worm traces, and wood (Stoyanow 1949). Other burrows and pelecypods are found lower in the formation, in the lagoonal mudstone beds, and some algal limestone is also present (Lindberg 1987). Jamison (1987) remarked that fossil wood is relatively abundant in the formation. No fossils were reported by Hayes and Raup (1968) for the Morita Formation in the area of CORO and the southern Huachuca Mountains. The fossils described by Stoyanow came from the Mule Mountains, in the area of Bisbee, about 32 km (20 miles) northeast of CORO. The fossils

described by Lindberg (1987) came from Rucker Canyon in the Chiricahua Mountains, about 90 km (55 miles) northeast of CORO.

Quaternary rocks and sediments (Pleistocene-Holocene)

Quaternary deposits are most common in the eastern third of CORO (Hayes and Raup 1968). As with any park or monument in the SODN, any rocks or sediments of Quaternary age may contain isolated remains of the Quaternary fauna, such as testudinids, equids, camelids, and proboscideans (R. McCord, Arizona Museum of Natural History paleontologist, pers. commun., May 2008). Additionally, the distribution of packrats (*Neotoma* spp.) suggests that ancient packrat middens could be present in crevices. Caves, important sources for Quaternary fossils in Arizona, are well known at CORO (Santucci et al. 2001; National Park Service 2006). No fossils were reported by Hayes and Raup (1968) in the Quaternary rocks of CORO and the southern Huachuca Mountains.

There are a number of sites in Cochise County where Quaternary fossils have been found. Several of them are in the immediate vicinity of CORO (Lindsay and Tessman 1974; Lindsay 1978; Agenbroad 1984; Lindsay 1984; Nations and Landye 1984; Lucas and Morgan 2005). Late Pleistocene sites known as Ash Canyon (University of Arizona Laboratory of Paleontology-6916) and Wakefield (UALP-6917) are about 2 to 3 km (1 or 2 miles) north of CORO borders, and preserve *Mammuthus* remains (Lindsay and Tessman 1974). Another site, the well-known Lehner ranch mammoth-kill site, is about 16 km (10 miles) northeast of CORO, near Hereford. This locality has yielded Clovis artifacts in association with remains of *Panthera atrox* (American lion), *Equus*, *Tapirus* (tapir), *Mammuthus*, and *Bison* from about 11,260 years before the present (Lindsay 1978; Lucas and Morgan 2005), as well as pollen (Mehringer and Haynes 1965). Bones of a juvenile mastodon were also found, below the Clovis level, from more than 30,000 years before the present (Mead et al. 1979). Two locations near the Lehner site, Hereford Dairy (UALP-44) and Hargis (UALP-6753), have *Equus* and *Bison* remains, respectively (Lindsay and Tessman 1974). Additionally, Cochise Culture sites are known in CORO (Stewart 1976). The presence of archeological sites in and near CORO presents the possibility of fossils associated with humans. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Park Collections

Danielle Foster (CORO resource program manager, pers. commun., May and June 2008) did not know of any paleontological resources in CORO collections, and a check of the Western Archeological Conservation Center (WACC) database by Anne Iverson in June 2008 did not find any specimens from CORO within this collection.

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division coordinated geologic scoping for CORO during April 2006. The participants of the CORO Geologic Scoping meeting developed a series of recommendations for future work. Stromatolite fossils have been tentatively identified from CORO and additional fossil material might be found within the park during future field investigations. Currently (October 2008) there are no fossil specimens within CORO museum collections.
- Caves within CORO may potentially preserve fossils in two contexts: as marine invertebrates in the bedrock (walls) of the cave (e.g. Naco Group limestones) and/or in Pleistocene-Holocene sediments. The former are contemporaneous with carbonate deposition. The latter represent organisms that lived within or were transported into the cave much later.
- The park should consider future field inventories for paleontological resources to more fully document *in situ* occurrences of fossils. The park may consider a formal site documentation and

condition assessment for significant fossil localities. Monitoring of significant sites should be undertaken at least once a year in the future.

- A forthcoming (late 2008 or early 2009) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management and monitoring.
- Park staff should be encouraged to observe sedimentary rock outcrops and loose Quaternary 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 Western Archeology & Conservation Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Fossil packrat middens are typically found in dry rockshelters, and resemble piles or mounds of plant material with a dark glossy coating of crystallized packrat urine. Fossil middens can provide important paleoecological information. If one is located, there are several midden researchers in the Southwest who may be contacted. The GRD maintains a list of active researchers and can facilitate communication between the park and these researchers.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at CORO.

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Fort Bowie National Historic Site

Fort Bowie National Historic Site (FOBO) was established July 29, 1972, with a boundary change after 1984. Fort Bowie was a center of United States military operations against the Chiricahua Apaches for more than 30 years in the second half of the 19th century. FOBO encompasses 404.47 ha (999.45 acres), all of which are under Federal administration. Legislation under consideration would add another 239 ha (590 acres) of BLM land to FOBO (National Park Service 2006); in the event of passage, this report may need to be updated with descriptions of rock formations currently outside of the historic site.

Geologic Background

FOBO is located in Cochise County, Arizona, at Apache Pass, in the southernmost Dos Cabezas Mountains. The main body of the Dos Cabezas Mountains are found to the northwest, and the Chiricahua Mountains are just southeast, with the San Simon Valley to the northeast and the Sulphur Springs Valley to the southwest. FOBO crosses the northwest trending Apache Pass Fault, which divides it into two groups of rocks. The western and central two-thirds to three-quarters of FOBO are underlain by Mesoproterozoic (see Figure 2 for a geologic time scale) igneous rock (granodiorite, a granite-like rock, dated to 1.375 billion years ago from samples found within FOBO; Drewes 1984, with boundary changes taken into account). East of the Apache Pass Fault, FOBO is underlain by folded and faulted outcrops of Paleozoic and Mesozoic sedimentary rocks. There is also some Quaternary gravel and sand (Drewes, 1984). FOBO has been the subject of a geologic report by the National Park Service (2006); this is an internal National Park Service document.

The geologic history of the area is complex, with multiple episodes of tectonic activity, folding, faulting, sea level changes, igneous intrusion, volcanism, and metamorphism. Precambrian time is represented by the Pinal Schist and igneous intrusions, and included a mountain-building event (Sabins 1957a). The Apache Pass Fault also dates to the Precambrian, with later reactivation (National Park Service 2006). Cambrian sandstones (Bolsa Quartzite) and Ordovician limestones (El Paso Formation or Limestone) were followed by more mountain building. Subsequent to this was the deposition of a series of formations under varying marine to terrestrial conditions from the Upper Devonian to the Middle Permian. Deposition was interrupted by another period of uplift (Sabins 1957a) that ended by the Upper Jurassic with the deposition of the Bisbee Group's Glance Conglomerate (long assumed to be Lower Cretaceous in total, but with datable volcanics at 150 million years ago; Dickinson et al. 1989). The Lower Cretaceous Bisbee units, like the earlier Naco Group, show marine-terrestrial alternation from sea level changes. Bisbee deposition was ended by another episode of uplift, including volcanism and more faulting. This episode ended before the Pliocene, and was followed by the Basin and Range tectonics and associated basin fill sediments that gave the area its present geography (Sabins 1957a).

The following rock units are exposed within FOBO boundaries: the unnamed Precambrian granodiorite; the Escabrosa Limestone (Lower-Middle Mississippian); the Naco Group's Horquilla Limestone (Upper Pennsylvanian-?Lower Permian), Earp Formation (?Upper Pennsylvanian-Lower Permian), Epitaph Formation (chemically altered Colina Limestone per Patch 1973 and Blakey and Knepp 1989), Colina Limestone, Scherrer Formation (all Lower Permian), and Concha Limestone (Lower to Middle Permian); the Bisbee Group's Glance Conglomerate (Upper Jurassic-Lower Cretaceous), Mural Limestone (upper Lower Cretaceous), and Cintura Formation (upper Lower Cretaceous-lower Upper Cretaceous); an unnamed Upper Cretaceous mixed sedimentary and volcanic unit; and Quaternary gravels, sand, and silt (Pleistocene and Holocene) (Drewes 1984).

Fossils have been reported from many of these units; the Escabrosa Limestone, Horquilla Limestone, Colina Limestone, Concha Limestone, and Mural Limestone are specifically described in Drewes (1984) as having fossils of various aquatic invertebrates within the 1:24,000 quadrangle that includes FOBO. On this 1984 map, Drewes plotted seven fossil localities in the Upper Horquilla that are within FOBO boundaries, establishing FOBO as a National Park Service unit with fossil resources. The fossils are

described as large fusulinid foraminifera (Drewes 1984). Foraminifera are amoeba-like single-celled protists that form shells called tests, fusulinids being a large extinct variety with macroscopic tests. These fossils were not recorded by the 2006 scoping report, but are easily overlooked, being roughly the shape and size of a grain of wheat.

Additionally, fossils have been reported from the Earp Formation in the Dos Cabezas-Chiricahua area (Sabins and Ross 1963; Ross and Tyrrell 1965). The Epitaph Formation (Butler 1971; Patch 1973), Scherrer Formation (Butler 1971; Blodgett et al. 2002), and Cintura Formation (Gilluly 1956; Lindberg 1978; Novak et al. 2004) also have reports of fossils, but from more distant locations, and the Glance Conglomerate has produced reworked fossils (Gilluly 1956; Lawton and Olmstead 1995). It should be noted, though, that most of the sedimentary units in the Apache Pass area have undergone medium-grade metamorphism in the course of various tectonic episodes (Drewes 1984), raising the possibility of destruction of fossils.

Sources of Paleontological Resources

Horquilla Limestone (Upper Pennsylvanian-?Lower Permian)

The Horquilla Limestone is dominated by limestones with interbedded mudstones. The limestones are interpreted as representing shallow marine to shoreline deposition, and the mudstones more terrestrial deposition. Mudstones increase toward the top, where the Horquilla Limestone grades into the Earp Formation. The Horquilla Limestone typically ranges in age from about 311 to 304 million years ago, from the Middle to Upper Pennsylvanian, although in areas of extreme southeastern Arizona and southwestern New Mexico it ends in the Lower Permian (Blakey and Knepp 1989). Fossils in the Horquilla Limestone are typically found toward the base and top of the formation, in the limestone beds (Ross 1973). Organisms known from the Horquilla Limestone include algae, fusulinid foraminifera, corals, bryozoans, brachiopods (Ross and Sabins 1965), mollusks, crinoids (Blakey and Knepp 1989), conodonts (eel-like extinct chordates; Johnson et al. 1986), and rare echinoids and fish (Williams 1954), along with burrows and algal layering in the limestone (Blakey and Knepp 1989). Depending on rock unit correlation, there may be cartilaginous fish known from the Horquilla Limestone (Pennsylvanian Naco Formation of Elliott et al. 2004 and Elliott and Blakey 2005), and root traces in non-limestone beds (Kenny and Neet 1993). The fusulinid foraminifera in the Horquilla Limestone are useful for dating, and show that there are 9 to 11 fusulinid zones in the formation, separated by periods without deposition interpreted as the result of sea level fluctuation (Ross 1978).

At FOBO, Drewes recorded seven localities in the upper Horquilla Limestone with large fusulinids, which he regarded as probably Permian in age. He also recorded small Pennsylvanian fusulinids in the lower Horquilla Limestone outside of FOBO, and additional upper Horquilla Limestone fusulinid sites (Drewes 1981, 1984). He described the upper Horquilla Limestone of the Bowie Mountain South quadrangle as preserving fusulinids, corals, bryozoans, and brachiopods, and the lower as preserving fusulinids, corals, and brachiopods (Drewes 1981). He reported both upper and lower as being fossiliferous and moderately recrystallized by metamorphism in the Bowie Mountain North quadrangle, where FOBO is located (Drewes 1984).

Potential Sources of Paleontological Resources

Escabrosa Limestone (Lower-Middle Mississippian)

The Escabrosa Limestone is a carbonate unit deposited under shallow marine conditions (Beus 1989; Elliott and Blakey 2005), between about 359 and 333 million years ago (Beus 1989). It is considered a group by some stratigraphers, notably Armstrong, who identified the lower Escabrosa Limestone as the Keating Formation and the upper Escabrosa Limestone as the Hachita Formation (Armstrong 1962, 1965; Armstrong et al. 1978). There is a break in deposition between the two formations or portions of the Escabrosa Limestone (Armstrong and Mamet 1978). Fossils are best known from the lower and upper

Keating Formation, and upper Hachita Formation (Armstrong 1962). The lower Keating Formation has produced foraminifera, corals, bryozoans, brachiopods, gastropods, trilobites, crinoids, and blastoids; the upper Keating Formation has produced foraminifera, corals, bryozoans, brachiopods, possible worms, and crinoids (Armstrong 1962); and the upper Hachita Formation has produced corals, bryozoans, and brachiopods (Armstrong 1965). Sponges, holothurians (sea cucumbers) (Langenheim and Epis 1957), and conodonts (Beus 1989) have also been reported from the Escabrosa Limestone. Drewes recorded the Escabrosa Limestone as a crinoid-rich limestone in the two Bowie Mountain quadrangles, recrystallized in the north quadrangle (Drewes 1981, 1984).

Earp Formation (?Upper Pennsylvanian-Lower Permian)

The Earp Formation is a heterogeneous rock unit with an arbitrary lower boundary with the Horquilla Limestone, defined as where clastic (rock fragment) beds begin to predominate over limestone beds. It typically ranges in age between about 304 million years ago and sometime around 280 million years ago, and is thought to represent a variety of environments from shallow marine to shoreline, estuarine, coastal plain, and river, as sea level fluctuated (Blakey and Knepp 1989). Fossils found in Earp Formation rocks in Arizona pertain to a "typical Pennsylvanian shallow marine fauna," particularly fusulinid foraminifera, brachiopods, mollusks, and echinoids, along with burrows (Blakey and Knepp 1989). Different fossils are known from more terrestrial Earp Formation beds in southwestern New Mexico, including plants, brachiopods, conchostracans (bivalve-like crustaceans), ostracodes, pelecypods, and the tracks of temnospondyl amphibians and early reptiles (Lucas and Hunt 1995). Drewes (1984) did not mention fossils in his description of the Earp Formation in the Bowie Mountain North quadrangle. However, fusulinids from the Earp Formation are known from the Dos Cabezas-Chiricahua area, and have been described by Sabins and Ross (1963) and Ross and Tyrrell (1965).

Epitaph Formation/Colina Limestone (Lower Permian)

The Epitaph Formation and Colina Limestone are regarded as two portions of the same unit, with the Epitaph in part having been chemically altered into dolomite, incorporating clastics and limestone toward its top (Sabins 1957b; Patch 1973; Blakey and Knepp 1989). Usually the Colina Limestone is represented as the lower "unit," but the structure of the Naco Group exposures in the Bowie Mountain North quadrangle is complex and may have been misinterpreted by Drewes (1984). The Earp Formation grades into the Colina/Epitaph, which in turn passes conformably into the overlying Scherrer Formation. The Colina/Epitaph ranges in age between sometime before 280 million years ago and sometime before 271 million years ago (Blakey and Knepp 1989).

The Colina Limestone is a relatively uniform limestone unit that is interpreted as a shallow marine shelf deposit, from subtidal to intertidal. Typical Colina Limestone fossils include bryozoans, brachiopods, pelecypods, gastropods, and echinoids (Blakey and Knepp 1989). Just across the border in Sonora (Mexico), algae, trilobites, and conodonts have been documented (Blodgett et al. 2002). The Epitaph Formation has an uncertain depositional setting for its non-dolomite beds (Blakey and Knepp 1989), and is less fossiliferous; Butler (1971) reported corals, brachiopods, gastropods, and echinoids. Drewes (1984) reported no fossils from the Epitaph Formation in the Bowie Mountain North quadrangle, but noted the presence of gastropods and echinoids in the Colina.

Scherrer Formation (Lower Permian)

The Scherrer Formation is a heterogeneous unit of sandstone and carbonate rock (limestone or dolomite) beds, possibly deposited under marginal marine to mudflat conditions. Its age is not well known, but it was deposited after the Colina/Epitaph and before about 271 million years ago. The only abundant fossils belong to echinoids; "ghosts" of dissolved gastropod shells (Blakey and Knepp 1989), bryozoans, brachiopods, crinoids (Butler 1971), and burrows have also been found (Blodgett et al. 2002). No fossils were reported by Drewes (1984) for the Scherrer Formation of the Bowie Mountain North quadrangle.

Concha Limestone (Lower-Middle Permian)
The Concha Limestone is a chert-rich fossiliferous limestone deposited under quiet open-water shelf conditions. It ranges in age from sometime before 271 million years ago to sometime before 260 million years ago (Blakey and Knepp 1989). It has a fossil assemblage including the remains of fusulinid foraminifera, sponges, corals, bryozoans, brachiopods, gastropods, scaphopods, pelecypods, ammonoid cephalopods, echinoids, and crinoids (Bryant and McClymonds 1961). A tooth and associated fin spine, both possibly from the petalodontid cartilaginous fish *Megactenopetalus*, have been reported from Concha Limestone rocks in Santa Cruz County (Hansen 1978; note though that the coordinates given actually lie just north of the border, in Coronado National Forest land in Pima County). Drewes (1984) noted the presence of brachiopods in the Concha Limestone of the Bowie Mountain North quadrangle.

Glance Conglomerate (Upper Jurassic-Lower Cretaceous)
The Glance Conglomerate is a conglomerate of variable thickness and age, commonly incorporating Precambrian granite and schist, Paleozoic sedimentary rocks (notably limestone), and Jurassic igneous rocks, deposited as subaerial alluvial fans (Dickinson et al 1989). It does not have an *in situ* flora or fauna (Bilodeau 1978), but does include fossils from older units (Gilluly 1956), including Concha Limestone brachiopods (Lawton and Olmstead 1995). Drewes (1984) did not report any fossils in the Glance Conglomerate of the Bowie Mountain North quadrangle, but did note the presence of Paleozoic rock fragments within this formation.

Mural Limestone (upper Lower Cretaceous)
The Mural Limestone was deposited under shallow marine conditions around 112 million years ago, in the time surrounding the Aptian-Albian stage boundary in the upper Lower Cretaceous. It is well known for its patch reefs, up to 10 m (33 ft) tall and made up of coral, stromatolites, and rudist bivalves (Dickinson et al. 1989). These reefs are found in the lower part of the upper half of the formation, and have been discussed in a number of publications; some good summaries are Scott 1979 and 1981, and Roybal 1981. Multiple depositional environments and associated fossils have been discovered from the reef layers. A typical set may include the following: a fore reef setting with mollusk debris; a reef front largely made up of coral with an associated fauna of algae, foraminifera, bryozoans, brachiopods, gastropods, pelecypods, ostracodes, and echinoids; a reef crest to reef flat of corals and stromatolites; and a reef flat to back reef of rudist bivalves (Roybal 1981). Beds lower in the Mural Limestone have produced algal fragments, foraminifera, gastropods, and pelecypods (Lindberg 1987), and there is one report of a possible marine reptile, from Sonora, Mexico (Novak et al. 2004). Drewes (1984) found the Mural Limestone of the Bowie Mountain North quadrangle to be locally fossiliferous, and marked the location of pelecypod-bearing rocks, including one locality less than 500 m (1,640 ft) from present FOBO boundaries.

Cintura Formation (upper Lower Cretaceous-lower Upper Cretaceous)
The Cintura Formation is made up of sandstones and mudstones, representing tidal deltas and other shoalwater deposits (Dickinson et al. 1989), and fluvial deposits (Lawton et al. 2004). It was laid down shortly before to just after the Lower Cretaceous/Upper Cretaceous boundary (99.6 million years ago) (Lucas and Heckert 2005). It has not produced many fossils to date. There are a few pelecypod-bearing limestone beds in the lower portion of the formation (Gilluly 1956), and some other marine fossils (Ransome 1904), and logs are known from mudstone layers (Lindberg 1987). Additionally, a possible dinosaur bone has been reported from the Cintura Formation of the Mule Mountains (Hayes 1970), and wood and a theropod dinosaur footprint from Cintura Formation localities in Sonora (Mexico; Novak et al. 2004). No fossils were reported by Drewes (1981, 1984) from the Cintura Formation of either the Bowie Mountain North or South quadrangles; he noted it as having been metamorphosed in the Apache Pass region (Drewes 1984).

Gila Conglomerate/Group (Miocene?-Pleistocene?)?
The Gila Conglomerate is not recorded as being present in FOBO (Drewes 1984), but a few nearby reports, including one of uncertain locality, make its inclusion useful. The Gila Conglomerate, also

known as Gila Formation or Group depending on the stratigrapher, is a generalized term for late Cenozoic basin fill found throughout east-central Arizona and western New Mexico (Heindl 1962; Morgan et al. 1997; Thrasher 2004). In the Mangas Basin, the age of the Gila Conglomerate ranges from about 21 million years ago (Lower Miocene) to at least 2.5 million years ago (Upper Pliocene) (Morgan and Sealey 1995), but is known to reach the Pleistocene in some locations (Morgan and Lucas 1993). Fossils are known from many locations in the Gila Conglomerate, typically in lacustrine or floodplain depositional environments (Knetchel 1936; Lindsay and Tessman 1974; Lindsay 1978; Nations and Landye 1984; Morgan and White 2005). The unit appears to be particularly productive in southern portions of Arizona's Graham and Greenlee counties (Nations and Landye, 1984; Morgan and White 2005), producing several well-studied faunas including the important 111 Ranch fauna. These faunas span the Blancan land mammal age, which lasted from about 4.75 to 1.806 million years ago. Common vertebrate constituents include turtles, snakes, birds, and a variety of mammals, including: glyptodonts; canids; badgers; bears; felids; rabbits; geomyid, heteromyid, and murid rodents; equids; peccaries; camelids; and gomphotherid proboscideans (Morgan and White 2005).

There is a specimen known as the "Bowie Mastodon" from an unknown location, excavated by Major L.F. Brady in the 1940s. It is a University of Arizona specimen on long-term loan to the Arizona Museum of Natural History, assigned to the genus *Pliomastodon*. Robert McCord (Arizona Museum of Natural History paleontologist, pers. commun., August 2008) has suggested that it is a Gila Conglomerate specimen, "associated broadly with the 111 beds." Additionally, camelid footprints are known in the Gila Conglomerate's Bowie zeolite deposits, just below the marker tuff layer, although these are distant at around 48 km (30 miles) north of FOBO in the San Simon Valley (Eyde 1982; Sheppard et al. 1987).

Quaternary rocks and sediments (Pleistocene-Holocene)

As with any park or monument in the SODN, any rocks or sediments of Quaternary age may contain isolated remains of the Quaternary fauna, such as testudinids, equids, camelids, and proboscideans (R. McCord, pers. commun., May 2008). Additionally, the distribution of packrats (*Neotoma* spp.) suggests that ancient packrat middens could be present in crevices. Caves and karst, also sources for Quaternary fossils in Arizona, are not known at FOBO to date. No fossils were reported by Drewes (1981, 1984) from the Quaternary rocks of either the Bowie Mountain North or South quadrangles.

There are a number of sites in Cochise County where Quaternary fossils have been found. To date, these are almost all from the western half of the county (Lindsay and Tessman 1974; Lindsay 1978; Nations and Landye 1984; Agenbroad 1984; Lucas and Morgan 2005), with the nearest well-documented material coming from the Willcox (Wilcox in some sources) gravel pit and playa deposits to the west, but clearly the potential is there. Willcox Playa, representing the deposits of Lake Cochise, is about 32 km (20 miles) to the west of FOBO and has yielded pollen and Ice Age body fossils of turtles (Moodie and Van Devender 1978), equids, camelids, and proboscideans (Schreiber 1978; Bezy 1998). Another nearby site is at Mustang Mountain, in the vicinity of Chiricahua National Monument; it is listed as having Pleistocene invertebrates by Nations and Landye (1984). Fossils may be included among cultural artifacts as well.

Park Collections

Danielle Foster (FOBO resource program manager, pers. commun., May and June 2008) did not know of any paleontological resources in FOBO collections, and a check of the Western Archeological Conservation Center (WACC) database by Anne Iverson in June 2008 did not find any specimens from FOBO within this collection.

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division coordinated geologic scoping for FOBO during April 2006. The participants of the FOBO Geologic Scoping meeting developed a series of recommendations for future work. The Horquilla Limestone is known to be fossiliferous in

FOBO, and several other formations may preserve marine invertebrate remains (albeit possibly metamorphosed) within FOBO. There is good potential for continued fossil discovery within the park. Currently (October 2008) there are no fossils within FOBO museum collections.

- The park should consider future field inventories for paleontological resources to more fully document *in situ* occurrences of fossils particularly in the eastern portion of FOBO. The park may consider a formal site documentation and condition assessment for significant fossil localities. Monitoring of significant sites should be undertaken at least once a year in the future.
- A forthcoming (late 2008 or early 2009) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management and monitoring.
- Park staff working east of the Apache Pass Fault should be encouraged to observe exposed bedrock and associated eroded 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 Western Archeology & Conservation Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Fossil packrat middens are typically found in dry rockshelters, and resemble piles or mounds of plant material with a dark glossy coating of crystallized packrat urine. Fossil middens can provide important paleoecological information. If one is located, there are several midden researchers in the Southwest who may be contacted. The GRD maintains a list of active researchers and can facilitate communication between the park and these researchers.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at FOBO.

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

Gila Cliff Dwellings National Monument

Gila Cliff Dwellings National Monument (GICL) was established to protect cliff dwellings that date from the 1270s to the early 1300s. These dwellings were built by the Mogollon people in alcove caves in the Gila Conglomerate. GICL was proclaimed November 16, 1907, and was transferred from the U.S. Forest Service to the National Park Service on August 10, 1933. Its boundaries were changed April 17, 1962, and the Forest Service resumed administration of the National Park Service area on April 28, 1975. In 2003, the National Park Service once again took over full administration of GICL. GICL encompasses 215.75 ha (533.13 acres), all of which are under Federal administration. The monument is split into two sections, and is completely surrounded by the Gila Wilderness of the Gila National Forest.

Geologic Background

GICL is located on the Gila River in southeastern Catron County, New Mexico, in the Mogollon-Datil Volcanic subprovince (Reid and Buffler 2004). The monument is about 16 km (10 miles) south of Black Mountain, north of the Pinos Altos Range, east of the Mogollon Range, and west of the Black Range. The underlying geology of GICL is a combination of Tertiary volcanic rocks and conglomerate (Ratté and Gaskill 1975). GICL geology has been documented in several reports (Gould 1937; Trauger 1963; U.S. Forest Service 1993; Ratté 1997, 1999, 2000), most recently in a geologic scoping summary by the National Park Service (2008); this is an internal National Park Service document.

The geologic history of GICL can be divided into four general stages, taking place over the last 28 or so million years (National Park Service 2008). At about 28 million years ago, in the middle Oligocene (see Figure 2 for a geologic time scale), two nearby volcanoes erupted, producing the Bloodgood Canyon Tuff and Bearwallow Mountain Andesite. These volcanoes collapsed and formed the Bursum and Gila Cliff Dwellings calderas. The next stage consisted of faulting associated with Basin and Range tectonic activity, which formed the Gila Hot Springs graben and promoted the deposition of the Gila Conglomerate. This was followed by Pleistocene (Ice Age) erosion that led to the formation of Cliff Dweller Canyon and the alcove caves that later housed the cliff dwellings; Ratté (2000) dated the initiation of alcove formation to about 500,000 years ago. Finally, groundwater circulated along the faults and produced geothermal minerals in the vicinity.

From oldest to youngest, the following rock units are exposed at GICL: the Bloodgood Canyon Rhyolite Tuff (middle Oligocene); the slightly younger Bearwallow Mountain Andesite lava flows; the Gila Conglomerate (also identified as Formation or Group; Miocene to Pleistocene); and Quaternary alluvium, gravels, and river deposits (Ratté and Gaskill 1975; National Park Service 2008). The Gila Conglomerate and Quaternary deposits are the only rocks in GICL with the potential for fossil resources. Fossils are documented within the Quaternary deposits in the form of packrat middens. (National Park Service 2008).

Sources of Paleontological Resources

Quaternary rocks and sediments (Pleistocene-Holocene)

The recent National Park Service geologic scoping summary (2008) has reported the presence of unstudied packrat (*Neotoma* spp.) middens in alcoves. These collections of plant material and food waste, cemented by viscous packrat urine, can be well-preserved in dry caves, and illustrate the environment of the builder's foraging range. Packrat middens are important tools for reconstructing the ecology and climate of the late Pleistocene and Holocene of the southwestern United States (Strickland et al. 2001). The presence of seven alcove caves at GICL (National Park Service 2008) raises the possibility of other cave fossils as well. Karst, another source for Quaternary fossils in New Mexico, is not known at GICL. Santucci et al. (2001) summarized fossils from National Park Service caves.

As with any park or monument in the SODN, any rocks or sediments of Quaternary age may contain isolated remains of the Quaternary fauna, such as testudinids, equids, camelids, and proboscideans (R. McCord, Arizona Museum of Natural History paleontologist, pers. commun., May 2008). For example, a partial skull of the horse *Equus conversidens* is known from Pleistocene-age terrace deposits near Lake Roberts in Gila National Forest, about 24 km (15 miles) southeast of GICL (Wolberg 1981). Finally, the cultural setting of GICL presents the possibility of fossils associated with humans. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Potential Sources of Paleontological Resources

Gila Conglomerate/Group (Miocene?-Pleistocene?)

The Gila Conglomerate, also known as Gila Formation or Group depending on the stratigrapher, is a generalized term for late Cenozoic basin fill found throughout east-central Arizona and western New Mexico (Heindl 1962; Morgan et al. 1997; Thrasher 2004). In the nearby Mangas Basin, the age of the Gila Conglomerate ranges from about 21 million years ago (Lower Miocene) to at least 2.5 million years ago (Upper Pliocene) (Morgan and Sealey 1995), but is known to reach the Pleistocene in some locations (Morgan and Lucas 1993). Fossils are known from many locations in the Gila Conglomerate, typically in lacustrine or floodplain depositional environments (Knetchel 1936; Lindsay and Tessman 1974; Lindsay 1978; Nations and Landye 1984; Morgan and White 2005). The unit appears to be particularly productive in southern portions of Arizona's Graham and Greenlee counties (Nations and Landye, 1984; Morgan and White 2005), producing several well-studied faunas including the important 111 Ranch fauna. These faunas span the Blancan land mammal age, which lasted from about 4.75 to 1.806 million years ago. Common vertebrate constituents include turtles, snakes, birds, and a variety of mammals, including: glyptodonts; canids; badgers; bears; felids; rabbits; geomyid, heteromyid, and murid rodents; equids; peccaries; camelids; and gomphotherid proboscideans (Morgan and White 2005).

At GICL, the Gila Conglomerate is made up of the fragments of volcanic rocks (Chronic 1987; Ratté 2000), and has not produced fossils. Sonya Berger (GICL chief of interpretation, pers. commun., May 2008), James Ratté (U.S. Geological Survey geologist emeritus, pers. commun., June 2008), and Steve Riley (GICL superintendent, pers. commun., May 2008) all reported an absence of fossils at GICL. If fossils are present in the Gila Conglomerate of GICL, it is unlikely that any large articulated specimens would be found; single pieces of sturdy refractory abraded bone or wood would be more likely.

The nearest documented Gila Conglomerate fossils come from two areas about 40 to 48 km (25 to 30 miles) south and southwest. These comprise the Walnut Canyon and Buckhorn local faunas (Morgan and Lucas 2003; Morgan and Sealey 1995, 1997; Morgan et al. 1997). The Walnut Canyon fauna has been found from four localities, and existed about 5.5 to 4.5 million years ago, in the Upper Miocene and Lower Pliocene. This fauna included rodents, rabbits, foxes, felids, two genera of equids, peccaries, three genera of camelids, cervids, and antelopes (Morgan et al. 2005). The Buckhorn Fauna is known from fourteen sites and existed between about 4.0 and 3.0 million years ago. This fauna was more diverse than the Walnut Canyon fauna, and included fish, frogs, salamanders, multiple species of colubrid snakes, two species of duck, turkeys, flamingos, rails, passeriforms, rabbits, ground squirrels, three genera of murids, felines, sabercats, badgers, bears, two genera of equids, peccaries, two genera of camelids, and gomphotherid proboscideans (Morgan et al. 2005). Additionally, Ratté has mentioned vertebrate fossils from the Gila Conglomerate near Pleasanton (pers. commun., June 2008), about 56 km (35 miles) west of GICL; this locality was not discussed in reviews by Morgan and Lucas (2003) and Morgan et al. (1997).

Park Collections

Both Sonya Berger and Steve Riley had no knowledge of any fossils in the museum collections (pers. communs., May 2008). Riley did mention a buffalo rib, but thought that it was probably too young to be classified as a paleontological resource.

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division coordinated geologic scoping for GICL during November 2007. The participants of the GICL Geologic Scoping meeting developed a series of recommendations for future work. Packrat middens within the park are a potential source of paleoecological research. There is little potential for macrofossil discovery within the bedrock of the park. Currently (October 2008), there are no fossils within GICL/WACC collections.
- Although the presence of *in situ* pre-Pleistocene fossils is unlikely, park staff should be encouraged to observe the Gila Conglomerate and river 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 Western Archeology & Conservation Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Fossil packrat middens are typically found in dry rockshelters, and resemble piles or mounds of plant material with a dark glossy coating of crystallized packrat urine. Fossil middens can provide important paleoecological information. If one is located, there are several midden researchers in the Southwest who may be contacted. The GRD maintains a list of active researchers and can facilitate communication between the park and these researchers.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at GICL.

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Data Sets

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

Montezuma Castle National Monument

Montezuma Castle National Monument (MOCA) was proclaimed December 8, 1906, to protect a well-preserved cliff dwelling built by the Sinagua people in the 12th and 13th centuries. It has since been expanded to include Montezuma Well, a large permanent spring. Its boundaries have been changed several times, on February 23, 1937, October 19, 1943, April 4, 1947, June 23, 1959, November 10, 1978, and December 19, 2003. Currently, MOCA encompasses 347.09 ha (857.69 acres), all but 6.81 ha (16.83 acres) of which are under Federal administration.

Geologic Background

MOCA is located in the south-central part of the Verde Valley in Yavapai County, Arizona. It is split into two units, Montezuma Castle and Montezuma Well, which are separated by about 6.5 km (4.0 miles). Beaver Creek drainage runs through both units on its way to the Verde River about 3.2 km (2.0 miles) south of Montezuma Castle. Montezuma Well is farther north and east than Montezuma Castle, and is somewhat smaller. Although both units are much larger than their titular components, for convenience the southwest unit will be referred to as Montezuma Castle, and the northeast unit as Montezuma Well. Montezuma Well is about 4.8 km (3.0 miles) north of Camp Verde, and Montezuma Well is about 1.6 km (1.0 miles) east of Rimrock. Both units are nearly surrounded by Coconino National Forest. The south edge of the Mogollon Rim is to the east and north, and Arizona's Black Hills are found to the west.

The geology and paleontology of MOCA have been described in several published reports (Lange 1957; Brady and Seff 1959; Hevly 1974; Shafer and Davis 1987, 1988; Davis and Shafer 1992; Blinn et al. 1994; Konieczki and Leake 1997), unpublished reports (McGeorge and Schur 1994), and internal National Park Service literature (Gould 1936, 1938; Schafer 1971; Batchelder and Cole 1978). Most recently, MOCA was the subject of a geologic resources scoping report by the Geological Resources Division of the National Park Service (2006); this is an internal National Park Service document.

The geologic history of the area is one of cycles of sea level change recorded by marine and terrestrial deposition in the Paleozoic. The Paleozoic is followed by a prolonged period of terrestrial exposure with little to no preserved deposition from the Mesozoic to the middle of the Cenozoic (see Figure 2 for a geologic time scale). This was followed by volcanism, tectonic activity, and the formation of the Verde Valley in the Miocene, and partial flooding of the basin due to damming of the Verde River by lava flows and faulting through the Pliocene. More recently, there has been tectonic stabilization and basin reorganization up to the present, after the dams were breached for the last time in the early Quaternary (Lehner 1962; Nations et al. 1981).

MOCA itself preserves only rocks from late Cenozoic and younger events. Most of the rocks of Montezuma Castle are limestone and other lake rocks of the Verde Formation (Middle Miocene-Pliocene), and Quaternary terrace gravel and alluvium from Beaver Creek. Most of the rocks at Montezuma Well are Verde Formation travertine and lake deposits, and Quaternary alluvium (Weir et al. 1989; DeWitt 2005). The Verde Formation and Quaternary deposits are known to be fossiliferous within MOCA boundaries (Brady and Seff 1959; Hevly 1974; Shafer and Davis 1987, 1988; Davis and Shafer 1992; Blinn et al. 1994; McGeorge and Schur 1994; Hunt et al. 2005b; National Park Service 2006), and other localities are as close as about 0.4 km (0.25 miles) (J. Gillette, Museum of Northern Arizona, associate collections manager, pers. commun., June 2008).

Additionally, MOCA is near several other fossiliferous formations. Montezuma Well, in particular, is only 1.6 km (1.0 miles) southwest of Permian rocks of the Hermit Formation less than 80 m (260 ft) higher in elevation, exposed along the course of Wet Beaver Creek and its tributaries (Weir et al. 1989; DeWitt 2005). Other formations are more remote; the Coconino Sandstone is about 5.0 km (3.0 miles) to the northeast of Montezuma Well and over 220 m (720 ft) higher. The most distant formation along the canyons leading to MOCA is the Kaibab Formation, about 6.5 km (4.0 miles) southeast of Montezuma

Well and 500 m (1,640 ft) higher. Given that active drainage passes through MOCA, there is the potential for rocks from these other formations to be transported into the monument. This is important because several of them are fossiliferous.

In order from oldest to youngest, potential sources of eroded rocks in the vicinity include the Hermit Formation (Lower Permian), Schnebly Hill Formation (Lower Permian), Coconino Sandstone (Lower Permian), Toroweap Formation (Lower Permian), Kaibab Formation (Lower-Middle Permian), and Hickey Formation (Miocene). To date, fossils are known from all of these formations except the Hickey Formation, although the Hickey Formation incorporates conglomerates that could have fragments of older fossil-bearing rocks. Given the steep topography, relative distance of some of these formations, extent of outcrops, and nature of fossils, the most likely sources for recognizable eroded fossils are the Schnebly Hill Formation, followed by the Toroweap Formation. These two formations both have marine invertebrate fossils (Blakey and Knepp 1989; Turner 1990), whereas the Hermit Formation preserves animal trackways and plant fossils (Mamay and Watt 1971; Hunt et al. 2005a), the Coconino Formation preserves only tracks (Middleton et al. 1990; Hunt et al. 2005a), and the Kaibab Formation has the smallest outcrops, is the most distant formation, and is at the highest elevation (Weir et al. 1989; DeWitt 2005).

Note that Weir et al. (1989), which is used as one of the base maps for the MOCA scoping summary, uses outdated stratigraphy concerning the Supai Formation. Ron Blakey proposed a revision (see Blakey and Knepp 1989 and Blakey 1990 for versions) incorporating recognition of different members in the Supai, and removal of several upper units. Thus, the lower member of the Supai Formation (per Weir et al. 1989) is divided into, in ascending order, the Watahomigi Formation, Manakacha Formation, Wescogame Formation, and Esplande Sandstone of the Supai Group. The middle member is reassigned to the Hermit Formation, and the upper member is reassigned to the Schnebly Hill Formation. This revision, while not accepted wholeheartedly at the time (Peirce 1989), appears to be in wide use today. The contributions to the 2005 New Mexico Museum of Natural History and Science bulletin on vertebrate paleontology of Arizona (although note that Blakey is a contributor) reflect this new interpretation. Another base map, DeWitt (2005), uses the newer nomenclature.

Sources of Paleontological Resources

Verde Formation (Middle Miocene-Pliocene)

The Verde Formation is a heterogeneous formation formed from a combination of tectonics, volcanism, and the action of the Verde River, with much of its deposition due to the river being tectonically dammed and turned into a lake (Nations et al. 1981). Its age is constrained by underlying volcanics from 14 million years ago (Royse and Wadell 1970), internal basalt flows of 8.3, 5.5, and 4.5 million years ago (Nations et al. 1981), mammal faunal ages, and paleomagnetic evidence (Czaplewski 1987). Deposition began in the Miocene with unfossiliferous clastic material leading to limestone, dolomite, and evaporites later in the Miocene, followed by mostly limestone deposition in the Pliocene; spring deposits, as at Montezuma Well, are also present. Miocene-age Verde Formation fossils are limited and mostly found in the southern Verde Basin, with diatoms in the lower Miocene beds, and algae, diatoms, plants, mollusks, ostracodes, amphibians, rodents, artiodactyls, and mammal tracks in the upper Miocene (Nations et al. 1981); these tracks include “Elephant Hill” at Montezuma Castle (Brady and Seff 1959; Nations and Landye 1984; McGeorge and Schur 1994; Hunt et al. 2005b). The Miocene organisms lived in a basin that was periodically flooded when the Verde River was cut off from external drainage.

By the Pliocene, the lack of evaporites indicates that the river, while still forming a shallow lake, had some external drainage to prevent concentration. Fossils from the Pliocene portion of the formation include algae, diatoms, various parts of a variety of vascular plants (herbs and sedges to gymnosperm and deciduous trees, many of which no longer live in Arizona), gastropods, fish, turtles, bats, rodents, rabbits, camelids, equids, and proboscideans (Nations et al. 1981).

Several Verde Formation fossil sites are known within or near MOCA boundaries. "Elephant Hill" in Montezuma Castle is the best-known site within MOCA. This locality is #33 in Twenter's 1962 survey of Verde Formation fossil sites. The fossils at "Elephant Hill" are large footprints from proboscideans (Hunt et al. 2005b), and tracks of camelids, tapirs, antelope-like artiodactyls, and other unidentified animals (McGeorge and Schur 1994). One such track is illustrated on the cover of this report. These tracks were first documented in the scientific literature in 1959 by Brady and Seff, although they were known previously. Myron Sutton, a Montezuma Castle ranger, made note of them in 1953 (Sutton 1953; Protas 2002); at the time, they were within Coconino National Forest, and were acquired by MOCA through a land transfer in the 10 November 1978 boundary change (Protas 2002). They have been covered several times with soil to protect them, and are currently buried (Protas 2002). "Elephant Hill" may be conflated in references with another track locality. This locality, Twenter's #25, is about 10 km (6 miles) northwest of Montezuma Castle in Bee Canyon near Oak Creek, and was described by Nininger in 1941. Most of these tracks were purchased by the American Museum of Natural History (Protas 2002). Trackmakers here included felids, ursids, and camelids (Brady and Seff 1959).

The Museum of Northern Arizona has two locality numbers assigned to Verde Formation fossil sites within or directly adjacent to MOCA, and two others in the near vicinity. MNA 239-0 includes land within and near both units, and has produced plant (MNA.P.720) and gastropod fossils (MNA.N.6954). MNA 295-0 was established for the area of Montezuma Well, and has produced plant (MNA.P.714, 715, 716, 717, and 718), gastropod (MNA.N.7698), and fish fossils (MNA.V.1759). MNA 700-1, in Red Tank Draw about 0.4 km (0.25 miles) east of Montezuma Well, has produced a camel ankle bone (MNA.V.4989). Finally, MNA 699-1, about 4.0 km (2.5 miles) northeast of Montezuma Well at Sacred Mountain, has produced fossils from unidentified vertebrates (MNA.V.4987), cricetid rodents (MNA.V.4986), equids (MNA.V.4985), and proboscideans (MNA.V.4988) (J. Gillette, pers. commun., June 2008). Sacred Mountain is also Twenter's #29, and he mentions that invertebrate fossils are present as well (Twenter 1962).

There are several other Verde Formation or possible Verde Formation fossil sites within about 3.2 km (2.0 miles) of one of the two MOCA units (Twenter 1962). Twenter's #27, about 3.2 km (2.0 miles) northwest of Montezuma Well between Hog Canyon and Interstate 17, has produced plants, gastropods, and pelecypods. Twenter's #28, about 3.2 km (2.0 miles) north of Montezuma Well atop a butte west of Beaver Creek Road, has produced algal fruiting bodies, ostracodes, and gastropods. Twenter's #30 and #31 are both a little over 1.6 km (1.0 miles) northeast of Montezuma Well in Red Tank Draw. #30 has produced plant hash and pelecypods, and #31 has produced plant hash, gastropods, and pelecypods. Twenter's #32 is about 1.0 km (0.62 miles) north of Montezuma Castle at a road cut, and has produced shells. Finally, Twenter's #34 is about 1.5 km (0.95 miles) west of Montezuma Castle in a wash between West Middle Verde Road and Interstate 17, and has produced plants and invertebrates, especially gastropods. Sites #30, #31, #32, and #34 may be younger than the Verde Formation (Twenter 1962).

Quaternary rocks and sediments (Pleistocene-Holocene)

The Quaternary lake deposits of Montezuma Well are fossiliferous, and these fossils have been the subject of several reports (Hevly 1974; Shafer and Davis 1987, 1988; Davis and Shafer 1992; Blinn et al. 1994). The two most extensive publications to date are Davis and Shafer (1992), primarily on pollen, and Blinn et al. (1994), on diatoms (a type of phytoplankton that secretes a cell wall made of silica). Both reports made use of an 11.25 meter-long (36.91 ft) core from the north-central part of the lake that covers at least the last 12,000 years. Davis and Shafer (1992) also incorporated plant macrofossils (to provide radiocarbon dates), and mentioned the presence of macrofossils from aquatic organisms, including gastropods. From their work, it appears that the area changed from a pinyon and juniper woodland to a steppe and desertscrub setting in the middle Holocene (9,000-6,000 years ago), and there were several rapid climate fluctuations (Davis and Shafer 1992). Blinn et al. (1994) found evidence that the lake had been very low or dry at several times in the middle Holocene, and that there may have been a period of wall collapses or other alterations to the geography of the lake about 4,000 to 2,000 years ago. The Sinagua people may have been present during a moderately dry period that occurred about 1,200 to 600 years ago. The wood

and invertebrate macrofossils are in storage at the University of Arizona, but no curatable material remains from the palynomorphs (O. Davis, University of Arizona Department of Geosciences professor, pers. commun., July 2008).

In addition to the Montezuma Well lake fossils, there are scattered reports of bones, including human bones, desiccated carcasses, and bone and shell artifacts in the ruins (Gould 1936; Protas 2002), although much material from Verde Valley archeological sites was lost in the 1860s (the collections of Edward Palmer) or, in the case of the collections of Dr. Edgar A. Means from between 1884 and 1888, sent to the Army Medical Museum (human remains; now the National Museum of Health and Medicine) or the American Museum of Natural History (artifacts) (Protas 2002). See Kenworthy and Santucci (2006) for an overview of National Park Service fossils found in cultural resource contexts.

As with any park or monument in the SODN, any rocks or sediments of Quaternary age may contain isolated remains of the Quaternary fauna, such as testudinids, equids, camelids, and proboscideans (R. McCord, Arizona Museum of Natural History paleontologist, pers. commun., May 2008). Additionally, the distribution of packrats (*Neotoma* spp.) suggests that ancient packrat middens could be present in caves or crevices. Caves and karst, in the Verde Formation, are well-known at MOCA; Montezuma Well is a sinkhole, and the archeological sites are located in alcove caves (National Park Service 2006, although this report implies that caves may also be formed in Redwall Limestone within MOCA; the Redwall Limestone is not exposed in MOCA, and is not exposed within 5 km [3 miles] per Weir et al. 1989 and DeWitt 2005). See Santucci et al. (2001) for a discussion of paleontological resources associated with National Park Service caves.

There is little known about the Quaternary paleontology of Yavapai County and surrounding areas (Lindsay and Tessman 1974; Nations and Landye 1984; Agenbroad 1984; Lucas and Morgan 2005). Nations and Landye (1984) assign Pleistocene remains to Buckboard Wash, over 22 km (14 miles) northwest in the valley, but this is not followed by other reports (Lindsay and Tessman 1974; Nations 1974; Nations et al. 1981; Agenbroad 1984; Lucas and Morgan 2005), and may just be a case of mistaken or reassessed age. Aside from the Montezuma Well finds, and this equivocal report, there appears to be only one other documented Quaternary locality in all of Yavapai County, over 58 km (36 miles) southwest of the Verde Valley at Black Mountain (Lindsay and Tessman 1974; Nations and Landye 1984; Lucas and Morgan 2005). This site, MNA 190, has produced remains of *Mammuthus* (Lindsay and Tessman 1974).

Potential Sources of Paleontological Resources

Hermit Formation (Lower Permian)

The Hermit Formation (or Shale), deposited between 300 million years ago and sometime before 275 million years ago depending on location, is mostly mudstone and siltstone red beds interpreted as a fluvial system (Blakey 1990). It is known for plant fossils (Mamay and Watt 1971) and tetrapod tracks. Trackmakers include temnospondyl amphibians, early reptiles, and pelycosaur synapsids (mammal-like reptiles) (Hunt et al. 2005a).

The Hermit Formation is identified as the Hermit Shale by DeWitt (2005). In Weir et al. 1989, it corresponds to the middle part of the Supai Formation. The nearest exposures are in the canyonland northeast of Montezuma Well, about 1.6 km (1.0 miles) away and 80 m (260 ft) higher in elevation. Weir et al. (1989) and DeWitt (2005) do not mention if any fossils were found in their mapping of this unit.

Schnebly Hill Formation (Lower Permian)

The Schnebly Hill Formation, deposited between 280 and 275 million years ago, is a heterogeneous rock unit of sandstone, siltstone, mudstone, evaporites, limestone, and dolomite, interpreted as a basin rimmed by wind-blown sand deposits. This unit is divided into six members; the third from the top, the Fort Apache Member, is a fossiliferous unit of limestone, dolomite, evaporites, and siltstone (Blakey 1990), probably from a shallow marine shelf and shoreline setting (Blakey and Knepp 1989). Fort Apache

Member fossils are mostly marine invertebrates, particularly mollusks and echinoderms, and come from the limestone and dolomite layers. Organisms represented include algae, foraminifera, corals, bryozoans, brachiopods, worm-like animals, gastropods, pelecypods, scaphopods, cephalopods, ostracodes, trilobites, and echinoids (Gerrard 1969; the worms are known only from trace fossils); tetrapods are represented by a single track from the possible pelycosaur *Dimetropus* (Hunt et al. 2005a).

The Schnebly Hill Formation is identified as such by DeWitt (2005). In Weir et al. 1989, it is identified as the upper part of the Supai Formation, and is mapped with the middle part (=Hermit Formation) as undivided in the area of MOCA. Its nearest exposures are about 4.5 km (2.8 miles) northeast of Montezuma Well, above exposures of the Hermit Formation. Weir et al. (1989) mention sparse fossils in this unit, mostly abraded mollusks, while DeWitt (2005) does not mention if any fossils were found in his mapping of this unit.

Coconino Sandstone (Lower Permian)

The Coconino Sandstone, deposited about 275 million years ago, is a dune sandstone, deposited by wind action (Blakey and Knepp 1989). It is known for its tetrapod tracks, long assigned to a variety of trackmakers but probably from only three ichnospecies pertaining to *Chelichus*, thought to be a synapsid (McKeever and Haubold 1996; Hunt et al. 2005a). Invertebrate traces are also known, including possible worms, millipedes, isopods, spiders, and scorpions (Middleton et al. 1990).

The Coconino Sandstone and Toroweap Formation are mapped together as undivided in the area of MOCA by both DeWitt (2005) and Weir et al. (1989). Its nearest exposures are about 5.0 km (3.0 miles) to the northeast of Montezuma Well and over 220 m (720 ft) higher in elevation. Weir et al. (1989) and DeWitt (2005) do not mention if any fossils were found in their mapping of this unit.

Toroweap Formation (Lower Permian)

The Toroweap Formation, deposited between about 275 and 270 million years ago, is largely limestone, with sandstone, mudstone, evaporites, and dolomite. It is interpreted as a marine shelf to coastal salt flat environment of deposition; it is fossiliferous, though lacking in fossils useful for dating (Blakey and Knepp 1989). Fossils include sponges (Rigby 1988), corals, bryozoans, brachiopods, gastropods, pelecypods, cephalopods, scaphopods, crinoids (Turner 1990), and possible fish plates (Hunt et al. 2005a); there are two distinct assortments, one dominated by mollusks, and one interpreted as open marine, hosting the coral-bryozoan-brachiopod-crinoid fauna (Turner 1990).

The Toroweap Formation, as mentioned above, is mapped with the older Coconino Sandstone as undivided in the area of MOCA by both DeWitt (2005) and Weir et al. (1989), making its nearest exposures somewhat more than about 5.0 km (3.0 miles) to the northeast of Montezuma Well and over 220 m (720 ft) higher in elevation. Weir et al. (1989) and DeWitt (2005) do not mention if any fossils were found in their mapping of this unit.

Kaibab Formation (Lower-Middle Permian)

The Kaibab Formation, deposited about 270 million years ago, is a heterogeneous formation composed mostly of limestone and dolomite, formed in a variety of settings from shallow marine to salt flat to coastal plain (Blakey and Knepp 1989). It has abundant fossils of marine invertebrates, including sponges, foraminifera, corals, bryozoans, brachiopods, gastropods, pelecypods, scaphopods, cephalopods, trilobites, ostracodes, crinoids, and conodonts. As with the Toroweap Formation, there are distinct mollusk and open marine faunas (Hopkins 1990). Additionally, there are a few reports of chondrichthyan and phyllodont fish teeth and tooth plates (Hunt et al. 2005a).

The Kaibab Formation is relatively remote from the MOCA units, with its nearest exposures about 6.5 km (4.0 miles) southeast of Montezuma Well and 500 m (1,640 ft) higher (Weir et al. 1989; DeWitt 2005). These exposures are not as extensive as the exposures of the other formations, and given the elevation difference between them and Montezuma Well, their fossils would also be subject to the most hazardous

travel of the formations mentioned in this section. Weir et al. (1989) mention the presence of a brachiopod-rich bed in the Kaibab Formation in the southern part of their mapping area; DeWitt (2005) does not mention if any fossils were found in his mapping of this unit.

Hickey Formation (Miocene)

The Hickey Formation is a heterogeneous rock unit of sedimentary and volcanic rocks. The base is composed of two units. The lower is well-consolidated and in large part a conglomerate of Paleozoic rock fragments, and the upper is largely a conglomerate of Precambrian rock fragments and Tertiary volcanic rock fragments. A fragment of basalt from this section has been dated to 15.7 ± 1 million years ago, and overlying basalt lava flows are dated to 13.6 million years ago (Sanders and Nations 1989), establishing the end of sedimentary deposition at around 14 million years ago. The beginning, though, is not known. Basalt flows above continued until about 10.1 million years ago. Fossils have not been reported from the Hickey Formation to date (Sanders and Nations 1989), but because it incorporates Paleozoic rocks, reworked fossils may be present.

The nearest exposures of Hickey Formation sedimentary rocks are about 2.0 km (1.2 miles) northeast of Montezuma Well. Weir et al. (1989) and DeWitt (2005) do not mention if any fossils were found in their mapping of this unit.

Park Collections

Dennis Casper (MOCA resource program manager, pers. commun., May 2008) did not know of any paleontological resources in MOCA collections.

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division coordinated geologic scoping for MOCA during May 2006. The participants of the MOCA Geologic Scoping meeting developed a series of recommendations for future work. The Verde Formation that underlies most of MOCA and the Quaternary lake deposits in Montezuma Well have known fossil localities. Additionally, eroded fossils from nearby Paleozoic formations may be transported into the monument by Beaver Creek waterways.
- Because there are Museum of Northern Arizona localities for the Verde Formation at or near MOCA, it may be worthwhile to make arrangements with the MNA to investigate the old finds.
- Park staff should be encouraged to observe exposed bedrock, old river deposits, and the modern river drainage 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.
- Development of a funding proposal to support an evaluation, condition assessment, documentation, and stabilization of the "Elephant Hill" site could provide for long-term preservation of the site and lead to a monitoring strategy for the fossil track locality.
- A forthcoming (late 2008 or early 2009) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management and monitoring.
- 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 Western Archeology & Conservation Center and the Geologic Resources Division can coordinate additional documentation/research of such material.

- Fossil packrat middens are typically found in dry rockshelters, and resemble piles or mounds of plant material with a dark glossy coating of crystallized packrat urine. Fossil middens can provide important paleoecological information. If one is located, there are several midden researchers in the Southwest who may be contacted. The GRD maintains a list of active researchers and can facilitate communication between the park and these researchers.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at MOCA.

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Organ Pipe Cactus National Monument

Organ Pipe Cactus National Monument (ORPI) was established to protect unique plants and animals of the Sonoran Desert, most prominently the Organ Pipe Cactus (*Stenocereus thurberi*) that gives the monument its name. ORPI was proclaimed a national monument on April 13, 1937, and was designated a Biosphere Reserve in 1976. A wilderness area was designated within ORPI on November 10, 1978. ORPI encompasses 133,822.53 ha (330,688.86 acres), of which 133,286.91 ha (329,365.29 acres) are under Federal administration. Designated wilderness area in the monument totals 126,502 ha (312,600 acres).

Geologic Background

ORPI occupies a large part of western Pima County. It is bordered on the east by the Tohono O'odham Nation, and on the south by Mexico. The Cabeza Prieta National Wildlife Refuge borders ORPI to the west and part of the north; BLM land also borders ORPI to the north. There are several small mountain ranges in the area. The Ajo Range, including Montezuma's Head, forms much of the eastern border of ORPI. The Sierra de Santa Rosa Mountains are found in the southeastern corner of the monument. In central ORPI, from north to south, are the Bates Mountains, Cipriano Hills, Puerto Blanco Mountains, and Sonoyta Mountains. Between the eastern and central ranges are the Valley of the Ajo in the north, and Sonoyta Valley in the south. In west ORPI, the Growler Mountains end in the north, and the Quitobaquito Hills are found in ORPI's southwestern corner. Growler Valley takes up most of northwestern ORPI, and La Abra Plain is ringed, clockwise from the west, by the Quitobaquito Hills, Cipriano Hills, Puerto Blanco Mountains, and Sonoyta Mountains.

The geology of ORPI is not known as completely as that of other Sonoran Desert parks and monuments, as it is a large, remote monument on an international border that at times has been unsafe for fieldwork and mapping. However, its varied geology has attracted interest, and the area is known for its igneous, metamorphic, and tectonic features. Despite its relative lack of undeformed sedimentary units that would be candidates for fossils, ORPI is also a prominent location for the study of fossil packrat middens. The geology of ORPI has been described in the professional literature (May et al. 1981; Morrison 1984a, b; Brown 1992; Anderson and Campbell 1994; Pohl 1995; Dembosky et al. 1996, 1999; Liu et al. 1996a, b; Bezy et al. 2000; McAuliffe and McDonald 2006), theses and dissertations (Jones 1974; Oliver 1984; Simpson 1991; Dembosky 2001), and internal National Park Service documents (Gould 1938; Maxwell 1940; Hunt 1972; Eddy 1983). Its packrat middens have been described internally (Warren 1976; Van Devender 1984, 1985; Davis and Anderson 1986; Hall et al. 1986; Hall and Van Devender 1987) and in external publications (Van Devender 1977, 1982, 1987, 1988, 1990; Mead et al. (1983); Spaulding 1983; Davis and Anderson 1987, 1988; Hall et al. 1989, 1990; Davis 1990; Van Devender et al. 1990, 1991) as well. The most recent internal document concerning the geology of ORPI is a geologic resources scoping report by the Geological Resources Division of the National Park Service (2006).

Much of the geologic history of the ORPI area has been obscured by volcanism, metamorphism, and tectonics. Granites and metamorphics from the Lower Proterozoic (2.5-1.6 billion years ago; see Figure 2 for a geologic time scale) are present in the Quitobaquito Hills. Paleozoic-age rocks are almost completely absent. There may be isolated metamorphosed remnants of the Bolsa Quartzite (Middle Cambrian), Abrigo Formation (Middle-Upper Cambrian), Martin Formation (Upper Devonian), and Escabrosa Limestone (Lower-Middle Mississippian) in the area north of Growler Pass in the northwest corner of ORPI (Bezy et al. 2000); these rocks represent deposition under conditions fluctuating from marine to terrestrial. Widespread volcanism and other igneous activity is recorded through the Jurassic, particularly in the Quitobaquito Hills and Puerto Blanco Mountains (Bezy et al. 2000). The central Puerto Blancos are made up of metamorphosed Mesozoic rocks, and the southern Puerto Blancos are made of Mesozoic granites (Chronic 1983). Thrust faulting in the Quitobaquito Hills may have been active in the Upper Jurassic or Cretaceous (May et al. 1981; Anderson and Campbell 1994). The Quitobaquito Thrust may be related to a postulated giant strike-slip fault called the Mojave-Sonora Megashear (Anderson and Campbell 1994) that may have run through the Lukeville area in south ORPI (Shafiqullah et al. 1980).

Jurassic igneous rocks are topped by a metamorphosed conglomerate in the Growler Pass area (Bezy et al. 2000).

The Upper Cretaceous and Early Tertiary of the ORPI area, as with most of the West, exhibit the influence of the Laramide Orogeny (mountain building event, associated with the formation of the Rocky Mountains) and related tectonic and igneous events (Shafiqullah et al. 1980; Haxel et al. 1981). In the ORPI area, volcanic eruptions and intrusions of igneous bodies occurred from about 65 to 55 million years ago, and are found in the Quitobaquito Hills and Sonoyta Mountains (Bezy et al. 2000). A mid-Tertiary orogeny is associated with the Ajo volcanic field that left another layer of lava flows over the area, with units in the Ajo Range dated to 17.4 to 15.4 million years ago. Basin and Range faulting at that time and for a period thereafter sculpted ORPI into its present configuration of mountains and valleys, decreasing in activity around 8 million years ago (Shafiqullah et al. 1980). At various points during the orogeny and faulting, coarse sedimentary units were deposited in the area, including the Locomotive Fanglomerate before 25 million years ago, and the Daniels Conglomerate before 15 million years ago (Nations et al. 1982). A final round of volcanism in the last few million years left behind basalt lava and a variety of volcanic geographic features (Bezy et al. 2000). The Bates Mountains and other features of the area show evidence of this, as flat-topped mesas capped with recent basalts (Chronic 1983). In the last few thousand years, as the glaciers receded, local climate and biota transitioned from a cooler, wetter regime before 9,000 years ago, to hotter but still wetter conditions until about 4,000 years ago, to the modern climate with few winter freezes and less precipitation (Van Devender 1990).

The geologic formations in ORPI and immediate vicinity include the following, in approximate order from oldest to youngest: the Pinal Schist (Proterozoic); Proterozoic gneiss and monzogranite; metamorphosed sandstone, shale, and siltstone that may be derived from the Bolsa Quartzite (Middle Cambrian) and Abrigo Formation (Middle-Upper Cambrian); metamorphosed carbonate rocks that may have derived from the Martin Formation (Upper Devonian) and Escabrosa Limestone (Lower-Middle Mississippian) (per the 2006 National Park Service scoping report, both formations are known from just north of ORPI and Growler Pass, near Scarface Mountain); Jurassic intrusive and metamorphic rocks; a variety of volcanic, intrusive igneous, metamorphic, and coarse sedimentary rocks originally formed sometime between the Jurassic and early Tertiary; the granite of Schuchuli (Lower Miocene, 23 million years ago); the rhyolite of Pinkley Peak, including some sedimentary rocks (Lower Miocene, 22-18 million years ago); the Childs Latite (Lower Miocene, 18.4 million years ago); the monzogranite of Siovi Shuatak Wash (Lower Miocene); the Daniels Conglomerate (Lower Miocene, 18.4 million years ago base); the rhyolite of the Growler Mountains (Lower Miocene); the rhyolite of Montezuma's Head (Lower-Middle Miocene, 17.5-16.0 million years ago); the Batamote Andesite, including some basalt flows and sedimentary breccias (Middle Miocene, 16.4-14.0 million years ago); Upper Tertiary terrace gravels; Upper Tertiary-Quaternary basalts; and Quaternary gravel and sand (Gray et al. 1985; Tosdal et al. 1986; Eddy et al. 1988; Beikman et al. 1995; Bezy et al. 2000). ORPI rocks older than the Miocene are often metamorphosed, which limits their usefulness for accurate age-dating.

Fossils are known at ORPI from reworked rocks in an undesignated Tertiary conglomerate (Daniels Conglomerate?), and from Quaternary deposits, particularly Quaternary packrat middens. Several other formations that outcrop in the area are known to be fossiliferous elsewhere, but due to metamorphism and small exposures within ORPI, may not have fossils. These include the Bolsa Quartzite, the Abrigo Formation, the Martin Formation, and the Escabrosa Limestone. Additionally, because of the relative lack of attention paid to the sedimentary and partially metamorphosed sedimentary rocks of ORPI, in comparison to its other geologic features, there is much that is still to be investigated.

Sources of Paleontological Resources

Unidentified Tertiary conglomerate (?Daniels Conglomerate [Lower Miocene])

The National Park Service geologic scoping report (2006) mentions that fossils of marine invertebrates (brachiopods, shells, and crinoid stems) are known from an unspecified Tertiary conglomerate within

ORPI boundaries, and are likely to be reworked from Paleozoic rocks. Peter Holm (ORPI resource program manager, pers. commun., May and September 2008) reports that these specimens came from along the west boundary of the monument, in a closed area. Several conglomeratic units are known from the Tertiary of ORPI, with the Daniels Conglomerate being the only one named to date. It is a pebbly conglomerate to pebbly sandstone with associated lake deposits (Gilluly 1946; Eddy et al. 1988), deposited between 18.4 million years ago (Eddy et al. 1988) and 15 million years ago (Nations et al. 1982). Gilluly (1946) reported no fossils in the Daniel Conglomerate in the Ajo district north of ORPI.

Quaternary packrat middens (Pleistocene-Holocene)

To date, fossil packrat middens are the most common, best studied, and most important fossil resources of ORPI. These collections of plant material and food waste, constructed by packrats (*Neotoma* spp.) and cemented by their viscous urine, can be well-preserved in dry caves, and illustrate the environment of the builder's foraging range. Packrat middens are important tools for reconstructing the ecology and climate of the late Pleistocene and Holocene of the southwestern United States (Strickland et al. 2001). Van Devender (1990) is probably the most extensive published survey of Sonoran middens, but many other publications have documented these middens. Additionally, the online U.S. Geological Survey/National Oceanic and Atmospheric Administration Packrat Midden Database (http://esp.cr.usgs.gov/data/midden/) provides extensive documentation on packrat middens, including coordinates, elevation, radiocarbon (C-14) ages, key publications, and lists of plants found in a given midden, although it does not list vertebrates or invertebrates. Note that papers dealing with fossils dated by radiocarbon typically use "radiocarbon years before present" (yr BP) or a similar formulation, and that 1950 is used as "Year Zero." Radiocarbon years before present do not correspond to calendar years, and unless the dates are labeled as "calendar years," radiocarbon dates require calibration to yield calendar years.

East-central ORPI, in the Ajo Range and the Puerto Blanco Mountains, is an important location for fossil packrat midden studies in the southwestern United States. Eleven middens have been studied from the Ajo Range (seven from Alamo Canyon and four from Montezuma's Head), and twenty-one from the Puerto Blanco Mountains (ten from Ajo Loop, seven from Twin Peaks, and four from Cholla Pass), for a total of thirty-two middens (USGS/NOAA no date). Plant macrofossils (Van Devender 1977, 1982, 1987, 1990; Spaulding 1983; Van Devender et al. 1990), pollen (Davis and Anderson 1987; Davis 1990), arthropods (Hall et al. 1989, 1990), and vertebrates (Mead et al. 1983; Van Devender et al. 1991) have been described from these middens, providing a detailed picture of the vegetation, climate, microvertebrates, and arthropods present in ORPI over approximately the last 35,000 years. The midden specimens are currently in ORPI collections (C. Conner, ORPI biological science technician, pers. commun., July 2008). A brief description of the middens follows, including some key references. Designations, locations, elevations, radiocarbon dates, and number of plant taxa (usually identified to species) are after USGS/NOAA (no date); calendar years are provided for those samples that are younger than 21,800 yr BP, using Calib5.0.2. All middens will also have droppings of *Neotoma*.

From Alamo Canyon, Ajo Range:

The seven middens from Alamo Canyon in the Ajo Range were collected from an elevation of approximately 915 m (3,000 ft), except for ALC2, which was collected at 855 m (2,805 ft). The three oldest middens, known as ALC1M1B, ALC1M2C, and ALC2X, have radiocarbon ages between 32,000 ± 4,400 yr BP and 14,500 ± 300 yr BP (17,555 ± 974 calendar years). They are interpreted as representing a pinyon-juniper-oak woodland paleoenvironment (Van Devender et al. 1991). The other four middens, ALC1M1A1, ALC1M1A2, ALC1U, and ALC2, have radiocarbon ages ranging from 9,585 ± 200 yr BP (10,832 ± 570 calendar years) to 1,150 ± 240 yr BP (1,057 ± 425 calendar years); ALC2, the Alamo Canyon midden with the different elevation, is also the youngest. ALC1U is described as coming from a juniper-oak woodland paleoenvironment (Van Devender et al. 1991). ALC1M1A1, about the same age, and younger ALC1M1B are described as coming from an oak-juniper chaparral paleoenvironment (Van Devender et al. 1991). ALC2 is interpreted as representing a Sonoran desertscrub/chaparral paleoenvironment (Van Devender et al. 1991).

Remains from ALC1M1A1 are discussed in Van Devender (1990) and Van Devender et al. (1991) (as AC1A1 in both); the latter reported a crotalid snake fossil. A partial list of seven plant taxa has been prepared for this midden. Two samples have been dated; one, with laboratory identification AA-539, has a radiocarbon age of 8,590 ± 470 yr BP (9,598 ± 1,184 calendar years), and the other, A-2210, has a radiocarbon age of 10,580 ± 220 yr BP (12,349 ± 591 calendar years). The average radiocarbon age is 9,585 ± 200 yr BP (10,832 ± 570 calendar years).

Remains from ALC1M1A2 are discussed in Van Devender et al. (1991; as AC1A2); the latter reported iguanid lizard and unknown bird fossils. A partial list of seven plant taxa has been prepared for this midden. Two samples have been dated; one, with laboratory identification AA-540, has a radiocarbon age of 8,130 ± 430 yr BP (9,169 ± 1,006 calendar years), and the other, A-2209, has a radiocarbon age of 8,130 ± 370 yr BP (9,054 ± 866 calendar years). The average radiocarbon age is 8,130 ± 280 yr BP (9,007 ± 625 calendar years).

Remains from ALC1M1B are discussed in Mead et al. (1983; as Alamo Canyon 1B, University of Arizona Laboratory of Paleontology 8140), Van Devender (1990), and Van Devender et al. (1991) (as AC1B in the latter two publications); the latter reported anguid and iguanid lizard, unknown bird, and heteromyid and murid rodent fossils. A partial list of seven plant taxa has been prepared for this midden. A sample with laboratory identification A-2120 has a radiocarbon age of 14,500 ± 300 yr BP (17,555 ± 974 calendar years).

Remains from ALC1M2C are discussed in Van Devender (1990) and Van Devender et al. (1991) (as AC2C in both); the latter reported iguanid lizard fossils. A partial list of seven plant taxa has been prepared for this midden. A sample with laboratory identification A-2119 has a radiocarbon age of 32,000 ± 4,400 yr BP.

Remains from ALC1U are discussed in Van Devender (1990) and Van Devender et al. (1991) (as AC1U in both); the latter reported anguid and iguanid lizard, colubrid snake, and heteromyid and murid rodent fossils. The anguid record is noteworthy because anguids are not found in ORPI today; the nearest record is *Elgaria*, which is probably present in the Baboquivari Mountains (P. Holm, ORPI resource program manager, pers. commun., September 2008). A partial list of seven plant taxa has been prepared for this midden. Two samples have been dated; one, with laboratory identification AA-533, has a radiocarbon age of 9,230 ± 370 yr BP (10,441 ± 966 calendar years), and the other, A-2211, has a radiocarbon age of 9,910 ± 210 yr BP (11,434 ± 716 calendar years). The average radiocarbon age is 9,570 ± 180 yr BP (10,844 ± 470 calendar years).

Remains from ALC2 are discussed in Mead et al. (1983; as Alamo Canyon 2, University of Arizona Laboratory of Paleontology 8141, with age given as 1,510 ± 240 yr BP) and Van Devender et al. (1991; as AC3). Van Devender et al. (1991) reported bufonid toad, iguanid lizard, unknown bird, shrew, and murid rodent fossils. A partial list of seven plant taxa has been prepared for this midden. A sample with laboratory identification A-2121 has a radiocarbon age of 1,150 ± 240 yr BP (1,057 ± 425 calendar years).

Remains from ALC2X are discussed in Van Devender et al. (1991; as AC2X), where fossils from iguanid lizards, colubrid snakes, carduelid birds, and three taxa of murid rodents are reported. No plant taxa have been reported from it. A sample with laboratory identification A-4985 has a radiocarbon age of 29,110 ± 1,210 yr BP.

From Montezuma's Head, Ajo Range:

The four middens from Montezuma's Head in the Ajo Range were collected at an elevation of 975 m (3,200 ft). These four middens, MONTH1A, MONTH1B, MONTH1C, and MONTH1D, range in radiocarbon age from 21,840 ± 650 yr BP to 13,500 ± 390 yr BP (16,057 ± 1,117 calendar years). They are

all interpreted as representing a pinyon-juniper-oak woodland paleoenvironment (Van Devender et al. 1991).

Remains from MONTH1A are discussed in Van Devender (1977 and 1990), and Van Devender et al. (1991) (as MH1A in the latter two publications); the latter reported iguanid lizard and unknown bird fossils. A partial list of seven plant taxa has been prepared for this midden. A sample with laboratory identification A-1695 has a radiocarbon age of 20,490 ± 510 yr BP (24,671 ± 1,309 calendar years).

Remains from MONTH1B are discussed in Van Devender (1977 and 1990), and Van Devender et al. (1991) (as MH1B in the latter two publications); the latter reported iguanid lizard, unknown bird, and sciurid rodent fossils. A partial list of seven plant taxa has been prepared for this midden. A sample with laboratory identification A-1696 has a radiocarbon age of 21,840 ± 650 yr BP.

Remains from MONTH1C are discussed in Van Devender (1977 and 1990; as MH1C), Mead et al. (1983; as Montezuma's Head 1C, University of Arizona Laboratory of Paleontology 8144), and Van Devender et al. (1991; as MH1C); the latter reported leporid rabbit and murid rodent fossils. A partial list of seven plant taxa has been prepared for this midden. A sample with laboratory identification A-1697 has a radiocarbon age of 17,830 ± 870 yr BP (21,363 ± 2,036 calendar years).

Remains from MONTH1D are discussed in Van Devender (1977 and 1990) and Van Devender et al. (1991) (as MH1D in the latter two publications); the latter reported unknown bird, shrew, and sciurid rodent fossils. A partial list of seven plant taxa has been prepared for this midden. A sample with laboratory identification A-1698 has a radiocarbon age of 13,500 ± 390 yr BP (16,057 ± 1,117 calendar years).

From Ajo Loop, Puerto Blanco Mountains:

The ten middens from Ajo Loop in the Puerto Blanco Mountains were all collected at an elevation of 550 m (1,805 ft), except for AL5B, which was found at 535 m (1,755 ft). These middens are designated AL1A, AL1D, AL1G, AL2B, AL2C, AL3A, AL4, AL5B, AL6B, and AL6C. Their ages are distributed in several small groups. The oldest are AL1D and AL1G, with radiocarbon ages of 7,970 ± 130 yr BP (8,822 ± 176 calendar years) and 7,560 ± 170 yr BP (8,364 ± 366 calendar years) respectively. AL1A has a radiocarbon age of 5,240 ± 90 yr BP (6,049 ± 168 calendar years). AL5B, AL6B, and AL6C cluster between 3,480 ± 80 yr BP (3,767 ± 206 calendar years) and 3,220 ± 100 yr BP (3,452 ± 237 calendar years). AL3A and AL4 have quite similar ages, at 990 ± 50 yr BP (839 ± 96 calendar years) and 980 ± 70 yr BP (843 ± 120 calendar years), respectively. Finally, AL2B and AL2C are modern, with ages of 30 ± 50 yr BP and 130 ± 50 yr BP. Older middens AL1G and AL1A are interpreted as coming from a cool Sonoran desertscrub paleoenvironment, and younger AL6B, AL7C, AL3A, AL4, AL2C, and AL2B are described as coming from a subtropical Sonoran setting (Van Devender et al. 1991).

Remains from AL1A (denoted by radiocarbon age except where noted) are discussed in Van Devender (1987), Hall et al. (1990), Van Devender et al. (1990), and Van Devender et al. (1991; as AL1A). Fossil taxa include two beetle taxa, an ant, a millipede (Hall et al. 1990), three taxa of iguanid lizard, two colubrid snake taxa, a perognathine rodent (Van Devender et al. 1991), one grass species (Van Devender et al. 1990), and sixteen other plant taxa. A sample with laboratory identification A-4213 has a radiocarbon age of 5,240 ± 90 yr BP (6,049 ± 168 calendar years).

Remains from AL1D (denoted by radiocarbon age) are discussed in Van Devender (1987), Hall et al. (1990), and Van Devender et al. (1990). Fossil taxa include two beetle taxa, a millipede (Hall et al. 1990), eight species of grasses (Van Devender et al. 1990), and eighteen other plant taxa. A sample with laboratory identification A-3981 has a radiocarbon age of 7,970 ± 130 yr BP (8,822 ± 176 calendar years).

Remains from AL1G (denoted by radiocarbon age except where noted) are discussed in Davis and Anderson (1987; as AJIG), Van Devender (1987), Hall et al. (1990), Van Devender et al. (1990), and Van

Devender et al. (1991; as AL1G). Fossil taxa include four beetle taxa, an ant, a scorpion, a millipede (Hall et al. 1990), a gekkonid and three taxa of iguanid lizards (Van Devender et al. 1991), three species of grasses (Van Devender et al. 1990), and sixteen other plant taxa. A sample with laboratory identification A-3985 has a radiocarbon age of 7,560 ± 170 yr BP (8,364 ± 366 calendar years).

Remains from AL2B (denoted by radiocarbon age except where noted) are discussed in Davis and Anderson (1987; as AL2B), Van Devender (1987), Hall et al. (1990), Van Devender et al. (1990), and Van Devender et al. (1991; as AL2B). Taxa from this midden include two beetle taxa, an antlion, a kissing bug, a millipede (Hall et al. 1990), a colubrid snake (Van Devender et al. 1991), one grass species (Van Devender et al. 1990), and fifteen other plant taxa. A sample with laboratory identification A-3970 has a radiocarbon age of 30 ± 50 yr BP.

Remains from AL2C (denoted by radiocarbon age except where noted) are discussed in Davis and Anderson (1987; as AL2C), Van Devender (1987), Hall et al. (1990), Van Devender et al. (1990), and Van Devender et al. (1991; as AL2C). Taxa from this midden include four beetle taxa, a scorpion, a millipede (Hall et al. 1990), two colubrid snake taxa (Van Devender et al. 1991), three species of grasses (Van Devender et al. 1990), and seventeen other plant taxa. A sample with laboratory identification A-3971 has a radiocarbon age of 130 ± 50 yr BP.

Remains from AL3A (denoted by radiocarbon age except where noted) are discussed in Van Devender (1987), Hall et al. (1990), Van Devender et al. (1990), and Van Devender et al. (1991; as AL3A). Taxa from AL3A include four beetle taxa, an ant, a soldier fly, a kissing bug, a millipede (Hall et al. 1990), a perognathine rodent (Van Devender et al. 1991), seven species of grasses (Van Devender et al. 1990), and twenty-seven other plant taxa. A sample with laboratory identification A-3972 has a radiocarbon age of 990 ± 50 yr BP (839 ± 96 calendar years).

Remains from AL4 (denoted by radiocarbon age except where noted) are discussed in Van Devender (1987), Hall et al. (1990), Van Devender et al. (1990), and Van Devender et al. (1991; as AL4). Taxa from AL4 include four beetle taxa, four ant taxa, a kissing bug, a scorpion, a millipede (Hall et al. 1990), a murid rodent (Van Devender et al. 1991), two species of grasses (Van Devender et al. 1990), and twenty-six other plant taxa. A sample with laboratory identification A-4214 has a radiocarbon age of 980 ± 70 yr BP (843 ± 120 calendar years).

Remains from AL5B (denoted by radiocarbon age except where noted) are discussed in Davis and Anderson (1987; as AJ5B), Van Devender (1987), Hall et al. (1990), and Van Devender et al. (1990). Taxa from AL5B include five beetle taxa, a scorpion, a millipede (Hall et al. 1990), two species of grasses (Van Devender et al. 1990), and twelve other plant taxa. A sample with laboratory identification A-4233 has a radiocarbon age of 3,480 ± 80 yr BP (3,767 ± 206 calendar years).

Remains from AL6B (denoted by radiocarbon age except where noted) are discussed in Van Devender (1987), Hall et al. (1990), Van Devender et al. (1990), and Van Devender et al. (1991; as AL6B). Taxa from AL6B include four beetle taxa, a scorpion, a millipede (Hall et al. 1990), an iguanid lizard (Van Devender et al. 1991), four species of grasses (Van Devender et al. 1990), and twenty-one other plant taxa. A sample with laboratory identification A-4234 has a radiocarbon age of 3,220 ± 100 yr BP (3,452 ± 237 calendar years).

Remains from AL6C (denoted by radiocarbon age except where noted) are discussed in Davis and Anderson (1987; as AJ6C), Van Devender (1987), Hall et al. (1990), Van Devender et al. (1990), and Van Devender et al. (1991; as AL6C). Taxa from AL6C include three beetle taxa, three ant taxa, a soldier fly, a burrowing bug, a scorpion, a millipede (Hall et al. 1990), an iguanid lizard, a heteromyid rodent (Van Devender et al. 1991), two species of grasses (Van Devender et al. 1990), and twenty-seven other plant taxa. A sample with laboratory identification A-4235 has a radiocarbon age of 3,400 ± 100 yr BP (3,692 ± 237 calendar years).

From Twin Peaks, Puerto Blanco Mountains:

The seven middens from Twin Peaks in the Puerto Blanco Mountains were collected at elevations between 550 m (1,805 ft) and 580 m (1,900 ft). They are designated TP1, TP2, TP3, TP4, TP5, TP6, and TP7. TP1, with a radiocarbon age of 14,120 ± 260 yr BP (16,961 ± 845 calendar years), is by far the oldest. As with the Ajo Loop middens, there are some distinct age clusters. TP5 and TP7 make one, at 9,720 ± 460 yr BP (11,390 ± 1,276 calendar years) and 9,860 ± 180 yr BP (11,361 ± 615 calendar years). TP2, TP3, and TP4 form another, at 2,340 ± 70 yr BP (2,419 ± 126 calendar years) to 1,910 ± 50 yr BP (1,834 ± 116 calendar years). TP6 stands alone at 7,580 ± 100 yr BP (8,371 ± 187 calendar years). TP1 is thought to represent a juniper-Joshua Tree woodland paleoenvironment. Younger TP7 is described as coming from a juniper/Sonoran desertscrub paleoenvironment. Still-younger TP6 is interpreted as representing a cool Sonoran desertscrub paleoenvironment, and TP2, in the youngest age cluster, is described as coming from a subtropical Sonoran desertscrub paleoenvironment (Van Devender et al. 1991).

TP1 was found at an elevation of 565 m (1,855 ft). Remains from TP1 (denoted by radiocarbon age except where noted) are discussed in Van Devender (1987 and 1990; TP1 in the latter), Hall et al. (1990), Van Devender et al. (1990), and Van Devender et al. (1991; as TP1). Taxa include a beetle, a cicada, a scorpion, a millipede (Hall et al. 1990), an iguanid lizard (Van Devender et al. 1991), one grass species (Van Devender et al. 1990), and sixteen other plant taxa. A sample with laboratory identification A-3986 has a radiocarbon age of 14,120 ± 260 yr BP (16,961 ± 845 calendar years).

TP2 was found at an elevation of 580 m (1,900 ft). Remains from TP2 (denoted by radiocarbon age except where noted) are discussed in Van Devender (1987), Hall et al. (1990), Van Devender et al. (1990), and Van Devender et al. (1991) (as TP2). Taxa include six beetle taxa, four ant taxa, an isopod, an orthopteran (grasshoppers, crickets, and locusts), a silkmoth, a scorpion, a millipede (Hall et al. 1990), one teiid and two iguanid lizard taxa, a leporid rabbit, a murid rodent (Van Devender et al. 1991), six species of grasses (Van Devender et al. 1990), and twenty-one other plant taxa. A sample with laboratory identification A-3973 has a radiocarbon age of 2,340 ± 70 yr BP (2,419 ± 126 calendar years).

TP3 was found at an elevation of 550 m (1,805 ft). Remains from TP3 (denoted by radiocarbon age) are discussed in Van Devender (1987), Hall et al. (1990), and Van Devender et al. (1990). Taxa include a beetle, a soldier fly (Hall et al. 1990), two species of grasses (Van Devender et al. 1990), and fourteen other plant taxa. A sample with laboratory identification A-3982 has a radiocarbon age of 2,160 ± 60 yr BP (2,162 ± 160 calendar years).

TP4 was found at an elevation of 555 m (1,820 ft). Remains from TP4 (denoted by radiocarbon age) are discussed in Van Devender (1987), Hall et al. (1990), and Van Devender et al. (1990). Taxa from TP4 include three beetle taxa, two ant taxa, a millipede (Hall et al. 1990), four species of grasses (Van Devender et al. 1990), and twenty-three other plant taxa. A sample with laboratory identification A-3998 has a radiocarbon age of 1,910 ± 50 yr BP (1,834 ± 116 calendar years).

TP5 was found at an elevation of 560 m (1,835 ft). Remains from TP5 (denoted by radiocarbon age) are discussed in Van Devender (1987), Hall et al. (1990), and Van Devender et al. (1990). Taxa from TP5 include six beetle taxa, two ant taxa, a millipede (Hall et al. 1990), five species of grasses (Van Devender et al. 1990), and sixteen other plant taxa. A sample with laboratory identification AA-625 has a radiocarbon age of 9,720 ± 460 yr BP (11,390 ± 1,276 calendar years).

TP6 was found at an elevation of 580 m (1,900 ft). Remains from TP6 (denoted by radiocarbon age except where noted) are discussed in Davis and Anderson (1987; as TP6), Van Devender (1987), Hall et al. (1990), Van Devender et al. (1990), and Van Devender et al. (1991; as TP6). Taxa from TP6 include four beetle taxa, a millipede (Hall et al. 1990), a shrew (Van Devender et al. 1991), four species of grasses (Van Devender et al. 1990), and eighteen other plant taxa. A sample with laboratory identification A-3980 has a radiocarbon age of 7,580 ± 100 yr BP (8,371 ± 187 calendar years).

TP7 was found at an elevation of 565 m (1,855 ft). Remains from TP7 (denoted by radiocarbon age except where noted) are discussed in Van Devender (1987), Hall et al. (1990), and Van Devender et al. (1991; as TP7). Taxa from TP7 include three beetle taxa (Hall et al. 1990), an iguanid lizard, a perognathine rodent (Van Devender et al. 1991), and fourteen plant taxa. A sample with laboratory identification A-4212 has a radiocarbon age of 9,860 ± 180 yr BP (11,361 ± 615 calendar years).

From Cholla Pass, Puerto Blanco Mountains:

The four middens from Cholla Pass in the Puerto Blanco Mountains were collected at an elevation of 605 m (1,985 ft), except for CP2, which was found at 590 m (1,935 ft). Designated CP1A, CP1B, CP1C, and CP2, these middens are relatively older than most of the other Puerto Blanco middens, ranging from 10,540 ± 250 yr BP (12,274 ± 673 calendar years) to 8,790 ± 210 yr BP (9,914 ± 488 calendar years). CP2 is the exception, with a radiocarbon age of 3,440 ± 90 yr BP (3,696 ± 226 calendar years). CP1A, CP1B, and CP1C are all interpreted as coming from a juniper/Sonoran desertscrub paleoenvironment. CP2 is described as coming from a subtropical Sonoran desertscrub paleoenvironment (Van Devender et al. 1991).

Remains from CP1A (denoted by radiocarbon age except where noted) are discussed in Van Devender (1987), Hall et al. (1990), Van Devender et al. (1990), and Van Devender et al. (1991; as CP1A). Taxa from CP1A include a beetle, a millipede (Hall et al. 1990), an iguanid lizard (Van Devender et al. 1991), two species of grasses (Van Devender et al. 1990), and sixteen other plant taxa. A sample with laboratory identification A-4276 has a radiocarbon age of 10,540 ± 250 yr BP (12,274 ± 673 calendar years).

Remains from CP1B (denoted by radiocarbon age except where noted) are discussed in Van Devender (1987), Hall et al. (1990), Van Devender et al. (1990), and Van Devender et al. (1991; as CP1B). Taxa from CP1B include three beetle taxa, an antlion, a burrowing bug, a false scorpion, a millipede (Hall et al. 1990), two iguanid lizards (Van Devender et al. 1991), three species of grasses (Van Devender et al. 1990), and twenty other plant taxa. A sample with laboratory identification A-4278 has a radiocarbon age of 9,070 ± 170 yr BP (10,171 ± 490 calendar years).

Remains from CP1C (denoted by radiocarbon age except where noted) are discussed in Van Devender (1987), Hall et al. (1990), Van Devender et al. (1990), and Van Devender et al. (1991; as CP1C). Taxa from CP1C include three beetle taxa, an ant, a scorpion, (Hall et al. 1990), an iguanid lizard (Van Devender et al. 1991), one grass species (Van Devender et al. 1990), and ten other plant taxa. A sample with laboratory identification A-4277 has a radiocarbon age of 8,790 ± 210 yr BP (9,914 ± 488 calendar years).

Remains from CP2 (denoted by radiocarbon age except where noted) are discussed in Davis and Anderson (1987; as CP2), Van Devender (1987), Hall et al. (1990), Van Devender et al. (1990), and Van Devender et al. (1991; as CP2). Taxa from CP2 include six beetle taxa, three ant taxa, a soldier fly, a burrowing bug, a millipede (Hall et al. 1990), a troglodytid bird (wren), a leporid rabbit (Van Devender et al. 1991), two species of grasses (Van Devender et al. 1990), and twenty-nine other plant taxa. A sample with laboratory identification A-4279 has a radiocarbon age of 3,440 ± 90 yr BP (3,696 ± 226 calendar years).

Quaternary rocks and sediments (Pleistocene-Holocene)

There are several isolated reports of other fossils or fossil-like features from Quaternary rocks and deposits in ORPI. Pohl (1995) used plant fossils and charcoal from two Quaternary deposits for radiocarbon dating; calendar ages for these two samples are 17,800 ± 100 years ago, and 2,552 ± 199 years ago. McAuliffe and McDonald (2006) reported on plant scar mounds and depressions in desert areas including ORPI. Plant scar mounds and depressions are alterations to the terrain that remain for thousands of years after the death of a large perennial plant in desert settings. When a large perennial plant is alive, animals are attracted and disturb the substrate underneath, mounding the area around the plant. After the plant dies, modifications occur to the location over time, leading first to a light-colored

mound 2-6 m (7-20 ft) across and 25 cm (1 ft) tall surrounded by a ring of larger cobbles, then a light-colored ringed depression with a desert pavement surface. McAuliffe and McDonald (2006) noted that mounds are found near modern water courses, and depressions are only found farther out. They suggested that the depressions correspond to Pleistocene-Holocene climate change, and the mounds to another episode of climate change a few thousand years ago. These features, if not true trace fossils, are close enough to bear mentioning; they are certainly large, easily-observed records of past life. Peter Holm (ORPI resource program manager, pers. commun., September 2008) reports finding but not collecting fossil testudinind material near Pozo Nuevo. Testudinid remains are common north of the monument and east of the Growler Mountains, and one area is known as "Tortoise Valley," with specimens from larger testudinids than *Gopherus* (Holm, pers. commun., September 2008). Holm also reports finding potential plant fossils in the Sonoyta Valley, northwest of the Salsola weather station. These are "root or stem-like fossils made of a caliche-like material" (Holm, pers. commun., September 2008). Finally, R. McCord (Arizona Museum of Natural History paleontologist, pers. commun., September 2008) has reported that vertebrate remains may be present along the strike of the seep that forms Quitobaquito Springs. This record is included in this section because the Quaternary is the most likely age for vertebrate fossils at ORPI.

As with any park or monument in the SODN, any rocks or sediments of Quaternary age may contain isolated remains of the Quaternary fauna, such as testudinids, equids, camelids, and proboscideans (R. McCord, pers. commun., May 2008). Caves of volcanic origin are present at ORPI, and some of them host fossil middens. Carbonate caves and karst are not known at ORPI and are unlikely to be present because of the small size of carbonate exposures in the monument (National Park Service 2006). See Santucci et al. (2001) for a discussion of paleontological resources associated with National Park Service caves. There is also the possibility of finding fossils associated with cultural resources. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Potential Sources of Paleontological Resources

Bolsa Quartzite (Middle Cambrian)

The Bolsa Quartzite is a slightly metamorphosed sandstone deposited sometime in the Middle Cambrian, under offshore bar or beach conditions (Hayes 1978), or fluvial to tidal flat conditions (Strickland and Middleton 2000). It lacks fossils that would help constrain its age beyond Middle Cambrian (~510 million years ago), preserving only *Skolithus* and other trace fossils, and the occasional brachiopod (Hayes and Cone 1975). It may be present in metamorphosed form at ORPI (Eddy et al. 1988), associated with the Growler Mountains. Metamorphism frequently destroys or alters fossil remains, and as such they may not be found within the park's exposures. Further field investigation may reveal the presence of these fossils within ORPI.

Abrigo Formation (Middle-Upper Cambrian)

The Abrigo Formation (Limestone in older references) is a heterogeneous unit with four widely recognized members: a lower shaly or mudstone member, with Middle Cambrian trilobites; an upper Middle Cambrian-lower Upper Cambrian ribbed limestone member so named for silty beds that erode more readily than the limestone, and which has trilobites and other fossils; a sandstone/dolomite member with lower Upper Cambrian trilobites; and the uppermost member, the Upper Cambrian Copper Queen Limestone. The upper two members are sometimes combined into one (Krieger 1968; Hayes 1972, 1978; Middleton 1989). The formation appears to record sea level changes from intertidal to shallow subtidal, to supratidal, and back to subtidal (Middleton 1989), between about 513 and 490 million years ago (Blodgett et al. 2002). Eddy et al. (1988) were not as sure of its presence in ORPI as they were of the Bolsa Quartzite. At any rate, as the possible occurrence consists of quartzite and metamorphosed siltstone, sandstone, and shale, the section of the Abrigo Formation present would more likely consist of the lower beds than the upper beds. Abrigo Formation outcrops would also be associated with the Growler Mountains.

Martin Formation (lower Upper Devonian)

The Martin Formation (or Martin Limestone) is largely made up of limestone or dolomite and has two members, deposited roughly 385 to 375 million years ago as a sea was moving into Arizona from the west. The lower, thinner Beckers Butte Member is made up of sandstone and conglomerate (Beus 1989), and has been interpreted as nonmarine channel fill or a transitional to marine environment. The upper, thicker Jerome Member is interpreted as a shallow continental shelf (Beus 1969). Both are known to produce fossils (Beus 1978). The Jerome Member is mostly unfossiliferous except for the upper section and rare finds in the middle (Beus 1978). Most fossils in the upper section are marine invertebrates, but conodonts (eel-like chordates) (Ethington 1962, 1965) and a largely undescribed fish fauna are also present (Johnson and Elliott 1990, 1996; Elliott and Blakey 2005). Common fossils include stromatoporoids (reef-building sponges) (Beus 1978), corals, brachiopods, mollusks (particularly gastropods and pelecypods), and conodonts (Beus 1969, 1989). Fish include several genera of placoderms (early jawed fish) and at least three sarcopterygians (lobe-fins). Fish fossils, mostly plates and teeth, are often found in paleovalley deposits (Elliott and Blakey 2005). At the top of the formation is another assemblage, composed of serpulid worm burrows forming bioherms (mounds, like worm-burrow reefs) among algal laminations and stromatolites, suggesting a quiet inter- or shallow tidal environment (Beus 1979, 1980). Eddy et al. (1988) indicate that potential Martin Formation exposures at ORPI are metamorphosed; as discussed for the Abrigo Formation, metamorphism is an agent of fossil destruction, so Martin Formation fossils may not be present. Outcrops are near Bendeja Well, and possibly west-southwest of the Bates Mountains.

Escabrosa Limestone (Lower-Middle Mississippian)

The Escabrosa Limestone is a carbonate unit deposited under shallow marine conditions (Beus 1989; Elliott and Blakey 2005), between about 359 and 333 million years ago (Beus 1989). It is considered a group by some stratigraphers, notably Armstrong, who identified the lower Escabrosa Limestone as the Keating Formation and the upper Escabrosa Limestone as the Hachita Formation (Armstrong 1962, 1965; Armstrong et al. 1978). There is a break in deposition between the two formations or portions of the Escabrosa Limestone (Armstrong and Mamet 1978). Fossils are best known from the lower and upper Keating Formation, and upper Hachita Formation (Armstrong 1962). The lower Keating Formation has produced foraminifera, corals, bryozoans, brachiopods, gastropods, trilobites, crinoids, and blastoids; the upper Keating Formation has produced foraminifera, corals, bryozoans, brachiopods, possible worms, and crinoids (Armstrong 1962); and the upper Hachita Formation has produced corals, bryozoans, and brachiopods (Armstrong 1965). Sponges, holothurians (sea cucumbers) (Langenheim and Epis 1957), and conodonts (Beus 1989) have also been reported from the Escabrosa Limestone. The Escabrosa Limestone is not reported by Eddy et al. (1988), but was mentioned by Bezy et al. (2000) as being present in the area north of Growler Pass, so it has been included here as potentially present. It would be metamorphosed if present (Bezy et al. 2000). Again, metamorphism may have destroyed any fossils, if the Escabrosa Limestone is present.

Unnamed Sedimentary and Metasedimentary Rocks (Jurassic-Tertiary)

There are several unnamed rock units made up of sedimentary rocks or somewhat metamorphosed sedimentary rocks present in ORPI. Most of them are composed of volcanic fragments, or are conglomerates, and fossils have not been reported by mapping geologists (Gray et al. 1985, Tosdal et al. 1986; Eddy et al. 1988; Beikman et al. 1995). Neither type of rock is favorable for preserving articulated specimens or delicate material, although isolated fragments of resistant remains and fossils within fragments of older rocks are both possible. Occurrences of Tertiary and Quaternary fossils in Arizona have been documented in several reviews. To date, no fossils of these ages, except for the packrat middens, have been reported from ORPI or nearby areas of Pima, Maricopa, and Yuma counties (Lance 1960; Lindsay and Tessman 1974; Agenbroad 1984; Nations and Landye 1984; Lucas and Morgan 2005a, b; Mead 2005; Lindsay and Mead 2005; and Morgan and White 2005).

Park Collections

There are twelve paleontologic specimens in ORPI collections. Nine specimens were collected at South Growler Mountain, collected April 9, 1970 by Charles B. Hunt: ORPI 4802, 4803, 4804, and 4805 are rugose corals (also known as horn corals when solitary; a type of coral that became common in the Ordovician and went extinct at the end of the Permian), and ORPI 4806, 4807, 4808, 4809, and 4810 are brachiopods. The type of coral suggests that the most likely local formations to have produced them are the Martin Formation and Escabrosa Limestone. ORPI 6624 is a specimen of the beetle *Phyllotreta*, collected November 22, 1987 at Aguajita Spring by R. Bailowitz and E. Draeger. ORPI 6646 is a specimen of the ant *Pseudomymex apache*, collected October 17, 1987 at Bull Pasture by R. Bailowitz and E. Draeger. ORPI 7103 is a specimen of the wasp *Eumenes bolli* collected November 21, 1987 at Dripping Springs by R. Bailowitz and E. Draeger (P. Holm, pers. commun., September 2008).

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division coordinated geologic scoping for ORPI during January 2006. The participants of the ORPI Geologic Scoping meeting developed a series of recommendations for future work. ORPI is in many respects an unknown where fossils and sedimentary rocks are concerned, outside of the well-documented packrat middens. There are 12 fossil specimens within ORPI museum collections.
- The park should consider future field inventories for paleontological resources to more fully document *in situ* occurrences of fossils. The park may consider a formal site documentation and condition assessment for significant fossil localities. Monitoring of significant sites should be undertaken at least once a year in the future.
- A forthcoming (late 2008 or early 2009) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management and monitoring.
- Park staff should be encouraged to observe sedimentary rock exposures and 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 Western Archeology & Conservation Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Fossil packrat middens are typically found in dry rockshelters, and resemble piles or mounds of plant material with a dark glossy coating of crystallized packrat urine. Fossil middens can provide important paleoecological information. If one is located, there are several midden researchers in the Southwest who may be contacted. The GRD maintains a list of active researchers and can facilitate communication between the park and these researchers.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at ORPI.

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Data Sets

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

Organ Pipe Cactus National Monument Museum Collections
1937-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by ORPI staff; status: Active.

Saguaro National Park

Saguaro National Park (SAGU) was established to protect forests of giant saguaro cactus (*Carnegiea giganteus*) in the Sonoran Desert of Arizona. It is composed of two sections: an eastern unit in the Rincon Mountains, and a western unit in the Tucson Mountains. The two sections have significantly different geology. SAGU was proclaimed a national monument on March 1, 1933, and was transferred to the National Park Service from the U.S. Forest Service later that year, on August 10. It was redesignated as a national park on October 4, 1994. The boundaries of SAGU have changed four times, on November 15, 1961, October 21, 1976, June 19, 1991, and October 4, 1994. A wilderness area was designated within SAGU on October 20, 1976. SAGU encompasses 37,005.14 ha (91,439.71 acres). 35,421.32 ha (87,526.07 acres) of this total are under Federal administration, and the wilderness area is 28,694.86 ha (70,905 acres).

Geologic Background

The two units of SAGU are found to the west and east of the city of Tucson in Pima County, separated by about 32 km (20 miles), each occupying a portion of one of the numerous small mountain ranges of southern Arizona. SAGU East, also known as the Rincon Mountains District, is the larger of the two and occupies part of the western Rincon Mountains, including Rincon Peak. Smaller SAGU West, also known as the Tucson Mountains District, is found in the northern Tucson Mountains. Between them lie Tucson, the Santa Cruz River, and Santa Cruz Valley. Several other mountain ranges surround the Tucson area. The Santa Catalina Mountains are found north of SAGU East and northeast of Tucson, the Santa Rita and Sierrita Mountains are found south of the city, and the Silver Bell Mountains are found west of SAGU West. The Rincon Wilderness of Coronado National Forest borders SAGU East on parts of three sides, north, east, and south.

The geology of SAGU has been the subject of several published reports (McColly 1961a; Davis and Frost 1976; Davis 1987; Kring 2002), theses (McColly 1961b,) and internal National Park Service documents (Krantz 1985). However, this is not an exhaustive list of geologic documents that may touch on SAGU rocks, given the detailed scientific coverage of the Rincon and Tucson Mountains in general, and changes in SAGU boundaries over the years. The most recent document is a geologic resources scoping report by the Geological Resources Division of the National Park Service (2006); this is an internal National Park Service document.

SAGU has complicated geology due to volcanism, metamorphism, and faulting; one rock unit in the area was even known as the "Tucson Mountain Chaos" for many years, and may still be called this informally. Although both units of the park are found in mountain ranges, the two ranges have distinctly different rocks and histories. The Rincon Mountains of SAGU East comprise one of the best examples in the world of a metamorphic core complex (a geologic feature where unmetamorphosed rocks that had originally formed the mountains' cover have been moved away on detachment faults, bringing ancient metamorphosed bedrock to the surface) (Davis 1987). The Tucson Mountains of SAGU West are the fault-displaced remnants of a massive volcanic eruption and collapse in the Late Cretaceous (Hagstrum and Lipman 1991).

The known geologic history of the SAGU area begins with the Precambrian deposition of sedimentary and volcanic rocks (ending around 1.66 billion years ago; Shafiqullah et al. 1980) that would be eventually metamorphosed into the Pinal Schist. The Pinal Schist was followed by numerous igneous intrusions deep underground (the Continental Granodiorite, Wrong Mountain Quartz Monzonite, Johnny Lyon Granodiorite, and Rincon Valley Granodiorite; Drewes 1974, 1977; Lipman 1993). These intrusions are probably associated with a larger mountain-building event called the Mazatzal Orogeny that took place between 1.45 and 1.40 billion years ago (Shafiqullah et al. 1980). Sedimentary and volcanic rocks of the Apache Group are the youngest Proterozoic rocks in the area (Drewes 1974, 1977; Lipman 1993); they

were deposited between 1.3 and 1.05 billion years ago in river to shallow marine environments (Wrucke 1989; Fletcher et al. 2004).

There is then a lengthy hiatus encompassing several hundred million years until deposition in the area is once again recorded, in the early Paleozoic. During the Paleozoic, several sedimentary rock formations were deposited during fluctuations between terrestrial and marine conditions. These include the Bolsa Quartzite (Middle Cambrian), Abrigo Formation (Middle-Upper Cambrian), Martin Limestone (early Upper Devonian), Escabrosa Limestone (Lower-Middle Mississippian), Horquilla Limestone (Upper Pennsylvanian to possibly Lower Permian), Earp Formation (possibly Upper Pennsylvanian to Lower Permian), Colina Limestone (Lower Permian), Epitaph Formation (Lower Permian), Scherrer Formation (Lower Permian), Concha Limestone (Lower-Middle Permian), and Rainvalley Formation (Middle Permian) (Drewes 1974, 1977; Lipman 1993).

Another depositional hiatus then occurred, but much shorter in duration than the previous gap. Two named sedimentary formations, the Walnut Gap Formation and Recreation Red Beds, and unnamed sedimentary and volcanic rock units were laid down during the Triassic to Jurassic. One of these, an andesite (a type of plagioclase feldspar-rich volcanic rock) with large crystals, has been dated to 159 ±5 million years ago, but otherwise the ages of these units are not well constrained. A volcanic conglomerate possibly indicating the onset of Andes-style continental arc volcanism is found above the Triassic and Jurassic units. After this, several units of the widespread Bisbee Group of Jurassic-Cretaceous sedimentary rocks were deposited, including the Glance Conglomerate (Upper Jurassic-Lower Cretaceous depending on location), Willow Canyon Formation (Lower Cretaceous), Shellenberger Canyon Formation (Lower Cretaceous), and Amole Arkose (Lower-Upper Cretaceous) (Drewes 1974, 1977; Lipman 1993). This time of deposition probably represents mostly terrestrial environments such as floodplains, rivers, and alluvial fans, although the Shellenberger Canyon Formation may have some marine influence depending on location (Dickinson et al. 1989).

The onset of Late Cretaceous volcanism in the area began with the tuff (welded ash layer) of Confidence Peak, from about 73 million years ago. This is covered by an unnamed sandstone and shale rich layer. Following this was the eruption of the Tucson Mountain Caldera, which is something of a misnomer since the caldera actually started out to the northeast, closer to the vicinity of the Santa Catalina Mountains (Kring 2002). The volcano that became the caldera first extruded great amounts of a quartz-rich volcanic rock called rhyolite that formed the Cat Mountain Tuff. Then, it collapsed from the emptying of its magma chamber and subsequent deposition of the magma as rhyolite on top of the volcano. This collapse led to the formation of the Cat Mountain Tuff Megabreccia, made up of the broken remnants of older formations that had formed the volcano's walls. Understandably, these rocks are difficult to map and interpret, and were known as the Tucson Mountain Chaos for many years (Hagstrum and Lipman 1991; Thayer 1991; Lipman 1993). The formation of the caldera and tuff occurred about 73.1 million years ago, followed shortly thereafter by the emplacement of the Amole Pluton at 73.0 million years ago (Lipman 1994). The Amole Pluton body of underground igneous rock may represent partial refilling of the old magma chamber, and other volcanic units of the immediate post-caldera period may derive from it, such as the Yuma Mine volcanics, Bilby Road andesite, Twin Hills dacite, John F. Kennedy Peak andesite, and Beehive Peak tuff (Lipman 1993). This period of volcanic activity is related to the Laramide Orogeny of about 75 to about 50 million years ago, a major mountain-building event that uplifted most of the modern Rocky Mountains (Shafiqullah et al. 1980).

Volcanism and other igneous activity resumed in the middle of the Tertiary, covering poorly known conglomerates formed from the previous period of volcanism. These igneous rocks include the Happy Valley granodiorite (emplaced around 27 to 26 million years ago, in the Oligocene), the Safford Dacite lava flows (25 million years ago), and the Tumamoc Hill volcanic flows (29 to 20 million years ago), along with a variety of less extensive dikes and lava flows. This episode of igneous activity is associated with a mountain-building event and crustal extension that resulted in, among other things, the Tucson Mountains moving some distance southwest to their present location (Kring 2002), and the top of the Rincon Mountains sliding off on the Catalina Fault (Davis 1987). Contemporaneous with this activity was

the deposition of the Pantano Formation, mostly conglomerate with some andesitic lava flows (Drewes 1974, 1977). Basin and Range extension later in the Miocene led to the formation of basins such as the Tucson Basin between SAGU East and West (Nations et al. 1982). As basins subsided, local deposits of alluvial fans, lakes, rivers, and floodplains followed, such as the Miocene-age Nogales Formation and Pliocene-Pleistocene formation of the St. David area. Similar rocks are being deposited up to the present day in similar environments (Drewes 1974, 1977; Lipman 1993).

Rock units exposed in SAGU East include, from oldest to youngest: the Pinal Schist (Precambrian, various metamorphosed rock types); the Continental Granodiorite, Wrong Mountain Quartz Monzonite, and Rincon Valley Granodiorite, all Proterozoic igneous intrusions; the Pioneer Shale and Dripping Spring Formation of the middle Proterozoic Apache Group, and a basalt flow that is probably from about the same time; the Bolsa Quartzite (Middle Cambrian); the Abrigo Formation (Middle-Upper Cambrian); the Escabrosa Limestone (Lower-Middle Mississippian); the Horquilla Limestone (Upper Pennsylvanian-?Lower Permian), Earp Formation (?Upper Pennsylvanian-Lower Permian), Epitaph Formation, and Scherrer Formation (Lower Permian) of the Naco Group; the Glance Conglomerate (Upper Jurassic-Lower Cretaceous) and other, undifferentiated rocks of the Bisbee Group; the Pantano Formation (Upper Eocene-?Miocene); a variety of volcanics from the Oligocene, with no named formation; Tertiary-Quaternary basin fill and rubble deposits; and Quaternary alluvium and terrace deposits (Drewes 1974, 1977; Lipman 1993).

Rock units exposed in SAGU West include, from oldest to youngest: the Escabrosa Limestone (Lower-Middle Mississippian); the Horquilla Limestone (Upper Pennsylvanian-?Lower Permian) and Scherrer Formation (Lower Permian) of the Naco Group; the Recreation Red Beds (Jurassic or Late Triassic); an unnamed sandstone and rhyolite (Jurassic) and volcanic conglomerate (Jurassic or Cretaceous); the Amole Arkose (Lower-Upper Cretaceous); the tuff of Confidence Peak and overlying sandstone and shale (Upper Cretaceous); the Cat Mountain Tuff and megabreccia (Upper Cretaceous); andesite and rhyolite of the Yuma Mine volcanics, granite of the Amole Pluton, and unnamed sedimentary and minor intrusive igneous rocks from the Upper Cretaceous and possibly Tertiary after the Cat Mountain Tuff; Tertiary colluvium; lava flows and tuffs from the Safford Dacite (Upper Oligocene); Tertiary-Quaternary basin fill and rubble deposits; and Quaternary alluvium and terrace deposits (Drewes 1974, 1977; Lipman 1993).

SAGU has multiple reports of fossils. Brachiopods and trilobites are preserved within the Abrigo Formation in SAGU East. Packrat middens are also known, from much closer in time to the present (D. Swann, SAGU resource program manager, pers. commun., May 2008). A midden described in the 1970s (Cole and Van Devender 1976) was found on land that is within current SAGU West boundaries. Three SAGU paleontological specimens are also held in the collections of the Western Archeological Conservation Center (WACC). Beyond these reports, several other formations that outcrop within SAGU are known to produce fossils elsewhere. These include the Dripping Spring Quartzite, Bolsa Quartzite, Escabrosa Limestone, Horquilla Limestone, Earp Formation, Epitaph Formation, Scherrer Formation, Recreation Red Beds, Glance Conglomerate, Amole Arkose, Safford Dacite, and Tertiary-Quaternary and Quaternary deposits. The Pantano Formation may also have fossils.

Sources of Paleontological Resources

Abrigo Formation (Middle-Upper Cambrian)

The Abrigo Formation (Limestone in older references) is a heterogeneous unit with four widely recognized members: a lower shaly or mudstone member, with Middle Cambrian trilobites; an upper Middle Cambrian-lower Upper Cambrian ribbed limestone member so named for silty beds that erode more readily than the limestone, and which has trilobites and other fossils; a sandstone/dolomite member with lower Upper Cambrian trilobites; and the uppermost member, the Upper Cambrian Copper Queen Limestone. The upper two members are sometimes combined into one (Krieger 1968; Hayes 1972, 1978; Middleton 1989). The formation appears to record sea level changes from intertidal to shallow subtidal,

to supratidal, and back to subtidal (Middleton 1989), between about 513 and 490 million years ago (Blodgett et al. 2002a).

The fossils from SAGU East are described as rare brachiopods and trilobites from the Rincon Limestone, per V. Santucci (pers. commun. to Bob Higgins, February 2001). "Rincon Limestone" is a term introduced by Stoyanow (1936) for what had been the upper Abrigo Limestone in the Tucson area. Stoyanow regarded it as equivalent to the Copper Queen Limestone, which he had coined for the upper Abrigo Limestone of the Bisbee area (1936). He noted the presence of abundant brachiopods and trilobites in the Rincon Limestone. Later authors regarded these and other formations he split from the Abrigo Limestone as just different members or depositional environments of a reassessed Abrigo Formation (Bryant 1968; Krieger 1968). Given the correlations, the Rincon Limestone of SAGU should probably be regarded as the Copper Queen Limestone Member of the Abrigo Formation. Other fossils from the Abrigo Formation include the vertical tube trace fossils called *Skolithus*, other trace fossils once thought to be seaweed impressions (fucoids) (Krieger 1968), and enigmatic probable mollusks known as hyolithids (classified as pteropods, a type of sea snail, when identified from the Abrigo Limestone by Ransome [1904]).

Of the two SAGU units, the Abrigo Formation is only exposed at SAGU East, and only in small isolated exposures on the southern border opposite the vicinity of Colossal Cave. Drewes noted the presence of trilobites in the Abrigo Formation of the Rincon Valley and Happy Valley quadrangles (Drewes 1974, 1977).

Quaternary rocks and sediments (Pleistocene-Holocene)

Don Swann (pers. commun., May 2008) reported that there are packrat middens within SAGU. These collections of plant material and food waste, cemented by viscous packrat urine, can be well-preserved in dry caves, and illustrate the environment of the builder's foraging range. Packrat middens are important tools for reconstructing the ecology and climate of the late Pleistocene and Holocene of the southwestern United States (Strickland et al. 2001). Middens are relatively common in Tucson-area mountain ranges, with published sites from Pontatoc Ridge in the Santa Catalina Mountains (may also be spelled Pontotoc Ridge, not to be confused with a ridge of the same name in Mississippi and Tennessee), the Tucson Mountains, the Waterman Mountains, and Wolcott Peak in the Silver Bell Mountains. Van Devender (1990) is probably the most extensive published survey of Sonoran middens, but many other publications have documented these middens. Additionally, the online U.S. Geological Survey/National Oceanic and Atmospheric Administration Packrat Midden Database (http://esp.cr.usgs.gov/data/midden/) provides extensive documentation on packrat middens, including coordinates, elevation, C-14 ages, key publications, and lists of plants found in a given midden, although it does not list vertebrates or invertebrates. The midden specimens described in this inventory are now in storage under the auspices of Julio Betancourt (U.S. Geological Survey) at his laboratory at the University of Arizona (K. Rylander, U.S. Geological Survey, pers. commun., July 2008).

The Tucson Mountains middens are naturally of the most interest for this document, as SAGU West occupies part of this range. A midden collected in the late 1960s by P. J. Mehringer and C. H. Lowe, and known as TM3 (an acronym for Tucson Mountains #3) in the USGS/NOAA database, would be within current SAGU West boundaries if found today. It was found in the vicinity of Picture Rocks Pass (T. R. Van Devender, Arizona-Sonora Desert Museum researcher, pers. commun., July 2008). TM3 was found at an elevation of 740 m (2,430 ft), and is dated to 21,000 ± 700 yr BP (radiocarbon years before present); papers dealing with fossils dated by radiocarbon typically use "radiocarbon years before present" or a similar formulation. Years before present do not correspond to calendar years; radiocarbon dating uses 1950 as "Year Zero," and radiocarbon dates require calibration to yield calendar years. Using the calibration program Calib5.0.2 on this date, for example, yields a calendar age of 24,768 ± 1,213 years old. TM3 preserves 13 plant species, with *Aplopappus cuneatus* (wedgeleaf) making up 34.8% of the specimens, *Juniperus* making up 16.5%, *Agave* and *Opuntia chlorotica* (dollarjoint pricklypear) each making up 13.9%, *Pinus monophylla* (single-leaf pinyon) making up 7.0 %, and eight other making up 3.5% or less each

(*Amaranthus* [amaranth], *Amsinckia intermedia* and *tessellata* [fiddlenecks], *Cereus giganteus* [another name for the giant saguaro], *Cryptantha* [cryptantha], *Dasylirion wheeleri* [desert spoon], *Opuntia* cf. *spinosior* [prickly pear], and *Physalis* [groundcherry]) (USGS/NOAA no date). The primary latitude and longitude given for this and other Tucson Mountain middens in the USGS/NOAA database are erroneous (T. R. Van Devender, pers. commun., July 2008); the database coordinates as of July 2008 (32.317° N, 111.200° W) give a location about 380 m (1,250 ft) north of SAGU West's border with West Rudasill Road, between North Noel Lane and North Wild Buttercup Lane. Instead, it should have the approximate coordinates of TM2 (32.333° N, 111.333° W). TM3 is described as coming from a pinyon-juniper-oak woodland paleoenvironment (T. R. Van Devender, pers. commun., July 2008).

Three other middens or midden series are known from the Tucson Mountains. TM1 (Tucson Mts. #1, locality UALP 7233 at the University of Arizona Laboratory of Paleontology), actually a series of three middens (T. R. Van Devender, pers. commun., July 2008), is from about 4.2 km (2.6 miles) south of SAGU West, in the Gates Pass area. Tucson Mountains #1A, a midden dated to 12,430 ± 400 yr BP (14,554 ± 1,078 calendar years), was documented by Mead et al. (1983) as containing the remains of the chipmunk *Eutamias*, deer mouse *Peromyscus*, pocket gopher *Thomomys*, and cottontail rabbit *Sylvilagus*. There are also Tucson Mountains #1B (9,115 ± 75 yr BP or 9,125 ± 75 yr BP; 10,337 ± 162 calendar years or 10,341 ± 157 calendar years) and #1C (3,550 ± 90 yr BP; 3,775 ± 218 calendar years), although the USGS/NOAA database only reports the age of 1A. Lindsay and Tessman (1974) reported the collared lizard *Crotaphytus* from a Tucson Mountains #1 midden. The USGS/NOAA database provides a list of 20 species of plants found from TM1, although it doesn't specify if 1A, 1B, and 1C are pooled, or if the list is only for 1A. Pollen from Tucson Mountains #1A was described by King and Van Devender (1977); *Juniperus* contributed 60% of the sample, *Pinus* somewhat less than 20%, and *Artemisia* (sagebrush) and *Salix* (willow) each contributed about 5%. #1A is described as coming from a pinyon-juniper paleoenvironment, #2A is described as coming from a juniper-oak woodland paleoenvironment, and 3A# is described as coming from a Sonoran desertscrub paleoenvironment. All three were found at an elevation of 890 m (2,920 ft) (T. R. Van Devender, pers. commun., July 2008).

TM2 (Tucson Mts. #2, locality UALP 7234) comes from the Rillito Peak area, about 5.6 km (3.5 miles) north of SAGU West at the northern extreme of the Tucson Mountains (T. R. Van Devender, pers. commun., July 2008). This differs from the USGS/NOAA database, which places TM2 about where TM3 should be, within SAGU West. Similar to TM1, there are two distinct sampled specimens. Tucson Mountains #2A, the specimen with the quoted radiocarbon date in the database, dates to 2,720 ± 100 yr BP (2,889 ± 193 calendar years). Cole and Van Devender (1976) reported a scale of the lizard *Sceloporus* (American Museum of Natural History 111994, herpetological collection) from Tucson Mountains #2A. Tucson Mountains #2B is somewhat older, from 3,940 ± 55 yr BP (4,380 ± 147 calendar years). Lindsay and Tessman (1974) listed the gecko *Coleonyx*, whipsnake *Masticophis*, and squirrel *Spermophilus* from TM2, and the USGS/NOAA database provides a list of 21 species of plants from TM2, although again it doesn't specify if this list is pooled or, if not, if #2A or #2B is documented (USGS/NOAA no date). Both #2A and #2B are described as coming from Sonoran desertscrub paleoenvironments, and were found at an elevation of 700 m (2,300 ft) (T. R. Van Devender, pers. commun., July 2008).

Finally, TM4 is also from Rillito Peak (T. R. Van Devender, pers. commun., July 2008). In the USGS/NOAA database, it has the same erroneous coordinates as TM2. It is close in age to Tucson Mountains #2B at 3,760 ± 45 yr BP (4,115 ± 135 calendar years) (T. R. Van Devender, pers. commun., July 2008). TM4 is described as coming from a Sonoran desertscrub paleoenvironment, and was found at an elevation of 700 m (2,300 ft) (T. R. Van Devender, pers. commun., July 2008).

Of the other nearby midden sites, seventeen are known from the Waterman Mountains, with extensive descriptions in Van Devender (1990) and Anderson and Van Devender (1991). The Waterman sites are about 23 km (14 miles) northwest of SAGU West. The three middens from Wolcott Peak in the Silver Bell Mountains are about 27 km (17 miles) northwest of SAGU West, and are discussed in Cole and Van Devender (1976), Van Devender and Mead (1978), Mead et al. (1983), Spaulding (1983), and Van Devender and Wiens (1993). In addition to the USGS/NOAA database list of plants, vertebrate faunal lists

are provided by Lindsay and Tessman (1974) for these sites. Vertebrate fossils from these middens belong to lizards, snakes, insectivores, rodents, and rabbits (Lindsay and Tessman 1974). Eleven middens are known from Pontatoc Ridge in the southwestern Santa Catalina Mountains, about 19 km (12 miles) northeast of SAGU East. These are discussed by references including Thompson and Van Devender (1982), Spaulding (1983), and Van Devender (1990).

As with any park or monument in the SODN, any rocks or sediments of Quaternary age may contain isolated remains of the Quaternary fauna, such as testudinids, equids, camelids, and proboscideans (R. McCord, Arizona Museum of Natural History paleontologist, pers. commun., May 2008). A site in the Tucson Mountains (Werner, UALP 7112) has produced *Bison* remains, and a site about 8 km (5 miles) east of SAGU West, known as Tucson Brickyards (UALP 10) has yielded the tortoise *Geochelone*, *Equus*, *Mammuthus*, and *Bison* (Lindsay and Tessman 1974).

Caves are another important source of Quaternary fossils in Arizona, but are not common at SAGU. There is one potential talus cave at SAGU, and a cave was included in 1950s resource maps, but has not been located (National Park Service 2006). Karst, a common source for caves, is present south of SAGU East in the vicinity of Colossal Cave, but is not known within SAGU borders (NPS 2006). If a cave was to be found, it would probably have a similar fauna to Deadman Cave about 32 km (20 miles) north of SAGU East, on the northeast side of the Santa Catalina Mountains. Deadman Cave has an extensive fauna dating from about 12,000 to 8,000 years ago, from the Late Pleistocene to Early Holocene. Animals found there include five species of frogs and toads; one species of teiid, one species of helodermatid, and twelve species of iguanid lizards; ten species of colubrids and two species of pit vipers; three species of quail, one species of dove, three species of owl, one species of nightjar, one species of woodpecker, and four species of passeriforms; shrews; two species of bat; ground sloths; two species of rabbits; one species of sciurid, one species of geomyid, two species of heteromyid, and five species of cricetid rodents; ringtails; two species of skunks; mountain lions; horses; deer; and shrub ox (Mead et al. 1984). See Santucci et al. (2001) for a discussion of paleontological resources associated with National Park Service caves.

There is also the possibility of finding fossils associated with cultural resources. There are 450 surveyed archeological sites in SAGU East, and scattered sites in SAGU West (National Park Service 2006); the map of Tucson Mountains archeological sites in Brakenrigde and Schuster (1986) is useful in this regard. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Potential Sources of Paleontological Resources

Dripping Spring Quartzite (Mesoproterozoic)

The Dripping Spring Quartzite (or Formation) is composed of three members: the basal Barnes Conglomerate Member, an arkose-rich middle member, and a siltstone-rich upper member (Wrucke 1989). These rocks were deposited sometime between after 1.3 billion years ago (Fletcher et al. 2004) and before 1.14 billion years ago (Wrucke 1989). A layer in the upper member known as the gray unit is known for its unusually high organic carbon content, particularly in its black subunit (Granger and Raup 1964; Wrucke 1989). It is in these dark shales of the upper member that acritarchs have been described, at Roosevelt Dam in Gila County (Horodyski et al. 1989). Acritarchs are a nebulous group of microfossils of unknown evolutionary relationships. Raup (1959) in his report on TONT (see TONT section of this report) cited free carbon in the monument's exposures of Dripping Spring Quartzite as a possible sign of ancient life.

The Dripping Spring Quartzite is only found in SAGU East, along the southern border in small outcrops. Drewes did not report any fossils in the Dripping Spring Quartzite of the Rincon Valley and Happy Valley quadrangles (Drewes 1974, 1977).

Bolsa Quartzite (Middle Cambrian)

The Bolsa Quartzite is a slightly metamorphosed sandstone deposited sometime in the Middle Cambrian, under offshore bar or beach conditions (Hayes 1978), or fluvial to tidal flat conditions (Strickland and Middleton 2000). It lacks fossils that would help constrain its age beyond Middle Cambrian (~510 million years ago), preserving only *Skolithus* and other trace fossils, and the occasional brachiopod (Hayes and Cone 1975).

As with the Abrigo Formation and Dripping Spring Quartzite, the Bolsa Quartzite is only exposed in SAGU East, and only in small outcrops along the southern border in the vicinity of Colossal Cave. Additionally, much of it has been metamorphosed beyond quartzite, likely destroying any fossil remains due to the extreme temperature and pressure. Drewes did not report any fossils in the Bolsa Quartzite of the Rincon Valley and Happy Valley quadrangles (Drewes 1974, 1977).

Escabrosa Limestone (Lower-Middle Mississippian)

The Escabrosa Limestone is a carbonate unit deposited under shallow marine conditions (Beus 1989; Elliott and Blakey 2005), between about 359 and 333 million years ago (Beus 1989). It is considered a group by some stratigraphers, notably Armstrong, who identified the lower Escabrosa Limestone as the Keating Formation and the upper Escabrosa Limestone as the Hachita Formation (Armstrong 1962, 1965; Armstrong et al. 1978). There is a break in deposition between the two formations or portions of the Escabrosa Limestone (Armstrong and Mamet 1978). Fossils are best known from the lower and upper Keating Formation, and upper Hachita Formation (Armstrong 1962). The lower Keating Formation has produced foraminifera, corals, bryozoans, brachiopods, gastropods, trilobites, crinoids, and blastoids; the upper Keating Formation has produced foraminifera, corals, bryozoans, brachiopods, possible worms, and crinoids (Armstrong 1962); and the upper Hachita Formation has produced corals, bryozoans, and brachiopods (Armstrong 1965). Sponges, holothurians (sea cucumbers) (Langenheim and Epis 1957), and conodonts (Beus 1989) have also been reported from the Escabrosa Limestone.

The Escabrosa Limestone is present in both SAGU units. SAGU East has very small exposures in the west, and SAGU West has several exposures in the southwest. Both Drewes (1974, 1977) and Lipman (1993) reported that the Escabrosa Limestone has crinoids in their respective field areas, which may signal the potential for similar discoveries within the park.

Horquilla Limestone (Upper Pennsylvanian-?Lower Permian)

The Horquilla Limestone is dominated by limestones with interbedded mudstones. The limestones are interpreted as representing shallow marine to shoreline deposition, and the mudstones more terrestrial deposition. Mudstones increase toward the top, where the Horquilla Limestone grades into the Earp Formation. The Horquilla Limestone typically ranges in age from about 311 to 304 million years ago, from the Middle to Upper Pennsylvanian, although in areas of extreme southeastern Arizona and southwestern New Mexico it ends in the Lower Permian (Blakey and Knepp 1989). Fossils in the Horquilla Limestone are typically found toward the base and top of the formation, in the limestone beds (Ross 1973). Organisms known from the Horquilla Limestone include algae, fusulinid foraminifera (foraminifera are single-celled organisms that form a hard protective outer casing called a test; fusulinids are unusually large forams), corals, bryozoans, brachiopods (Ross and Sabins 1965), mollusks, crinoids (Blakey and Knepp 1989), conodonts (eel-like extinct chordates; Johnson et al. 1986), and rare echinoids and fish (Williams 1954), along with burrows and algal layering in the limestone (Blakey and Knepp 1989). Depending on rock unit correlation, there may be cartilaginous fish known from the Horquilla Limestone (Pennsylvanian Naco Formation of Elliott et al. 2004 and Elliott and Blakey 2005), and root traces in non-limestone beds (Kenny and Neet 1993). The fusulinid foraminifera in the Horquilla Limestone are useful for dating, and show that there are 9 to 11 fusulinid zones in the formation, separated by periods without deposition interpreted as the result of sea level fluctuation (Ross 1978).

The Horquilla Limestone is present in both SAGU East and West, although many of the SAGU East outcrops are metamorphosed. In SAGU East, it is found in isolated exposures in the south and west, and

in SAGU West, it is found in small outcrops in the southwest. Lipman (1993) did not report fossils in the Horquilla Limestone of the Tucson Mountains Caldera. Drewes (1974, 1977) noted that some unmetamorphosed beds had fusulinid foraminifera in the Rincon Valley and Happy Valley quadrangles.

Earp Formation (?Upper Pennsylvanian-Lower Permian)

The Earp Formation is a heterogeneous rock unit with an arbitrary lower boundary with the Horquilla Limestone, defined as where clastic (rock fragment) beds begin to predominate over limestone beds. It typically ranges in age between about 304 million years ago and sometime around 280 million years ago, and is thought to represent a variety of environments from shallow marine to shoreline, estuarine, coastal plain, and river, as sea level fluctuated (Blakey and Knepp 1989). Fossils found in Earp Formation rocks in Arizona pertain to a "typical Pennsylvanian shallow marine fauna," particularly fusulinid foraminifera, brachiopods, mollusks, and echinoids, along with burrows (Blakey and Knepp 1989). Different fossils are known from more terrestrial Earp Formation beds in southwestern New Mexico, including plants, brachiopods, conchostracans (bivalve-like crustaceans), ostracodes, pelecypods, and the tracks of temnospondyl amphibians and early reptiles (Lucas and Hunt 1995).

The Earp Formation is only present near the western border of SAGU East. Drewes (1974, 1977) did not report any fossils in the Earp Formation of the Rincon Valley and Happy Valley quadrangles.

Epitaph Formation (Lower Permian)

The Epitaph Formation (or Dolomite) is typically regarded as deriving in part from the underlying Colina Limestone, having been chemically altered into dolomite, incorporating clastics and limestone toward its top (Sabins 1957; Patch 1973; Blakey and Knepp 1989). The Earp Formation grades into the Colina/Epitaph, which in turn passes conformably into the overlying Scherrer Formation. The Colina/Epitaph ranges in age between sometime before 280 million years ago and sometime before 271 million years ago (Blakey and Knepp 1989). The Epitaph Formation has an uncertain depositional setting for its non-dolomite beds (Blakey and Knepp 1989), and has relatively few fossils compared to some other Naco Group formations. Butler (1971) reported corals, brachiopods, gastropods, and echinoids from the Epitaph Formation.

The Epitaph Formation is only present near the western border of SAGU East. Drewes (1974, 1977) did not report any fossils in the Epitaph Formation of the Rincon Valley and Happy Valley quadrangles.

Scherrer Formation (Lower Permian)

The Scherrer Formation is a heterogeneous unit of sandstone and carbonate rock (limestone or dolomite) beds, possibly deposited under marginal marine to mudflat conditions. Its age is not well known, but it was deposited after the Colina/Epitaph and before about 271 million years ago. The only abundant fossils belong to echinoids; "ghosts" of dissolved gastropod shells (Blakey and Knepp 1989), bryozoans, brachiopods, crinoids (Butler 1971), and burrows have also been found (Blodgett et al. 2002b).

The Scherrer Formation is found in both units of SAGU. There is only one outcrop of any size in SAGU East, in the western portion, and in SAGU West it is found with the other Paleozoic formations, in the southwest. Lipman (1993) did not report any fossils in the Scherrer Formation of the Tucson Mountains Caldera, and Drewes (1974, 1977) did not report any fossils in the Scherrer Formation of the Rincon Valley and Happy Valley quadrangles.

Recreation Red Beds (?Upper Triassic-Jurassic)

The Recreation Red Beds (or Redbeds) are composed of mudstone, shale, and sandstone from Jurassic or possibly Upper Triassic deposition (Lipman 1993) in terrestrial environments. These rocks have long been part of the confusion surrounding the Tucson Mountains Caldera. The term was introduced by Brown in 1939 for the red beds below the Amole Arkose in the Tucson Mountains, and greatly expanded by Mayo in 1963 to include overlying volcanic conglomerate and rhyolite tuff. Lipman (1993) recommended using Brown's original, more restricted definition. The age of the unit can only be inferred;

Brown (1939) suggested a Cretaceous age, but further work has shown that an igneous unit from 159 million years ago has intruded the rocks (Bikerman and Damon 1966), giving the Recreation Red Beds an age older than 159 million years ago. Otherwise, the age is not constrained, and could be older (Collins 2006). The Recreation Red Beds were thought to be unfossiliferous (Brown 1939). However, Collins (2006) has reported trace fossils in these rocks, about 0.40 km (0.25 miles) south of SAGU West, west of the Sonora Desert Museum. The fossils consisted of lizard tracks and a partial track of a three-toed dinosaur (no catalog numbers).

The Recreation Red Beds are only found in SAGU West, with outcrops in the southwest area of the park, running along the southwestern reaches of the northern Tucson Mountains. Lipman (1993) did not report any fossils from the Tucson Mountains Caldera exposures.

Glance Conglomerate (Upper Jurassic-Lower Cretaceous)

The Glance Conglomerate is a conglomerate of variable thickness and age, commonly incorporating Precambrian granite and schist, Paleozoic sedimentary rocks, and Jurassic igneous rocks, deposited as subaerial alluvial fans. This unit was long assumed to be Lower Cretaceous in total, but has datable volcanics from 150 million years ago (Dickinson et al. 1989). It does not have an *in situ* flora or fauna (Bilodeau 1978), but does include fossils from older units (Gilluly 1956), including Concha Limestone brachiopods (Lawton and Olmstead 1995).

The Glance Conglomerate is only present in SAGU East, near the west border. Drewes (1974, 1977) did not report any fossils from the Glance Conglomerate of the Rincon Valley and Happy Valley quadrangles, but did note that the outcrops were largely made up of the fragments of Paleozoic rocks, some of which may contain fossils.

Bisbee Group undivided (Upper Jurassic-Lower Cretaceous)

There are some outcrops of undivided Bisbee Group rocks in the western part of SAGU East, meaning that the formation is unknown. Aside from the Glance Conglomerate, the Willow Canyon Formation and Shellenberger Canyon Formation are known from the area (Drewes 1977). The Willow Canyon Formation is thought to represent braided floodplains and distal alluvial fans, with an uncertain Lower Cretaceous age (Dickinson et al. 1989). The Shellenberger Canyon Formation represents lake to lagoon or estuarine conditions (Dickinson et al. 1989), with an upper Lower Cretaceous age around 112 million years ago (Lucas and Heckert 2005). It has produced vertebrate fossils in the Empire Mountains about 45 km (28 miles) southeast of Tucson, including turtles, crocodiles, and sauropods (*Diplodocus*-like dinosaurs), nodosaurids (armored dinosaurs), and *Tenontosaurus* (a type of widespread herbivorous dinosaur related to the duckbilled hadrosaurs). In the Whetstone Mountains, about 50 km (30 miles) southeast of Tucson, marine invertebrates (including pelecypods) and pycnodontid fish are known from the Shellenberger Canyon Formation, as well as another *Tenontosaurus* bone from a more terrestrial bed.

Drewes (1974, 1977) did not report any fossils from the Bisbee Group rocks of the Rincon Valley and Happy Valley quadrangles.

Amole Arkose (Lower-Upper Cretaceous)

The Amole Arkose is a rock unit made up of feldspar-rich sandstone, with some siltstone and rare conglomerate and limestone. Its age is problematic: its base has been interpreted as of Early Cretaceous age (Risley 1987), but its upper extreme interbeds with ~73 million years ago rocks of the Tuff of Confidence Peak (Lucas et al. 2005). Thus, the Amole Arkose may include a lengthy time gap, or may be two rock units (R. McCord, pers. commun., August 2008). It was deposited in alluvial, lake, and floodplain settings (Risley 1987; Lipman 1993), and its fossils include algal laminations in lake rocks (Risley 1983, 1987), ostracodes (Bryant and Kinnison 1954), gastropods, pelecypods, conifer wood, coal, and peat (Brown 1939). Freshwater mussels (of a type known as unionids) are so common in one location, a saddle northeast of Cat Mountain about 9 km (6 miles) south-southeast of SAGU West, that they form a coquina, a rock made up mostly of shells (R. McCord, pers. commun., August 2008). Several

specimens of holostean fish (primitive bony fish that include gars and bowfins) have been recovered as well, south of Ajo Road (McCord and Gillette 2005). These were found outside of SAGU on private land, in the algal laminated limestone (R. McCord, pers. commun., August 2008).

There is also one published report of an Amole Arkose dinosaur, found 3 km (2 miles) from the south border of SAGU West near Gates Pass. Identifiable bones from this specimen, cataloged as University of Arizona Laboratory of Paleontology (UALP) 9007 and known as the "Tucson Mountains Dinosaur" (Lucas et al. 2005), include parts of the pelvis, at least seven vertebrae, the ends of a thigh bone, portions of the shin bones, and an ankle bone (McCord and Gillette 2005). These bones were first thought to pertain to an non-hadrosaur iguanodontian (similar to but not as specialized as a duckbilled dinosaur) that lived about 112 million years ago, but restudy indicates that the animal was a large duckbilled dinosaur (Lucas et al. 2005). Lucas et al. (2005) suggested an age of about 84 to 71 million years ago, while McCord and Gillette (2005) refrained from using the specimen to establish an age, noting that the proposed ages of the vertebrate remains of the Amole Arkose differ. The dinosaur suggests an age close to the end of the Cretaceous, the fish remains suggest a late Early Cretaceous age. The dinosaur specimen and the mussel coquina are among the Amole Arkose rocks caught up in the complex Cat Mountain tuff and megabreccia (R. McCord, pers. commun., August 2008).

The Amole Arkose is only found along the south border of SAGU. Lipman (1993) did not report any fossils from the Tucson Mountains Caldera exposures.

Pantano Formation (Upper Eocene-?Miocene)

The Pantano Formation is a heterogeneous rock unit with significant amounts of mudstone, conglomerate, and andesite lava flows. Rocks near its base are dated to 36.7 ± 1.1 million years ago, and a lava flow near its top to 24.4 ± 2.6 million years ago (Finnell 1970), so the formation spans the Upper Eocene through at least almost all of the Oligocene. It was deposited under terrestrial circumstances (Brennan 1962), possibly including an alkaline saline lake (Janders et al. 1978). Similar to the Glance Conglomerate, the Pantano Formation is regarded as unfossiliferous except for reworked fossils from older rock units (Finnell 1970).

The Pantano Formation is only found in SAGU East, with scattered outcrops in the south-central and northwest sections of the park. Drewes (1974, 1977) did not report any fossils in the Pantano Formation of the Rincon Valley and Happy Valley quadrangles.

Safford Dacite (Upper Oligocene)

The Safford Dacite is mostly composed of lava flows that were extruded from about 29 to 25 million years ago, in the Upper Oligocene. Despite its volcanic origins, plant fossils are known from interbedded sedimentary rocks. Brown (1939), in a publication on the Tucson Mountains, reported that conifer and dicot leaves are present in clay varve layers in Safford tuff, and reworked Cretaceous fossils can be found in a conglomerate that may be equivalent in age. The Safford Dacite is found only in SAGU West, and extensively outcrops in the northern portion. Lipman (1993) did not report any fossils from the Tucson Mountains Caldera exposures.

Brown also referred to a unit he unofficially designated as "Tertiary Lake Beds," which are distinct from the sedimentary units of the Safford Dacite and younger than them. The "Tertiary Lake Beds" preserve ostracodes in shale and algal laminations in limestone. It is not clear what these lake beds are. The best fit would seem to be the Pantano Formation, which is close to the right age and may include lake deposition (Janders et al. 1978). However, although the Pantano Formation was thought to outcrop in SAGU West in older reports (McColly 1961a), it was not represented by Lipman's 1993 map as being in SAGU West.

Unnamed Tertiary-Quaternary rocks

While the Tucson area of Pima County has several Quaternary sites (described under Quaternary Rocks and Sediments), there are not many older Tertiary finds that have been published from the area. The only

documented sites pertain to the Mineta Formation of Atravesada and the Quiburis Formation finds in the Redington area (Lindsay and Tessman 1974; Lindsay 1978; Nations and Landye 1984; Lucas and Morgan 2005; Morgan and White 2005; Lindsay and Mead 2005). The Atravesada locality, first published by Chew (1952), has produced a jaw of the rhinoceros *Dicetherium*, and is thought to date from around 32 million years ago, in the lower Oligocene (Lindsay and Tessman 1974; Lucas and Morgan 2005; Lindsay and Mead 2005). This site is also known as UALP 5 (Lindsay and Tessman 1974), and is about 10 km (6 miles) north of SAGU East. The Redington fauna, from the lower Quiburis Formation (about 5 million years ago, in the lower Pliocene), have been found at several quarries about 27 km (17 miles) north of SAGU East. Members of this fauna include bats, martens, badgers, wolverines, raccoons, two genera of canids, ursids, felids, three species of rabbits, rodents of the eomyid, heteromyid (three species), and murid (four species) families, equids, two genera of camelids, and two genera of antelopes (Morgan and White 2005).

Both units of SAGU have exposures of Tertiary-Quaternary rocks. Lipman (1993) did not report any fossils from them in the Tucson Mountains Caldera, and Drewes (1974, 1977) did not report any fossils from these rocks in the Rincon Valley and Happy Valley quadrangles.

Park Collections

Meg Weesner (SAGU chief of science and resource management, pers. commun., July 2008) confirmed the presence of paleontological specimens from SAGU at WACC. One specimen, SAGU 334, is a *Syringopora*, an extinct type of coral. It is from Devonian or Mississippian rocks (K. Beckwith, registrar, WACC, pers. commun., August 2008), which, if from the park itself, would suggest the Escabrosa Limestone.

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division coordinated geologic scoping for SAGU during April 2006. The participants of the SAGU Geologic Scoping meeting developed a series of recommendations for future work. Fossils are known from the bedrock exposures within the park (Abrigo Formation) and from packrat middens. There is good potential for continued fossil discovery within the park.
- The park should consider future field inventories for paleontological resources to more fully document *in situ* occurrences of fossils. The park may consider a formal site documentation and condition assessment for significant fossil localities. Monitoring of significant sites should be undertaken at least once a year in the future.
- A forthcoming (late 2008 or early 2009) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management and monitoring.
- Park staff should be encouraged to observe sedimentary rock exposures and 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 Western Archeology & Conservation Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Fossil packrat middens are typically found in dry rockshelters, and resemble piles or mounds of plant material with a dark glossy coating of crystallized packrat urine. Fossil middens can provide

important paleoecological information. If one is located, there are several midden researchers in the Southwest who may be contacted. The GRD maintains a list of active researchers and can facilitate communication between the park and these researchers.

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

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Data Sets

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

Saguaro National Park Museum Collections
1933-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by SAGU staff; status: Active.

Saguaro National Park collections at the Western Archeological Conservation Center (WACC)
1958-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by WACC staff; status: Active

United States Geological Survey collections
(museum specimens; associated specimen notes; collection records; maps; etc.). Originated by USGS staff; status: Active.

University of Arizona Laboratory of Paleontology collections
(museum specimens; associated specimen notes; collection records; maps; etc.). Originated by UALP staff; status: Active.

Tonto National Monument

Tonto National Monument (TONT) was proclaimed December 19, 1907 to protect cliff dwellings built by the Salado people during the 13th and 14th centuries. It was transferred to the National Park Service from the Forest Service (U.S. Department of Agriculture) on August 10, 1933, and was expanded to its present boundaries April 1, 1937. TONT today encompasses 453 ha (1,120 acres), all under Federal administration.

Geologic Background

TONT is located in the Tonto Basin within Tonto National Forest in Gila County, Arizona, southeast of the Salt River and near the south shore of Theodore Roosevelt Lake, a modern reservoir created in 1911. Found in the Basin and Range Province, TONT is part of an area of rugged topography near the southeast corner of the Mazatzal Mountains, and is also adjacent to several other small mountain ranges, including (counterclockwise from the west) the Superstition and Pinal Mountains and Sierra Anchas. TONT has been the subject of geologic reports by Gould (1938), Raup (1959), and the National Park Service (2006). All three are internal National Park Service documents.

The geological units present at TONT largely fall into two categories, from opposite ends of the geologic time scale (see Figure 2): formations in the Apache Group, deposited during the Mesoproterozoic about 1.3 to 1.1 billion years ago; and sedimentary rocks of Neogene age or younger (Raup 1959; Spencer and Richard 1999; Spencer et al. 1999). Rocks from both categories either are known to have fossil resources in the monument itself, or hold the potential for fossils. Fossils are also known from Paleozoic rocks found near TONT (the Devonian-age Martin Formation; Johnson 1995, 1999), but Paleozoic formations are not present in the monument and, based on the underlying geology, are unlikely to be found there (Spencer et al. 1999).

The stratigraphy of TONT incorporates only a handful of formations, of varying lithologies. In ascending order (oldest to youngest), the Pioneer Shale, Dripping Spring Quartzite, Mescal Limestone, and a capping basalt make up the Mesoproterozoic Apache Group, a group of formations exposed over ~42,000 km^2 of east-central Arizona (Wrucke 1989); all four of these are present at TONT. The base of the group, in the Pioneer Shale, was deposited approximately 1.3 billion years ago, during the Mesoproterozoic (Fletcher et al. 2004). The upper age is constrained by diabase sills that intruded the Mescal Limestone and overlaying Troy Quartzite sometime between 1.14 and 1.05 billion years ago (Wrucke 1989). Elsewhere the Apache Group rocks are overlain by the Troy Quartzite, but this Proterozoic unit is not present at TONT, except per a 1938 reference by Gould. He interpreted sedimentary rocks found in basalt flows there as from the Troy Quartzite, but this has not been supported by later research and may be due to contemporary confusion regarding the relationships of the Troy Quartzite, Mescal Limestone, the basalts that are sometimes found within the Mescal or capping it, the diabase sills, and overlying Cambrian formations (Wrucke 1989). Fossils or potential fossils have been reported from the Dripping Spring Quartzite (Horodyski et al. 1989) and Mescal Limestone (Wilson 1928; Raup 1959; McConnell 1973, 1974, 1975; Bertrand-Sarfati and Awramik 1992; Horodyski and Knauth 1994; Kenny and Krinsley 1998).

After the deposition of the Apache Group, no rocks have been preserved in the park until relatively recently. In the interim, faulting occurred around 19.4 to 18.9 million years ago (Nations 1990), leading to the rugged topography of TONT and the formation of Tonto Basin. Tonto Basin has been partially filled by a sedimentary unit known as the Gila Conglomerate, originally designated a formation but elevated to a group by some authors (Morgan et al. 1997; Thrasher 2004). This unit has a variety of depositional environments, from lake to floodplain to alluvial plain (Knetchel 1936), giving it variable lithology; in TONT, it is composed of conglomerate, gravel, and rare sandstone and siltstone (Raup 1959). The Gila Conglomerate ranges in age from possibly the late Miocene to the early Pleistocene (Thrasher 2004), but these ages are typically based on fossils from facies not present in TONT. Thus, the exact age of the Gila

Conglomerate in TONT is not known for certain, but is probably comparable to that seen elsewhere. Finally, there are Quaternary accumulations of rock debris, typically talus from Dripping Spring Quartzite and Mescal Limestone cliffs (Raup 1959). The Mesoproterozoic rocks of TONT dominate the southwestern half of the monument, and the Neogene and younger units are found in the northeastern half of TONT, and in valleys in the southwestern half.

Sources of Paleontological Resources

Dripping Spring Quartzite (Mesoproterozoic)

The Dripping Spring Quartzite is composed of three members: the basal Barnes Conglomerate Member of 0 to 18 m thickness, an arkose-rich middle member of 40 to 110 m thickness, and a siltstone-rich upper member of 55 to 130 m thickness (Wrucke 1989). A layer in the upper member known as the gray unit is known for its unusually high organic carbon content, particularly in its black subunit (Granger and Raup 1964; Wrucke 1989). It is in these dark shales of the upper member that acritarchs have been described, at Roosevelt Dam (Horodyski et al. 1989). Acritarchs are a nebulous group of microfossils of unknown evolutionary relationships. Raup (1959) in his report on TONT cited free carbon in the monument's exposures of Dripping Spring Quartzite as a possible sign of ancient life.

Mescal Limestone (Mesoproterozoic)

The Mescal Limestone, deposited between approximately 1.2 (Fletcher et al. 2004) and 1.1 billion years ago (Kenny and Knauth 2001), is known as a source of Proterozoic fossils. This unit is interpreted as having accumulated in a shallow sea as an intertidal to supratidal carbonate sequence, then being uplifted and weathered, followed by a combination of basalt eruption and additional deposition (Wrucke 1989; Kenny and Krinsley 1998). During the weathering, carbonate rocks were subject to dissolution to form cavities and caves, a process known as karstification (Beeunas and Knauth 1985; Kenny and Knauth 2001). The name Mescal Limestone is deceptive, as it was originally dolomite (Wrucke 1989), a carbonate rock with significant magnesium (limestone has little to no magnesium). Mescal Limestone rocks within TONT retain this dolomite composition (Raup 1959).

The Mescal Limestone is divided into four members. At the bottom is the lower member, 45 to 82 m thick, made up originally of dolomite and sandstone deposited under highly saline conditions, with later collapse breccias (rocks containing angular fragments). Next is the 12 to 40 m thick algal member, with stromatolites concentrated in the lower half to two thirds, followed by another layer of dolomite (Wrucke 1989). The stromatolitic portion of the algal member has strong lateral continuity (Conway and Wrucke 1986). Uplift and karstification occurred after the deposition of the algal member (Wrucke 1989). Following the algal member is usually an argillite (mudstone or shale) member 0 to 30 m thick, resting on the eroded upper surface of the algal unit. Rarely, a basalt layer 0 to 35 m thick is interposed between the two (Wrucke 1989). The argillite and basalt layers are only found in northern exposures of the formation (Armstrong and Wrucke 1990).

The stromatolites of the algal member outside of TONT have been the subjects of several reports (McConnell 1973, 1975; Bertrand-Sarfati and Awramik 1992). Stromatolites are not body fossils, but layered structures formed by algal colonies. Algal mats would passively trap sediment, which would block algal access to sunlight and nutrients, forcing the algae to grow over the sediment. This continuing process would lead to the formation of roughly concentric layers of sediment as long as the algal colony continued to grow and trap sediment. Today, stromatolites are only found in hypersaline tidal settings, such as Shark Bay, Australia, where prevailing conditions keep out animals that could feed on the algae building them, but in the Proterozoic, before the evolution of such grazers, stromatolites could form in a much wider range of settings (McConnell 1975). In the Mescal Limestone, there are two layers of stromatolites: a basal layer a few m thick of columnar stromatolites, followed by a thicker layer of stratified or pseudocolumnar stromatolites; conditions favorable to stromatolite growth did not last long enough for the creation of thick stromatolitic layers as seen in other formations. The stromatolites seen in the Mescal Limestone are unlike those present in other Proterozoic rocks of the southwestern United

States and northwestern Mexico, and also present unusually low diversity (Bertrand-Sarfati and Awramik 1992). The change from columnar to stratified stromatolites indicates a change from intertidal to possible supratidal conditions (Kenny and Krinsley 1998). Form taxa known from the Mescal Limestone include *Apachina henryi*, *Collenia frequens*, *Tungussia chyrotila*, *T. mescalita*, and possibly *Conophyton* cf. *garganicum* (Bertrand-Sarfiti and Awramik 1992). Per Raup (1959), apparent stromatolites are known from loose blocks of Mescal Limestone in Cholla Canyon, south of the Visitor Center in TONT. The stromatolites of the monument have not been described, however. The Museum of Northern Arizona has a stromatolite (MNA.P.890) in its collections from the Mescal Limestone at Theodore Roosevelt Dam (MNA.LOC.572-0), about 4.0 km (2.5 miles) northeast of TONT (J. Gillette, Museum of Northern Arizona, associate collections manager, pers. commun., July 2008).

The Mescal Limestone's reported fossils are not limited to stromatolites. It has also produced potential microfossils: filaments or spherules possibly from cyanobacteria (blue-green algae) found near the top of the Mescal Limestone, in the karsted zone (McConnell 1974; Horodyski and Knauth 1994; Kenny and Krinsley 1998; Skotnicki and Knauth 2001). These potential microfossils are included as evidence in a series of reports that argue for colonization of the Mescal Limestone terrestrial surface in the Mesoproterozoic (Beeunas and Knauth 1985; Horodyski and Knauth 1994; Kenny and Krinsley 1998; Kenny and Knauth, 2001). The uppermost Mescal Limestone is known to have been subjected to karstification before the intrusion of diabase sills, so it had terrestrial exposures during the Mesoproterozoic, and stable isotope analysis of the karsted rocks shows excursions that are suggestive of biological processes at this terrestrial interface (Kenny and Krinsley, 1998). Kenny and Knauth (2001), based on the magnitude of variation in carbon isotope levels, suggested substantial algal mats were present on the surface during the time of karstification, and that the laminated argillite laying over the paleokarst could be algal in origin. Skotnicki and Knauth (2001) interpreted microfossils and possible megafossils from the silica of the upper Mescal Limestone as evidence for cave biota or other near surface terrestrial Proterozoic biota. Microfossils are not known at this time from the Mescal Limestone at TONT, but given their microscopic size, could well be present. Their presence would be of interest to researchers on early life and the colonization of land.

Potential Sources of Paleontological Resources

Gila Conglomerate/Group (Miocene?-Pleistocene?)

The Gila Conglomerate or Group is a generalized term for late Cenozoic basin fill found throughout east-central Arizona and western New Mexico (Heindl 1962; Morgan et al. 1997; Thrasher 2004). Fossils are known from multiple locations within the Gila Conglomerate, typically in the lacustrine or floodplain depositional facies (Knetchel 1936; Lindsay and Tessman 1974; Nations and Landye 1984; Morgan and White 2005). The unit appears to be particularly productive in southern portions of Arizona's Graham and Greenlee counties, per maps in Nations and Landye (1984) and Morgan and White (2005), producing several well-studied faunas including the important 111 Ranch fauna. These faunas span the Blancan land mammal age, which lasted from about 4.75 to 1.806 million years ago. Common vertebrate constituents include turtles, snakes, birds, and a variety of mammals: glyptodonts; canids; badgers; bears; felids; rabbits; geomyid, heteromyid, and murid rodents; equids; peccaries; camelids; and gomphotherid proboscideans (Morgan and White 2005).

However, there has been very little published relating to Gila Conglomerate fossils from localities in Gila County, or nearby areas of the surrounding counties, with one notable exception in Tonto Basin. Fossils have been found in Pliocene-age Tonto Basin fill (unit not given) near Punkin (or Pumpkin) Center, a few kilometers northwest of Theodore Roosevelt Lake, or about 30 km (19 miles) northwest of TONT. Taxa represented include snails, ostracodes, a camelid, an equid (*Pliohippus* sp.), and multiple types of plants known from stems, leaves, fruitlets, pollen, and other remains (Gray 1960; Lance et al. 1962). Aside from the citations from the early 1960s, this locality has also been covered in reviews by Lindsay and Tessman (1974) and Mead and Lindsay (2005); it is the same as an otherwise undiscussed Pliocene locality mapped as Point 6 on Fig. 2.5 of Nations and Landye (1984) (E. Lindsay, University of Arizona geosciences

professor emeritus, pers. commun., 2008). Nations and Landye's Point 6 is identified as UALP-30 (a University of Arizona Laboratory of Paleontology locality). Lindsay (pers. commun., 2008) provided the following additional information on UALP-30. The locality is actually a series of sites explored over ten years within about a square mile, and may be on private land or covered by construction now. The fossils are from the Clarendonian land mammal age (approximately 12-9 million years ago, late Miocene), and thus somewhat older than better-known Gila Conglomerate faunas. A canid was reported in 1969, but Lindsay did not know of anything else being collected there since. Another camelid may have been collected from the area and curated at Arizona State University. The vertebrate taxa are not very diagnostic or well represented, and Lindsay could not relocate them in the University's collections in 2008.

The Gila Conglomerate has not yet produced fossils within the monument (Raup 1959), but holds the potential to do so. In the rugged topography of TONT, the Gila Conglomerate's lithology is largely conglomeratic (Raup 1959), so it is unlikely that any large articulated specimens would be found; single pieces of sturdy refractory abraded bone or wood would be more likely.

Quaternary rocks and sediments (Pleistocene-Holocene)

As with any park or monument in the SODN, any rocks or sediments of Quaternary age may contain isolated remains of the Quaternary fauna, such as testudinids, equids, camelids, and proboscideans (R. McCord, Arizona Museum of Natural History paleontologist, pers. commun., May 2008). Additionally, cave fossils are possible, as there are caves within TONT boundaries (in siltstones of the upper Dripping Spring Quartzite per Raup [1959]), and the distribution of packrats (*Neotoma* spp.) suggests that ancient packrat middens could be present in caves or crevices. See Santucci et al. (2001) for a discussion of paleontological resources associated with National Park Service caves. Again, as with the Gila Conglomerate there is little known about the Quaternary paleontology of Gila County and surrounding areas (Nations and Landye, 1984; Lucas and Morgan, 2005).

TONT, having been established to preserve the Salado cliff dwellings, also has the potential for fossils to be found among cultural artifacts. Tagg (1985) prepared a comprehensive study of the archeology of the monument, and found a good deal of remains of local flora and fauna; however, these are most likely too young to be within the purview of this inventory. Although Tagg reported that the Tonto Basin record of humans does not begin until about the Common Era (1 C.E. or A.D.), recent archeological survey in 2006 and 2007 at TONT indicates that humans occupied the land inside current TONT boundaries for nearly 10,000 years (D. Hubbard, TONT resource program manager, pers. commun., June 2008). See Kenworthy and Santucci (2006) for an overview of National Park Service fossils found in cultural resource contexts.

Park Collections

There are four specimens from TONT at the Western Archeological Conservation Center (WACC). TONT 2567 is a scraper with fossil impressions, TONT 4681 consists of two ground crinoid stem fragments, TONT 5509 is an unspecified fossil that is ground and split in half, and TONT 6930 is a possible piece of petrified wood. The latter three came from the upper ruin (K. Beckwith, registrar, WACC, pers. commun., August 2008). These are fossils from a cultural context, given that they are worked; TONT 4681 and 5509 are identified with the Salado culture (K. Beckwith, pers. commun., August 2008). Additionally, the crinoid specimen must have been brought in from elsewhere because there are no crinoid-bearing rocks exposed within TONT. Neither Gould (1938) nor Raup (1959) reported collecting any fossils from the monument.

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division coordinated geologic scoping for TONT during May 2006. The participants of the TONT Geologic Scoping meeting developed a series of

recommendations for future work. Fossils are known from the Mescal Limestone within the park and there is potential for additional fossil discoveries. Fossils originally discovered within a cultural resource context are within the TONT/WACC museum collections.

- The stromatolites of the Mescal Limestone, and the possibility that microfossils may be present within the Dripping Spring Quartzite and upper Mescal Limestone, indicate that TONT holds potential for researchers studying early life in general and early terrestrial life in particular. However, the wide distribution of the Mescal Limestone's algal member and other Apache Group units of interest makes the utility of the park's exposures equivocal, and the impossibility of finding the relevant microfossils by sight alone means that there is no way to know if they are present without involved laboratory study.
- The park should consider future field inventories for paleontological resources to more fully document *in situ* occurrences of fossils. The park may consider a formal site documentation and condition assessment for significant fossil localities. Monitoring of significant sites should be undertaken at least once a year in the future.
- A forthcoming (late 2008 or early 2009) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management and monitoring.
- Park staff should be encouraged to observe exposed cliffs, other erosional bedrock, and talus piles 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 Western Archeology & Conservation Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Fossil packrat middens are typically found in dry rockshelters, and resemble piles or mounds of plant material with a dark glossy coating of crystallized packrat urine. Fossil middens can provide important paleoecological information. If one is located, there are several midden researchers in the Southwest who may be contacted. The GRD maintains a list of active researchers and can facilitate communication between the park and these researchers.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at TONT.

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Data Sets

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

Tonto Natiojnal Monument collections at the Western Archeological Conservation Center (WACC)
1958-present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by WACC staff; status: Active

Tumacácori National Historical Park

Tumacácori National Historical Park (TUMA) was established to preserve the Spanish colonial Tumacácori Mission in southern Arizona. TUMA also includes the mission ruins of Calabazas and Guevavi. Each mission has a separate tract of land, giving TUMA three individual parcels. TUMA was proclaimed a national monument on September 15, 1908, and was redesignated a national historical park on August 6, 1990. Its boundaries have changed four times, on April 28, 1959, November 10, 1978, August 6, 1990, and August 21, 2002. TUMA encompasses 144.78 ha (357.74 acres), all but 1.04 ha (2.58 acres) of which are under Federal administration.

Geologic Background

TUMA is located in the Santa Cruz Valley in northwestern Santa Cruz County, Arizona. The three units are largely underlain by Quaternary sediments left by the Santa Cruz River and tributaries. Tumacácori Mission is on the west side of the Santa Cruz River, northeast of the Atascosa Mountains and southwest of the Santa Ritas. Calabazas and Guevavi are found to the southeast, in the vicinity of Mount Benedict. Calabazas is northwest of this landmark, and Guevavi is northeast. TUMA has been the subject of two internal National Park Service geologic reports, by Gould (1937) and the National Park Service's Geologic Resources Division (2006).

The TUMA area experienced Jurassic igneous activity, some of which occurred about 165 to 160 million years ago (see Figure 2 for a geologic time scale). The next rock-producing events occurred in the Upper Cretaceous with the Solaro Formation, largely consisting of sandstone. Volcanic activity followed in the Tertiary, with a pause between episodes recorded by the deposition of the Nogales Formation, mostly conglomerate and sandstone derived from the previous volcanic rocks. Deposition in the late Tertiary and Quaternary occurred in river, floodplain, and alluvial fan environments (Simons 1974; Youberg and Helmick 2001).

Tumacácori Mission's underlying rock units are Holocene-age floodplain, terrace, and alluvium deposits (Youberg and Helmick 2001). The sand, gravel, and conglomerate that it is found on eroded from nearby mountains and have an igneous origin (Gould 1937). Calabazas is built on alluvium ranging in age from Holocene to Pleistocene and possibly older. Guevavi is built on Quaternary alluvium and potentially some Jurassic-age igneous rocks (Simons 1974). Because the TUMA units are located away from current river drainage, and because of the lack of nearby fossiliferous formations, there is little chance of fossils eroding out of other formations and entering TUMA, unless the Santa Cruz changes course. Thus, potential fossils at TUMA would most likely be either in the Quaternary deposits, or associated with cultural artifacts.

Sources of Paleontological Resources

Currently the only documented fossils within the park are found in TUMA museum collections described in the "Park Collections" section below. The Quaternary rocks and sediments of the park, further described in the next section, may preserve fossils. Such fossils have not yet been documented within the park however.

Potential Sources of Paleontological Resources

Quaternary rocks and sediments (Pleistocene-Holocene)

As with any park or monument in the SODN, any rocks or sediments of Quaternary age may contain isolated remains of the Quaternary fauna, such as testudinids, equids, camelids, and proboscideans (R. McCord, Arizona Museum of Natural History paleontologist, pers. commun., May 2008). Additionally, the distribution of packrats (*Neotoma* spp.) suggests that ancient packrat middens could be present in

caves or crevices, although the topography of TUMA is not as conducive to middens as that of other Sonoran Desert Network units. Caves and karst, also sources for Quaternary fossils in Arizona, are not known at TUMA to date.

There are two Pleistocene-age sites in Santa Cruz County that have received wide publication, at Elgin School and the well-known Papago Springs Cave site. However, both of these sites are in the northeastern corner of the county and relatively distant from TUMA. There is a closer site, in the vicinity of Rio Rico about 6.5 km (4 miles) northwest of Guevavi, where the University of Arizona has recovered tortoise and mammoth remains (R. McCord, pers. commun., August 2008); this site has not been mentioned in the various reviews of Arizona paleontology. Two other sites that have not received a great deal of coverage are located north of Tumacácori: the fossils of two genera of testudinids, beavers, camelids, and equids have been found south of Green Valley, about 37 km (23 miles) away, and a testudinid known as the Duvall Tortoise was recovered near Sahurarita, about 42 km (26 miles) away (R. McCord, pers. commun., August 2008).

The closest published sites to TUMA are a cluster of sites in Pima County, about 24 km (15 miles) to the northwest in the Cerro Colorado Mountains (Lindsay and Tessman 1974; Lindsay 1978; Agenbroad 1984; Lindsay 1984; Nations and Landye 1984; Lucas and Morgan 2005). In this area, there are five University of Arizona Laboratory of Paleontology (UALP) sites, with typical Quaternary vertebrate fauna fossils. Cerro Colorado #1 (UALP-6919) has produced the tortoise *Geochelone*, unclassified bird remains, *Mammuthus*, and *Equus*. Cerro Colorado #2 (UALP-7013) and Calera Ranch (UALP-6951) have also produced *Mammuthus* remains. Canez Wash #1 (UALP-6920) has produced *Mammuthus* and *Equus*, and Canez Wash #2 (UALP-6948) has produced *Equus* (Lindsay and Tessman 1974).

Park Collections

There are at least four fossils from TUMA collections at the Western Archeological Conservation Center. TUMA 359 is a possible echinoid, TUMA 445 is a vertebra, TUMA 3404 is an ammonite, and TUMA 3656 is a shark tooth. TUMA 3404 came from the vicinity of Tumacácori, but the other three come from unknown locations (K. Beckwith, registrar, WACC, pers. commun., August 2008). Given the paucity of fossiliferous formations in the TUMA area, and the lack of marine rocks, the specimens were probably all brought from elsewhere.

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division coordinated geologic scoping for TUMA during April 2006. The participants of the TUMA Geologic Scoping meeting developed a series of recommendations for future work. The only fossils known from the park are the fossils within park collections. These specimens were likely brought in from outside of the park.
- 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 Western Archeology & Conservation Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Fossil packrat middens are typically found in dry rockshelters, and resemble piles or mounds of plant material with a dark glossy coating of crystallized packrat urine. Fossil middens can provide important paleoecological information. If one is located, there are several midden researchers in

the Southwest who may be contacted. The GRD maintains a list of active researchers and can facilitate communication between the park and these researchers.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at TUMA.

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Data Sets

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Tuzigoot National Monument

Tuzigoot National Monument (TUZI) was proclaimed July 25, 1939, to protect the ruins of a large pueblo built by the Sinagua people between about 1100 and 1450. Its boundaries were changed November 10, 1978 and March 28, 2006, in order to add Tavasci Marsh and other lands. Currently, TUZI encompasses 328.57 ha (811.89 acres), 157 ha (388 acres) of which are under Federal administration.

Geologic Background

TUZI is located near the northwestern end of the Verde Valley in Yavapai County, Arizona, and the Verde River passes through its southern extreme. It is just east of Clarkdale, and encompasses portions of a partially dry oxbow. Mingus Mountain, the highest point in Arizona's Black Hills, is found to the west. TUZI has been the subject of a geologic resources scoping report by the Geological Resources Division of the National Park Service (2006); this is an internal National Park Service document.

The geologic history of the area is one of cycles of sea level change recorded by marine and terrestrial deposition in the Paleozoic, followed by a prolonged period of terrestrial exposure with little to no preserved deposition from the Mesozoic to the middle of the Cenozoic (see Figure 2 for a geologic time scale). This was followed by volcanism, tectonic activity, and the formation of the Verde Valley in the Miocene, and partial flooding of the basin due to damming of the Verde River by lava flows and faulting through the Pliocene. More recently, there has been tectonic stabilization and basin reorganization up to the present, after the dams were breached for the last time in the early Quaternary (Lehner 1962; Nations et al. 1981).

TUZI itself preserves only rocks from late Cenozoic and younger events. Most of the rocks are either lake deposits of the Verde Formation (Middle Miocene-Pliocene), Quaternary river terraces from the Verde River, and Recent artificial fill (mine tailings), with Recent river wash as well. However, the monument is only a short distance (a few kilometers or miles) east and south from a variety of Paleozoic rock units (Lehner 1958; House and Pearthree 1993). Given that the Verde River passes through TUZI, there is potential for rocks from these other formations to be transported into the monument. This is important because several of them are fossiliferous.

In order from oldest to youngest, potential sources of eroded rocks in the vicinity include the Deception Rhyolite (Proterozoic), Grapevine Gulch Formation (Proterozoic), Tapeats Sandstone (Cambrian) unnamed Proterozoic igneous rocks, Martin Formation (lower Upper Devonian), Redwall Limestone (Mississippian), Supai Group (Upper Pennsylvanian- Lower Permian), Hermit Formation (Lower Permian), Schnebly Hill Formation (Lower Permian), Coconino Sandstone (Lower Permian), Toroweap Formation (Lower Permian), Kaibab Formation (Lower Permian), and Hickey Formation (Miocene). Fossils are known from a number of these formations, including: the Tapeats Sandstone, Martin Sandstone, Redwall Limestone, Supai Group, Hermit Formation, Schnebly Hill Formation, Coconino Sandstone, Toroweap Formation, and Kaibab Limestone. Given the steep topography (exposures of the Coconino Sandstone are more than 450 m (1500 ft) higher in elevation than TUZI), relative distance of some of these formations, and extent of outcrops, the most likely sources for recognizable eroded fossils are the Martin Formation and Redwall Limestone. Since the Verde River only passes through the extreme southern section of TUZI at this time, modern transport would leave Paleozoic rocks only in this southern area; however, the oxbow shows that the Verde River once had a more circuitous route in what would become TUZI boundaries, so older transported material could be found in a much wider area. Additionally, the Verde Formation has produced fossils within or near TUZI boundaries (J. Gillette, Museum of Northern Arizona, associate collections manager, pers. commun., June 2008), with well-documented localities as near as about 3 km (2 miles) from TUZI (Twenter 1962; Czaplewski 1987a).

Note that Lehner (1958), which is used as one of the base maps for the TUZI scoping summary, has outdated stratigraphy concerning the Supai Formation. Ron Blakey proposed a revision (see Blakey and

Knepp 1989 and Blakey 1990a for versions) incorporating recognition of different members in the Supai, and removal of several upper units. Thus, the lower member of the Supai Formation (per Lehner 1958) is divided into, in ascending order, the Watahomigi Formation, Manakacha Formation, Wescogame Formation, and Esplande Sandstone of the Supai Group. The middle member is reassigned to the Hermit Formation, and the upper member is reassigned to the Schnebly Hill Formation. This revision, while not accepted wholeheartedly at the time (Peirce 1989), appears to be in wide use today. The contributions to the 2005 New Mexico Museum of Natural History and Science bulletin on vertebrate paleontology of Arizona (although note that Blakey is a contributor) reflect this new interpretation. There is also a conflict with the scoping report; this document reports that marine invertebrate fossils are present at TUZI, and cites Beus (1978) for more information. Beus (1978) deals with the Martin Formation, which is not exposed within TUZI (Lehner 1958; House and Pearthree 1993) but could be a source of eroded fossils. Future field investigation may yield additional information.

Sources of Paleontological Resources

Verde Formation (Middle Miocene-Pliocene)

The Verde Formation is a heterogeneous formation formed from a combination of tectonics, volcanism, and the action of the Verde River, with much of its deposition due to the river being tectonically dammed and turned into a lake (Nations et al. 1981). Its age is constrained by underlying volcanics from 14 million years ago (Royse and Wadell 1970), internal basalt flows of 8.3, 5.5, and 4.5 million years ago (Nations et al. 1981), mammal faunal ages, and paleomagnetic evidence (Czaplewski 1987a). Deposition began in the Miocene with unfossiliferous clastic material leading to limestone, dolomite, and evaporites later in the Miocene, followed by mostly limestone deposition in the Pliocene; spring deposits, as at Montezuma Well, are also present. Miocene-age Verde Formation fossils are limited and mostly found in the southern Verde Basin, with diatoms in the lower Miocene beds, and algae, diatoms, plants, mollusks, ostracodes, amphibians, rodents, artiodactyls, and mammal tracks in the upper Miocene (Nations et al. 1981); these tracks include "Elephant Hill" at Montezuma Castle (Brady and Seff 1959; Nations and Landye 1984; Hunt et al. 2005b; see MOCA section of this report for more information). However, two of the Miocene sites are among the Buckboard Wash localities and only about 5 km (3 miles) northeast of TUZI (Twenter 1962; see below for more information on the Buckboard Wash). The Miocene organisms lived in a basin that was periodically flooded when the Verde River was cut off from external drainage.

By the Pliocene, the lack of evaporites indicates that the river, while still forming a shallow lake, had some external drainage to prevent concentration. Fossils from the Pliocene portion of the formation include algae, diatoms, various parts of a variety of vascular plants (herbs and sedges to gymnosperm and deciduous trees, many of which no longer live in Arizona), gastropods, fish, turtles, bats, rodents, rabbits, camelids, equids, and proboscideans (Nations et al. 1981). Lehner (1958) reported possible plant stems in the Verde Formation of the Clarkdale Quadrangle. Several fossil sites are known within or near TUZI boundaries.

The Museum of Northern Arizona has two locality numbers assigned to Verde Formation fossil sites within or directly adjacent to TUZI. MNA 330-0 appears to be within current TUZI boundaries, and has produced gastropod plant (MNA.P.739) and gastropod fossils (MNA.N.1429, 1430, 1715, 6959, and 6960). MNA 1475, a quarry at adjacent Pecks Lake, has produced tortoise remains (MNA.V.9149), although it is not certain if the site is from the Verde (J. Gillette, pers. commun., June 2008).

There is one well-documented Verde Formation fossil locality about 5 km (3 miles) to the northwest of TUZI; this site, MNA 181-1 (or just MNA 181) was found near the top of the formation in a Phoenix Cement Company Plant quarry. It has produced what is known as the Clarkdale Local Fauna, made up mostly of microvertebrates such as rodents. This site has produced slug plates and remains of cyprinid and other fish, salamanders, tortoises and turtles, iguanid lizards, colubrid snakes, turkeys, bats, rabbits, diverse rodents, a felid, the gomphothere *Stegomastodon*, equids, camelids, and antelopes (Czaplewski 1987a). This fauna is currently dated to the late early Blancan land mammal age (about 3.5 to 2.7 million

years ago; Morgan and White, 2005). Another, less documented set of fossil localities known collectively as Buckboard Wash has localities about 3 km (2 miles) north of TUZI (Twenter 1962; Czaplewski 1987b; J. Gillette, Museum of Northern Arizona, associate collections manager, pers. commun., June 2008). These nearby sites, MNA 701-1 and 701-2, have produced fossils from fish, salamanders, tortoises, rodents, rabbits, and bats (J. Gillette, pers. commun., June 2008).

Potential Sources of Paleontological Resources

Tapeats Sandstone (Lower-Middle Cambrian)

The Tapeats Sandstone, best known farther north in the Grand Canyon area (Middleton 1989), has at least one small exposure west of TUZI (Lehner 1958). It was deposited during the Lower and Middle Cambrian, about 540 to 510 million years ago. It is interpreted as representing shallow marine sand deposition under significant tidal influence, with more terrestrial environments toward the base (Hereford 1977; Middleton 1989). In the nearby Jerome area, it is interpreted as showing a tidal channel environment (Hereford 1977). Body fossils are not known from this unit, but the vertical burrow trace fossil *Corophioides* (perhaps from something like a polychaete worm) is common in the upper part of the formation (Hereford 1977; Blakey and Middleton 1988).

Martin Formation (lower Upper Devonian)

The Martin Formation (or Martin Limestone) is largely made up of limestone or dolomite and has two members, deposited roughly 385 to 375 million years ago as a sea was moving into Arizona from the west. The lower, thinner Beckers Butte Member is made up of sandstone and conglomerate (Beus 1989), and has been interpreted as nonmarine channel fill or a transitional to marine environment. The upper, thicker Jerome Member is interpreted as a shallow continental shelf (Beus 1969). Both are known to produce fossils, but the Beckers Butte Member may be absent from the Verde Valley (Beus 1978). The Jerome Member is mostly unfossiliferous except for the upper section and rare finds in the middle (Beus 1978). Most fossils in the upper section are marine invertebrates, but conodonts (eel-like chordates) (Ethington 1962, 1965) and a largely undescribed fish fauna are also present (Johnson and Elliott 1990, 1996; Elliott and Blakey 2005). Common fossils include stromatoporoids (reef-building sponges) (Beus 1978), corals, brachiopods, mollusks (particularly gastropods and pelecypods), and conodonts (Beus 1969, 1989). Fish include several genera of placoderms (early jawed fish) and at least three sarcopterygians (lobe-fins). Fish fossils, mostly plates and teeth, are often found in paleovalley deposits (Elliott and Blakey 2005). At the top of the formation is another assemblage, composed of serpulid worm burrows forming bioherms (mounds, like worm-burrow reefs) among algal laminations and stromatolites, suggesting a quiet inter- or shallow tidal environment (Beus 1979, 1980). This formation has significant exposures within about 6 km (4 miles) of TUZI (Lehner 1958), and has produced fossils in at least sixteen localities in the upper Verde Valley, several just beyond the 6 km distance, near Jerome (Beus 1978). Lehner (1958) reported that he collected no fossils or other paleontological data while mapping the Clarkdale quadrangle.

Redwall Limestone (Lower-Middle Mississippian)

The Redwall Limestone is, as its name suggests, made up mostly of limestone, with some dolomite, chert, and mudstone. It is interpreted as a marine formation recording two cycles of a sea advancing and regressing over the landscape between roughly 360 and 330 million years ago (Beus 1989). It is divided into four members, each of which has produced fossils, mostly marine invertebrates (Kent and Rawson 1980; Beus 1989). Fossils include most commonly foraminifera (single-cell shell-dwellers), corals, brachiopods, and crinoids, then gastropods, pelecypods, cephalopods, and blastoids, and more rarely algae, ostracodes (tiny shell-dwelling crustaceans), trilobites, holothurians (sea cucumbers), and fish (McKee and Gutschick 1969); stromatolites (Kent and Rawson 1980) and conodonts (Beus 1989) are also known. An interesting phenomenon is the mass-kill bed of nautiloid cephalopods found near the top of the lowest member and extending from Marble Canyon to Frenchman Mountain near Las Vegas, containing the remains of possibly billions of individuals (Austin and Wise 2002). Vertebrates from the Redwall Limestone are poorly known, with fragmentary remains representing four genera of

chondrichthyan fish (today including sharks, rays, and chimaeras) (Elliott and Blakey 2005). Like the Martin Formation, the Redwall Limestone has significant exposures within about 6 km of TUZI (Lehner 1958). Lehner (1958) reported crinoids in the third unit, and unidentified fossils in the second, from the Clarkdale Quadrangle.

Supai Group (Middle Pennsylvanian-Lower Permian)

The Supai Group (deposited between approximately 320 to 280 million years ago depending on location; Lower Supai of Lehner 1958 per Blakey and Knepp 1989) is divided into four formations (Blakey and Knepp 1989), but their divisions may not be apparent in the Verde Valley; only the Esplande Sandstone and an undivided underlying section are recognized in the Sedona area by Blakey (1990a). The Supai Group has been interpreted as a delta (Hughes 1949, 1952; Jackson 1951), and as being deposited under generally marine conditions going to more terrestrial conditions (Blakey 1990a). Fossils known from the Supai under Blakey's definition include foraminifera, brachiopods, and other marine invertebrates (Blakey 1990b), rare teeth of the holocephalian chondrichthyan *Deltodus*, footprints of two tetrapods (Elliott and Blakey 2005), and plant fossils in the upper Supai, with ferns and gymnosperm trees the dominant taxa (Canright 1978). Exposures of the Supai Group are extensive west and north of TUZI (Lehner 1958).

More remote Paleozoic formations

In order from oldest to youngest, the Hermit Formation, Schnebly Hill Formation, Coconino Sandstone, Toroweap Formation, and Kaibab Formation all have exposures between 10 and 24 km (6 and 15 miles) from TUZI. However, they also are generally more than 305 m (1,000 ft) higher in elevation than TUZI, going to 610 or 915 m (2,000 or 3,000 ft) for the youngest formations (Lehner 1958). With an elevation change of this extent over just a few miles of horizontal difference, identifiable fossils from these locations would have to survive a hazardous transport.

The Hermit Formation (Lower Permian, deposited between 300 million years ago and sometime before 275 million years ago depending on location, also Hermit Shale; Middle Supai of Lehner 1958 per Blakey and Knepp 1989) is mostly mudstone and siltstone red beds interpreted as a fluvial system (Blakey 1990a). It is known for plant fossils (Mamay and Watt 1971) and tetrapod tracks; trackmakers include temnospondyl amphibians, early reptiles, and pelycosaur synapsids (mammal-like reptiles) (Hunt et al. 2005a).

The Schnebly Hill Formation (Lower Permian, deposited between 280 and 275 million years ago; Upper Supai of Lehner 1958 per Blakey and Knepp 1989) is a heterogeneous rock unit of sandstone, siltstone, mudstone, evaporites, limestone, and dolomite, interpreted as a basin rimmed by wind-blown sand deposits. This unit is divided into six members; the third from the top, the Fort Apache Member, is a fossiliferous unit of limestone, dolomite, evaporites, and siltstone (Blakey 1990a), probably from a shallow marine shelf and shoreline setting (Blakey and Knepp 1989). Fort Apache Member fossils are mostly marine invertebrates, particularly mollusks and echinoderms, and come from the limestone and dolomite layers. Organisms represented include algae, foraminifera, corals, bryozoans, brachiopods, worm-like animals, gastropods, pelecypods, scaphopods, cephalopods, ostracodes, trilobites, and echinoids (Gerrard 1969; the worms are known only from trace fossils); tetrapods are represented by a single track from the possible pelycosaur *Dimetropus* (Hunt et al. 2005a).

The Coconino Sandstone (Lower Permian, deposited about 275 million years ago) is a dune sandstone, deposited by wind action (Blakey and Knepp 1989). It is known for its tetrapod tracks, long assigned to a variety of trackmakers but probably from only three ichnospecies pertaining to *Chelichus*, thought to be a synapsid (McKeever and Haubold 1996; Hunt et al. 2005a). Invertebrate traces are also known, including possible worms, millipedes, isopods, spiders, and scorpions (Middleton et al. 1990).

The Toroweap Formation (Lower Permian, deposited between about 275 and 270 million years ago) is largely limestone, with sandstone, mudstone, evaporites, and dolomite. It is interpreted as a marine shelf

to coastal salt flat environment of deposition; it is fossiliferous, though lacking in fossils useful for dating (Blakey and Knepp 1989). Fossils include sponges (Rigby 1988), corals, bryozoans, brachiopods, gastropods, pelecypods, cephalopods, scaphopods, crinoids (Turner 1990), and possible fish plates (Hunt et al. 2005a); there are two distinct assortments, one dominated by mollusks, and one interpreted as open marine, hosting the coral-bryozoan-brachiopod-crinoid fauna (Turner 1990).

The Kaibab Formation (Lower-Middle Permian, deposited about 270 million years ago) is a heterogeneous formation composed mostly of limestone and dolomite, formed in a variety of settings from shallow marine to salt flat to coastal plain (Blakey and Knepp 1989). It has abundant fossils of marine invertebrates, including sponges, foraminifera, corals, bryozoans, brachiopods, gastropods, pelecypods, scaphopods, cephalopods, trilobites, ostracodes, crinoids, and conodonts. As with the Toroweap Formation, there are distinct mollusk and open marine faunas (Hopkins 1990). Additionally, there are a few reports of chondrichthyan and phyllodont fish teeth and tooth plates (Hunt et al. 2005a).

Quaternary rocks and sediments (Pleistocene-Holocene)

As with any park or monument in the SODN, any rocks or sediments of Quaternary age may contain isolated remains of the Quaternary fauna, such as testudinids, equids, camelids, and proboscideans (R. McCord, Arizona Museum of Natural History paleontologist, pers. commun., May 2008). Additionally, the distribution of packrats (*Neotoma* spp.) suggests that ancient packrat middens could be present in caves or crevices, although the relatively level topography of TUZI makes it less likely than other Sonoran Desert Network parks and monuments to have the necessary settings. Caves and karst are not known at TUZI, but the Tavasci Marsh, added in 2006, has not been inventoried (National Park Service 2006). See Santucci et al. (2001) for a discussion of paleontological resources associated with National Park Service caves.

There is little known about the Quaternary paleontology of Yavapai County and surrounding areas (Lindsay and Tessman 1974; Nations and Landye 1984; Agenbroad 1984; Lucas and Morgan 2005). The best-known Quaternary fossils in the county are Holocene plants, diatoms, and invertebrate fossils from Montezuma Well (Davis and Shafer 1992; Blinn et al. 1994). Nations and Landye (1984) assign Pleistocene remains to the nearby Buckboard Wash, but this is not followed by other reports (Lindsay and Tessman 1974; Nations 1974; Nations et al. 1981; Agenbroad 1984; Lucas and Morgan 2005), and may just be a case of mistaken age. Aside from the Montezuma Well finds, and this equivocal report, there appears to be only one other documented Quaternary locality in all of Yavapai County, over 58 km (36 miles) southwest of the Verde Valley at Black Mountain (Lindsay and Tessman 1974; Nations and Landye 1984; Lucas and Morgan 2005). This site, Museum of Northern Arizona (MNA) 190, has produced remains of *Mammathus* (Lindsay and Tessman 1974). TUZI, having been established to preserve Sinagua ruins, also has the potential for fossils to be found among cultural artifacts. See Kenworthy and Santucci (2006) for an overview of National Park Service fossils found in cultural resource contexts.

Park Collections

Dennis Casper (TUZI resource program manager, pers. commun., May 2008) did not know of any paleontological resources in TUZI collections.

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division coordinated geologic scoping for TUZI during May 2006. The participants of the TUZI Geologic Scoping meeting developed a series of recommendations for future work. While Paleozoic fossils are not yet known *in situ* from TUZI (contra the 2006 scoping report), the Verde Formation that underlies TUZI is known to be fossiliferous in the area and probably within the monument itself, and eroded fossils from nearby Paleozoic formation (mostly marine invertebrates) may be transported into the monument by the Verde River. Fossils are not yet confirmed from the monument's museum collections.

- The park should consider future field inventories for paleontological resources to more fully document in situ occurrences of fossils. The park may consider a formal site documentation and condition assessment for significant fossil localities. Monitoring of significant sites should be undertaken at least once a year in the future.
- A forthcoming (late 2008 or early 2009) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource management and monitoring.
- Because there is a Museum of Northern Arizona locality for the Verde Formation at or near TUZI, it may be worthwhile to make arrangements with the MNA to investigate the old finds.
- Park staff should be encouraged to observe exposed bedrock, old river deposits, and the modern Verde channel 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 Western Archeology & Conservation Center and the Geologic Resources Division can coordinate additional documentation/research of such material.
- Fossil packrat middens are typically found in dry rockshelters, and resemble piles or mounds of plant material with a dark glossy coating of crystallized packrat urine. Fossil middens can provide important paleoecological information. If one is located, there are several midden researchers in the Southwest who may be contacted. The GRD maintains a list of active researchers and can facilitate communication between the park and these researchers.
- Contact the NPS Geologic Resources Division for any additional assistance regarding paleontological resource management or interpretation at TUZI.

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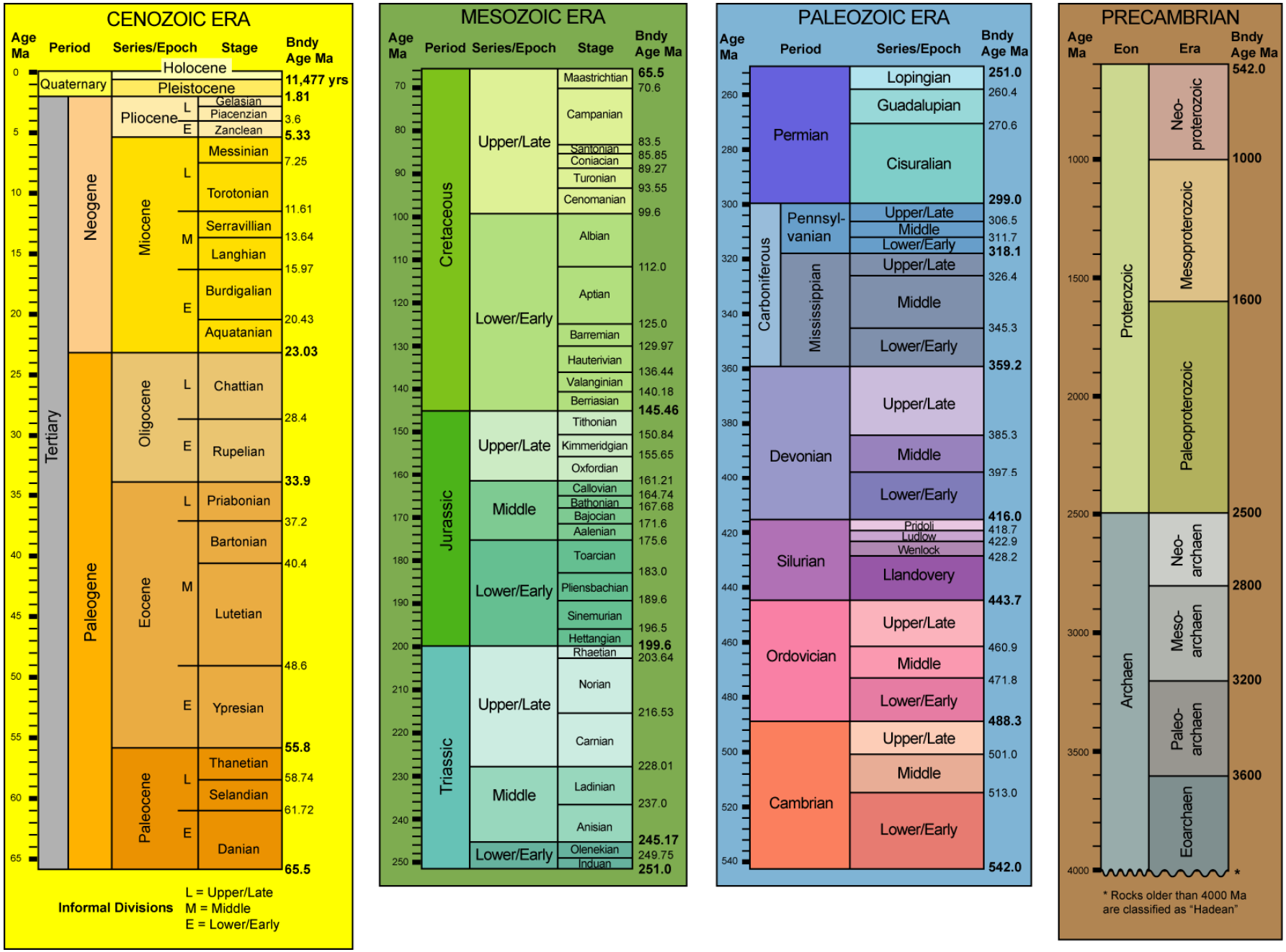


Figure 2. Geologic Time Scale. *Ma = Millions of year old. Bndy Age = Boundary Age*. Colors are USGS standard colors found on geologic maps. Modified from 1999 Geological Society of America Time scale (www.geosociety.org/science/timescale/timescl.pdf). Boundary dates and additional information from 2004 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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