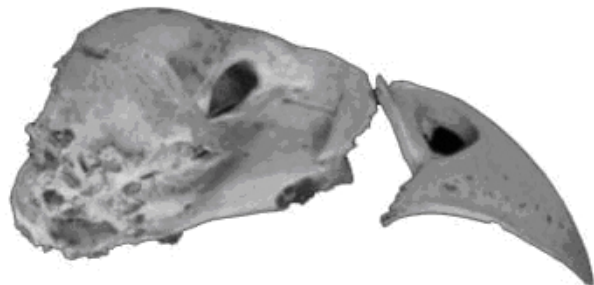
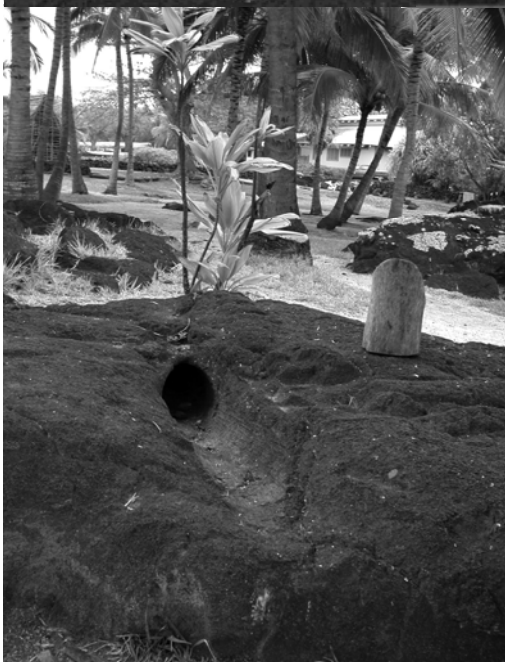
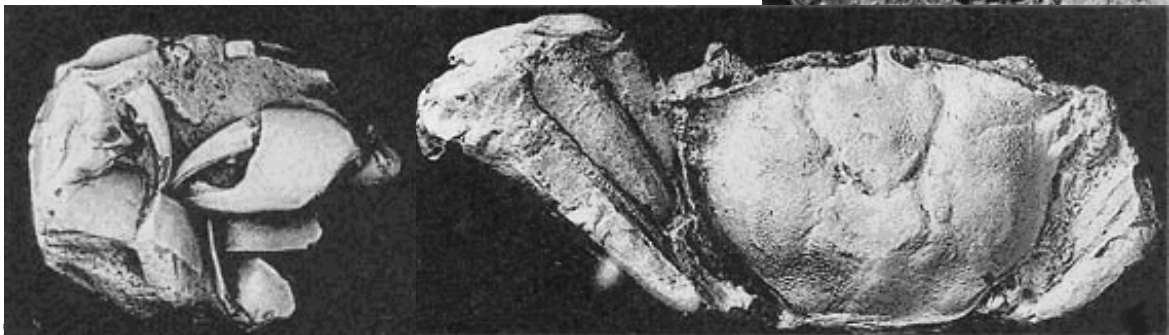




Paleontological Resource Inventory and Monitoring

Pacific Island Network



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NOTE:

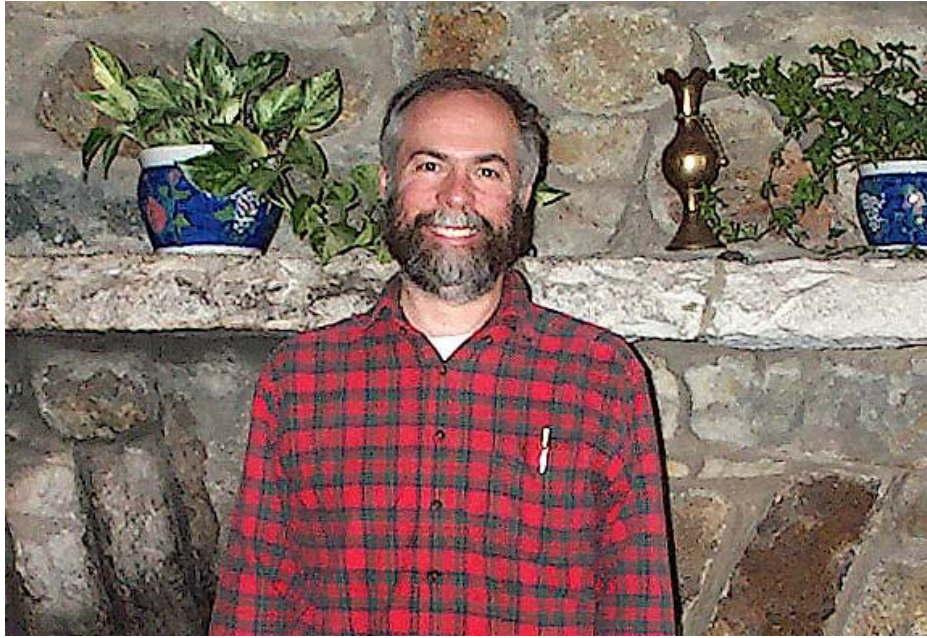
This report provides baseline paleontological resource data to National Park Service administration and resource management staff. The report contains information regarding the location of non-renewable paleontological resources within NPS units. **It is not intended for distribution to the general public.**

On the Cover:

An assortment of fossils from Pacific Island Network parks. Top left: Extinct moa-nalo (*Thambetochen chauliodous*; HALE; photo courtesy of Helen James). Top right: Human footprints are found within the hardened Keanakakoi Ash deposits of the Kau desert, within HAVO (NPS photo). Fossil crustaceans are well known from the island of Guam (Center Left - *Macrophthalmus guamensis*; Center Right – *M. latreilli*; Courtesy of University of Michigan Museum of Paleontology). Below Right: Fern impression discovered within volcanic ash of HAVO (NPS Photo courtesy of Jadelyn Moniz-Nakamura). Bottom Right: At HALE, fossils of both extinct and extant birds were found in the lava tubes, including the extinct koa-finch *Rhodacanthis forfex* (photo courtesy of Helen James). Bottom Left: Tree Molds are known from PUHO (pictured) and HAVO. These molds form when the trees were engulfed by the eruptions, but not immediately consumed by the lavas, leaving behind tree mold trace fossils (NPS Photo courtesy of Paula Hartzell). For more information, refer to each park's section in this report.

How to cite this document:

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This report is dedicated to NPS Geologic Resources Division Geologist and Washington Liaison Lindsay McClelland for his more than 15 years of enthusiastic support of NPS paleontological resource documentation efforts.

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INTRODUCTION

Paleontological resources, or fossils, are any remains of past life preserved in a geologic context. There are two main types of fossils: body fossils and trace fossils. Body fossils are parts 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 in National Park Service (NPS) areas. Although more than 180 NPS areas have been identified with paleontological resources, only a small percentage of those parks have adequate baseline paleontological resource data.

In conjunction with the NPS Geologic Resources Division and NPS Inventory and Monitoring (I&M) Program, paleontological resource inventories have been initiated in dozens of parks service-wide and are further described in the Methodology and Inventory Strategies section. This report presents paleontological resource inventory and monitoring data compiled for the parks of the Pacific Islands I&M Network (PACN).

The Pacific Island Network includes eleven National Park Service areas in the Commonwealth of the Northern Mariana Islands (island of Saipan), the state of Hawaii (on the islands of Hawaii, Oahu, Molokai and Maui), and the Territories of America Samoa (islands of Tutuila and the Manua group) and Guam as shown in Figure 1: Ala Kahakai National Historic Trail (Hawaii; ALKA), American Memorial Park (Commonwealth of the Northern Mariana Islands; AMME), Haleakala National Park (Hawaii; HALE), Hawaii Volcanoes National Park (Hawaii; HAVO), Kalaupapa National Historical Park (Hawaii; KALA), Kaloko-Honokohau National Historical Park (Hawaii; KAHO), National Park of America Samoa (Territory of America Samoa; NPSA), Puuhonua o Honaunau National Historical Park (Hawaii; PUHO), Puukohola Heiau National Historic Site (Hawaii; PUHE), USS Arizona Memorial (Hawaii; USAR), and War in the Pacific National Historical Park (Territory of Guam; WAPA). All together, the parks of the PACN encompass more than 376,000 acres and hosted approximately 5.4 million visitors in FY2006. Nine PACN parks were established for significant cultural and historic resources related to the native Pacific Islanders' culture and World War II (AMME, ALKA, HAVO, KAHO, NPSA, PUHO, PUHE, USAR, WAPA). Four parks in the network were established to preserve natural resources (ALKA, HALE, HAVO, NPSA).

While none of the parks were established specifically for paleontological resource stewardship, fossils are known from four of the PACN parks including Haleakala National Park, Hawaii Volcanoes National Park, Puuhonua o Honaunau National Historical Park, and War in the Pacific National Historical Park. Geologic formations that have produced fossils outside of park boundaries occur within American Memorial Park and War in the Pacific National Historical Park. Future fossil finds are possible from these formations within the parks, except for USAR, which is in a marine embayment. The paleontological resources of the PACN are unusual. Most PACN parks are on volcanic islands and incorporate a significant amount of igneous rocks. Due to their high temperature of formation, igneous rocks rarely preserve fossils. Nevertheless fossils including tree molds (HAVO and PUHO) and human footprints (HAVO) are found in volcanic rocks within the network. The human footprints preserved within the volcanic ash of HAVO are one of a kind within the NPS. Lava tubes throughout the Hawaiian Islands, including some within HALE, provided exceptional habitat for birds and preserve bird fossils. These fossils have provided an excellent window into bird populations and extinctions within the Hawaiian Islands.

The Hawaiian Islands are located in the central Pacific Ocean, 4,000 km southwest of California, forming an archipelago of nineteen islands and atolls, covering 16,700 square km. The Hawaiian archipelago is at the southeastern end of the Hawaiian-Emperor seamount chain, shield volcanoes formed by volcanic

activity over a hotspot in the earth's mantle. Each of the Hawaiian Islands is composed of one or more volcanoes that originated on the sea floor, only emerging from the Pacific after a long series of eruptions (Rutherford and Kaye 2006). After these volcanoes were at or very near the surface of the ocean, fringing reef and carbonate platforms began to form, followed by coral atolls. Often these reefs, atolls and platforms would be eroded by wave action and other natural causes, and/or buried by subsequent eruptions (Hearty et al. 2005). The island of Hawaii, the youngest of the chain, was built by five volcanoes: Kohala, Mauna Kea, Hualalai, Mauna Loa and Kilauea. Hualalai last erupted in 1801, Mauna Loa has erupted a dozen times in the last century, and Kilauea has been erupting since 1983. The island is primarily composed of basaltic lava, with some deposits of ash and coarser tephra from explosive volcanic activity. Eruptions are also building Loihi Seamount, 35 km southeast of the island, which has grown to within less than 1,000 m of sea level and may reach the surface in 10-100,000 years. Haleakala, on neighboring Maui, may have last erupted as recently as 1750, and like Hualalai is considered potentially active.

Taken together, the paleontological resources of the Pacific Island Network contribute much to a greater understanding of the history of life on earth. Continued paleontological resource inventories will serve to expand this ever-widening base of paleontological knowledge represented throughout the National Park Service. Although more than 180 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.

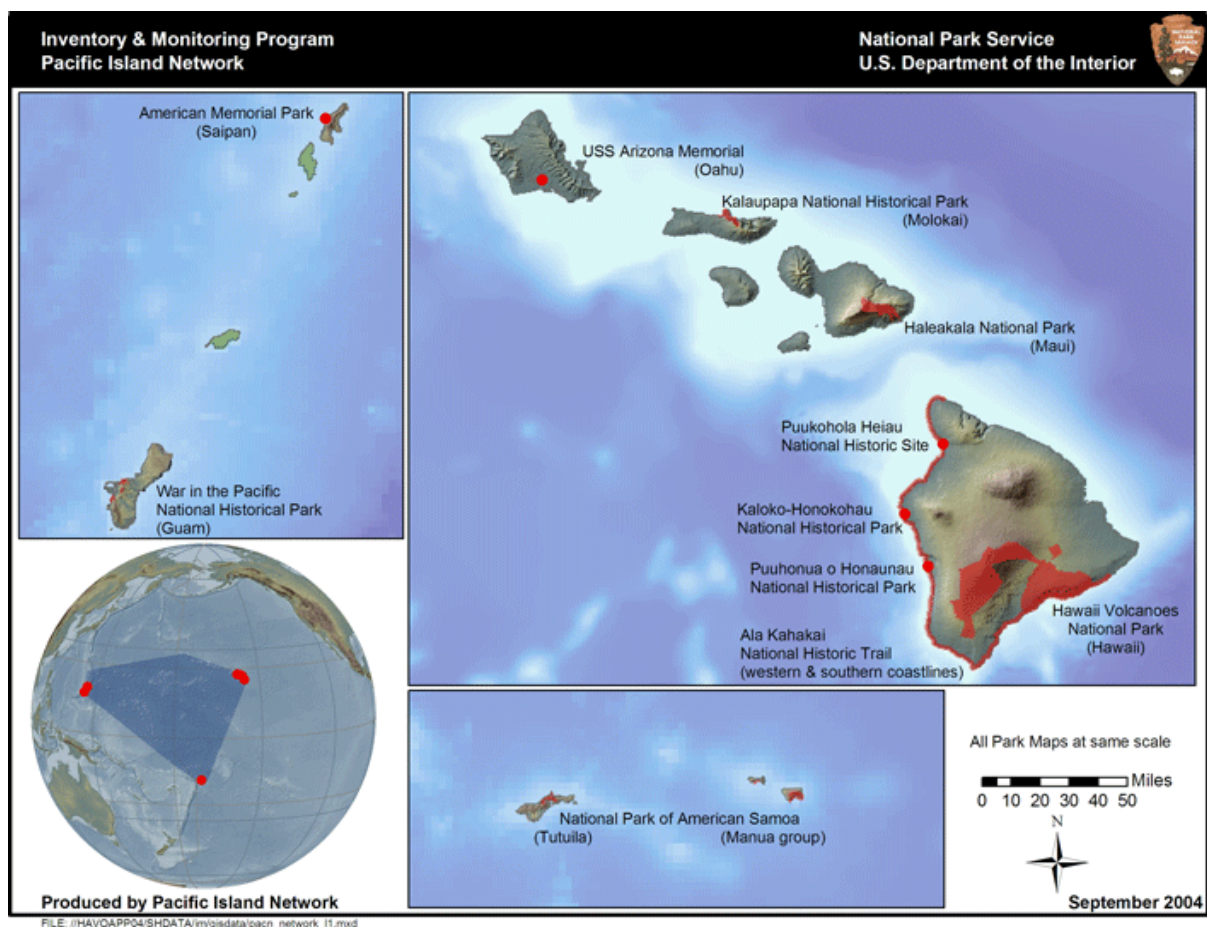


Figure 1. Map of Pacific Island I&M Network parks (map courtesy PACN staff).

NPS 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. These strategies include: comprehensive park-specific paleontological resource inventories, Servicewide thematic paleontological resource inventories, and Inventory & Monitoring Network-based baseline paleontological resource inventories, each established with their own goals and objectives. Basic paleontological resource monitoring strategies and potential threats to fossil resources are outlined by Santucci and Koch (2003).

Comprehensive Park Paleontological Resource Inventories

Comprehensive park inventories are designed to identify all known paleontological resources within a single park unit, using a team of specialists from within the NPS and from educational institutions and cooperators. These specialists work with the park to identify and address all aspects of its paleontological resources, including resource management, museum curation, law enforcement, and interpretation. The goals and objectives of a park-specific paleontological resource inventory are detailed by Santucci (2000). Paleontology-specific training for park staff is an important component of many comprehensive paleontological inventories. Park-specific inventories have been completed at Yellowstone NP (the first park to complete an inventory), 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 are designed to compile data regarding specific types of paleontological resources that occur in parks throughout the NPS. The first was an inventory that identified nineteen 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 twenty-five. Another inventory assessed paleontological resources associated with NPS caves (Santucci et al. 2001). 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

I&M Network-based paleontological resource inventories are designed to compile baseline paleontological resource data for each of the parks in a particular network. Network-based inventories have been completed for 14 of the 32 I&M Networks including: the Chihuahuan Desert, Eastern Rivers and Mountains, Greater Yellowstone, Gulf Coast, Mediterranean Coast, Mid-Atlantic, Mojave Desert, National Capital Region, Northeast Coastal and Barrier, Northern Colorado Plateau, Rocky Mountain, Southern Plains, Southwestern Alaska, and Upper Columbia Basin networks. Inventories are currently (spring 2007) underway for the Appalachian Highlands, San Francisco Bay Area, Sierra Nevada, and Southern Colorado Plateau networks. Reports will be initiated in 2007 for the Southeastern Coast and Northern Plains networks. The NPS I&M Program will provide funding to complete paleontological resource summaries for the remaining networks by FY2009. Citations for these reports are included in the Additional References section.

Inventory and Monitoring Network Paleontological Resource Inventory Methodology

Network-based paleontological inventories have been funded directly by the individual networks. Funds provide stipends or salary for contractors, interns, or paleontological technicians who perform data mining activities. The Pacific Island Network report represents a multi-faceted approach. To efficiently utilize available funding, data mining work for the PACN paleontology summary was performed concurrently by a paleontology intern through the Geological Society of America and a paleontology technician from the NPS Geologic Resources Division. Funding for the PACN report was from the NPS Inventory and Monitoring Program. The following brief summary outlines the basic techniques used to assemble an I&M Network-based inventory.

The most valuable component of any paleontological resource inventory is an intensive literature search. Various databases contain citations for geology or paleontology themed publications. GeoRef, established by the American Geological Institute, 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. NatureBib is a work in progress and 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 gray (unpublished) literature searches of 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. As part of the bibliographic searches, a search for geologic maps associated with each park is undertaken. Tim Connors, a geologist with the NPS Geologic Resources Division, maintains a database of geological map coverage for many parks in the NPS. 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 within a park.

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

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 before being submitted to the network. The 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, 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 four taxonomic groups: paleobotany (fossil plants), invertebrates (animals without backbones), vertebrates (animals with backbones), and trace fossils (evidence of biological activity such as track, trace, burrow, etc.). Fossils typically have a finite range and occurrence in geologic time (a geologic time scale is included in Appendix A). The period between the first and final occurrences of a fossil species is 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. 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 perhaps as many as three billion years, and the range of environments to which life has adapted, there is a broad spectrum of research interests in paleontology. It is not surprising that most of what is to be learned about the history of life remains to be discovered. Through research, more than 180 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 projects, if any, that the park has funded or supported relating to paleontological resources. 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. These data can then be utilized to 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 afforded to 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”, 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. That report, an “Assessment of Fossil Management on Federal & Indian Lands” summarized a number of principles relating to paleontological resources and their management. The report was 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. 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 also coordinating the assembly of a geologic resource monitoring manual. This manual 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. It 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. Currently the geological resource monitoring manual is undergoing review. 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 pave the way for future fossil discoveries in NPS areas.

ADDITIONAL REFERENCES AND WEBSITES OF INTEREST

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- Kenworthy, J.P., V.L. Santucci, M. McNerney, and K. Snell. 2005. Paleontological Resource Inventory and Monitoring, Upper Columbia Basin Network. National Park Service TIC# D-259. 71 pages.
- Kenworthy, J.P., C.C. Visaggi, and V.L. Santucci. 2006. Paleontological Resource Inventory and Monitoring, Mid-Atlantic Network. National Park Service, TIC# D-800. 83 pages.
- Koch, A.L. and V.L. Santucci. 2002. Paleontological Resource Inventory and Monitoring, Northern Colorado Plateau Network. National Park Service TIC# D-206. 44 pages.
- Koch, A.L. and V.L. Santucci. 2003. Paleontological Resource Inventory and Monitoring, Southern Plains Network. National Park Service TIC# D-107. 34 pages.
- Koch, A.L. and V.L. Santucci. 2003. Paleontological Resource Inventory and Monitoring, Greater Yellowstone Network. National Park Service TIC# D-1025. 20 pages.
- Koch, A.L. and V.L. Santucci. 2003. Paleontological Resource Inventory and Monitoring, Mediterranean Coast Network. National Park Service TIC# D-177. 27 pages.
- Koch, A.L. and V.L. Santucci. 2004. Paleontological Resource Inventory and Monitoring, Eastern Rivers and Mountains Network. National Park Service TIC# D-265. 50 pages.
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- Santucci, V.L., A.L. Koch, and J.P. Kenworthy. 2004. Paleontological Resource Inventory and Monitoring, Mojave Desert Network. National Park Service TIC# D-305. 50 pages.

General PACN Information

Pacific Island I&M Network: <http://www.nature.nps.gov/im/units/pacn/>

Geological Survey Websites

Hawaii Department of Land and Natural Resources: <http://www.hawaii.gov/dlnr/>
U.S. Geological Survey Hawaiian Volcano Observatory: <http://hvo.wr.usgs.gov/>
U.S. Geological Survey: <http://www.usgs.gov>
Geological Society of America: <http://www.geosociety.org>

Library catalogs and Museums

U.S. Geological Survey Library Catalog: <http://igsrglib03.er.usgs.gov:8080/#focus>
Smithsonian Institution Libraries Catalog: <http://www.siris.si.edu/>
Bishop Museum (Honolulu): <http://www.bishopmuseum.org/>
Smithsonian National Museum of Natural History Dept. of Paleobiology:
<http://www.nmnh.si.edu/paleo/>

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://www2.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.htm>
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://www2.nature.nps.gov/geology/>
NPS Paleontology Program: <http://www2.nature.nps.gov/geology/paleontology/>
NPS Park Paleontology Newsletter:
<http://www2.nature.nps.gov/geology/paleontology/news/newsletter.htm>

Other geology/paleontology tools

Topozone (interactive access to all USGS topographic maps): <http://www.topozone.com>
U.S. Geological Survey National Geologic Map Database (NGMDB): <http://ngmdb.usgs.gov/>
U.S. Geological Survey Geographic Names Information System: <http://geonames.usgs.gov/pls/gnispublic/>
Paleobiology Database: <http://paleodb.org/cgi-bin/bridge.pl>
Paleontology Portal: <http://www.paleoportal.org/>

ALA KAHAKAI NATIONAL HISTORIC TRAIL

Established in 2000 for the preservation, protection and interpretation of traditional Native Hawaiian culture and natural resources, the Ala Kahakai National Historic Trail (ALKA), on the main island of Hawaii, is a 280 km trail corridor full of cultural and historical significance. It traverses through hundreds of ancient Hawaiian settlement sites and through over 200 ahupuaa, or traditional sea to mountain land divisions. Natural Resources include anchialine ponds, pali (precipices), nearshore reefs, estuarine ecosystems, coastal vegetation, migratory birds, native sea turtle habitat, and several threatened and endangered endemic species of plants and animals (Else 2006). Seventeen percent of the Ala Kahakai National Historic Trail is within the four National Park Service units on the island of Hawaii: Hawaii Volcanoes National Park, Puuhonua o Honaunau National Historical Park, Kaloko-Honokohau National Historical Park, and Puukohola Heiau National Historic Site, with the remaining 83% traversing land not owned by the National Park Service (Else 2006).

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

Neither geological nor paleontological scoping sessions have been held for ALKA. Geological resource scoping sessions (sponsored by the NPS Geologic Resources Division) for the other parks of the PACN were held in March 2003. Formal paleontological inventories or surveys have likewise not yet been held for the park. Fossils are not yet known from within ALKA. Lava tubes and caves have been identified as potential resources within ALKA (Rutherford and Kaye 2006; Else 2006). Such tubes have produced fossil bird material in HALE, but are not yet documented within ALKA. Fossil coral resources are not yet documented within ALKA. Offshore marine resources of HAVO, PUHO, KAHO, and PUHE will be addressed in those park's sections of this report. Fishponds are present within ALKA (Else 2006). Sediment cores from fishponds within KAHO and PUHO provided important paleoecological reconstruction data.

Ala Kahakai National Historic Trail extends from the northern tip of the island of Hawaii at Puukohola Heiau National Historic Site, to the southeastern side of the island at Hawaii Volcanoes National Park, following the shoreline (Else 2006). The trail crosses Pleistocene and Holocene igneous rocks for its entire length, plus occasional alluvium and other erosional fill. These igneous rocks are associated with the Hawi volcanics and the Kau, Hilina, Hualalai, Puna, Pololu and Kahuku Basalts. All of the mapped geological formations along the trail are igneous; therefore *in situ* fossils would not be expected. Tree molds are known from the lavas of HAVO and PUHO, but are not documented within ALKA. Other fossils known from the island of Hawaii include the birds *Loxioides* sp., *Akialoa* sp., *Telespiza* sp., *Hemignathus vorpalis*, and 3 species of birds from Umii Manu Cave: *Porzana* sp., *Corvus* sp., and *Hemignathus* sp. (Griffin 1993; James 2004; James and Olson 2005).

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AMERICAN MEMORIAL PARK

American Memorial Park (AMME), on 0.54 square km along the western side of the island of Saipan, commemorates those who fought in the Marianas campaign of World War II. On August 18, 1978 (P.L. 95-348), the U.S. Congress authorized and directed the U.S. National Park Service “...to develop, maintain and administer the existing American Memorial Park located at Tanapag Harbor Reservation, Saipan” (Snyder 2005).

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

In March 2003 the NPS Geologic Resources Division conducted a geological resource scoping session for American Memorial Park and the other PACN parks. Formal paleontological resource inventories or summaries have not yet been held for the park. Fossils are known from Saipan’s limestones. However, these fossils were collected outside of the park, and are repositied at the Smithsonian Institution (Washington, D.C.) and the U.S. Geological Survey (Johnson 1957). At this time no known fossils have been collected within the park boundaries. Lava tubes and caves, which preserve avian fossils in HALE are not found within AMME (Rutherford and Kaye 2006; Snyder 2005). The coastal waters and coral reefs adjacent to AMME are not within park boundaries but may be incorporated in the future following a case pending in U.S. Federal Court (Snyder 2005). Fishponds which have produced important paleoecological data within KAHU and PUHU are not known from AMME.

Saipan is the largest of the fourteen islands in the Commonwealth of the Northern Mariana Islands with an area of 124 square km. This western Pacific island, is a subareal peak on the Mariana island arc (Carruth 2003). Origins of the Mariana Islands can be attributed to subduction of the Pacific Plate underneath the Philippine Plate. Volcanic activity that initiated the growth of these islands began some 10 to 45 million years ago during the Miocene or Eocene (Snyder 2005). The island’s lithology predominantly consists of dacitic tuffs, andesites, sandstones, limestones and tuffaceous limestone. Igneous rocks (all Eocene in age) compose the volcanic core of the island and are exposed on less than 10% of the land surface. Fossiliferous limestones overlay the volcanic core and dominate the surface lithology. Hydrogeological and paleosol (ancient soils) studies have also been undertaken for the island (Davis 1958; van der Brug 1985; Carruth 2003; Ersek et al. 2004). American Memorial Park is located on the western coast of Saipan, along Tanapag Harbor, on Pleistocene-Holocene coastal plain sediments (Cloud et al. 1956; Carruth 2003). Often parks will use local or imported fossiliferous rocks in buildings and monuments. At this time the types of stone that may have been used in park structures or monuments are unknown. However local limestone and sandstone units are known to be fossiliferous and they may have been used for building material.

Fossiliferous Limestones (Eocene-Pleistocene)—Outside of AMME

The fossiliferous rocks of Saipan consist of limestones, tuffaceous limestones and sandstones, of which there are seven named formations, from oldest to youngest: Eocene Hagman Formation, Eocene Densinyama Formation, Eocene Matansa Formation, Oligocene Fina-Sisu Formation, Miocene Tagpochau Limestone, Early Pleistocene Mariana Limestone, and Pleistocene Tanapag Limestone. However, none of these formations are present within American Memorial Park, which is on Pleistocene and Holocene outwash, fill and alluvium, directly east of Tagpochau Limestone formations (Cloud et al., 1956). Of these seven formations present on Saipan, all are known to contain fossils (Bramlette 1957; Cole 1957; Cooke 1957; Johnson 1957; Riedel 1957; Todd 1957; Carruth 2003). The Eocene Hagman, Densinyama and Matansa formations are known to contain calcareous algae and foraminifera (Cole 1957; Johnson 1957) while discoasters and radiolaria are known only from the Hagman and Densinyama formations (Bramlette 1957; Riedel 1957; Todd 1957). The Oligocene Fina-Sisu Formation is only known to contain small foraminifera and discoasters (Bramlette, 1957; Todd, 1957). The Miocene Tagpochau Limestone contains the fossil remains of calcareous algae, foraminifera, discoasters and echinoids (Bramlette 1957; Cole 1957; Cooke 1957; Johnson 1957; Todd 1957). The early Pleistocene Mariana Limestone contains calcareous algae and abundant coral remains (Carruth 2003). The Pleistocene

Tanapag Limestone is composed of a coral-algal reef and bioclastic limestone. Common fossils include coral heads and mollusk shells, along with calcareous algae (Johnson 1957; Carruth 2003).

The Miocene Tagpochau Limestone covers nearly half of the Saipan central highlands and is the nearest fossiliferous formation (less than 0.8 km) to the park (Carruth 2003). This formation includes eight different facies: the transitional, tuffaceous, marly, rubbly, equigranular, inequigranular, and the Donni Sandstone and Machegit Conglomerate members, containing fifteen known calcareous algae genera (most common genera being *Archaeolithothamnium*, *Lithothamnium*, *Lithophyllum*, *Jania*, *Corallina*, and *Halimeda*; Johnson 1957). Four genera (*Discoaster*, *Ceratolithus*, *Braarudosphaera*, and *Thoracosphaera*) of discoasters are known from the formation's Donni Sandstone Member, and the transitional and marly facies (Bramlette 1957). 161 species of smaller foraminifera are known from the Tagpochau Limestone, 95 in the Donni Sandstone. Most forms appear to be planktonic, with only eight benthonic species. These planktonic forms are the best evidence for the formation's age (Todd 1957). Thirty-three species of larger foraminifera are known from this formation, with *Heterostegina boreneensis*, *Lepidocyclina brouweri*, and *Spiroclypeus tidoenganensis* marking the lower section and *Flosculinella globulosa*, *Lepidocyclina verbeeki*, *L. verrucosa*, *Miogypsina thecideaformis*, *Miogypsinoidea dehaartii*, and *Spiroclypeus higginsii* marking the upper section (Cole 1957). Nine species of echinoids are known from this formation, including *Parasalenis marianae*, *Echinostrephus saipanicus*, *Heterocentrotus* sp., *Acanthocidaris* sp., *Echinoneus* sp., *Clypeaster saipanicus*, *Sismondia polymorpha*, *Paraster saipanicus*, and *Echinolampas* sp. *Sismondia polymorpha* is the most abundant, and supports its correlation to the early Miocene (Cooke 1957).

The Eocene Hagman Formation is found in the north-central and eastern portions of the island, north-northwest of Laolao Beach near Laolao area, east of I Lisong, in the vicinity of Bobo Achugoa Haya southeast of Oksp Dogas, and in the vicinity of As Mahettok east of Unai Tanapag. The Eocene Densinyama Formation is concentrated on the eastern portion of the island, but can also be found in the north-central areas. It is located near Ogso Talofofo in the Talofofo vicinity, near Machiget southeast of I Lisong, and in the Laderan Adelug vicinity directly east of Ogso Tagpochau. The Eocene Matansa Formation is concentrated in the north-central portion of the island, scattered throughout the Sabanan Nanasu and Ogso Achugau areas. The Oligocene Fina-Sisu Formation is concentrated in the southwestern position of the island, directly south of the Fina-Sisu area, and directly west of As Lito. The Miocene Tagpochau Limestone is the dominant formation on Saipan, occupying most of the island's central region, and is the formation occupying the area inland from AMME. The Early Pleistocene Mariana Limestone is commonly found along the northwestern, northeastern, eastern and southern coast of Saipan, dominating the southern portion of the island. The Pleistocene Tanapag Limestone is in small patches along the eastern and southern most coasts of Saipan and in the As Perdido region (see Cloud et al. 1956).

Outwash, fill, and alluvial deposits (Pleistocene-Holocene)

While there are fossiliferous formations found within the core of Saipan, sediments in American Memorial Park are much younger and consist of outwash, fill, and alluvial deposits that range from Pleistocene to Holocene age (modern; Cloud et al. 1956). Fossils are not known from these formations, but may wash ashore. War in the Pacific National Historical Park, located on Guam, is known to have fossils wash ashore from an unknown offshore source, possibly due to dredging in the area (Schweitzer and Feldmann 2000; Schweitzer et al. 2002; Scott-Smith 2004). While these processes have not yet been observed at American Memorial Park, the possibility could exist.

Avian fossil fauna (Pleistocene-Holocene)

Saipan's prehistoric avian fossil record is very poorly known. Avian fossil remains identified on Saipan include the rail *Gallirallus* sp., the dove *Gallicolumba xanthonura*, and the starling *Aplonis opaca* (Steadman 2006).

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DATA SETS

- DS-AMME- American Memorial Park Paleontological Archives. 5/1985–present. (hard copy data; XXX reports; electronic data; photographs; maps; publications, etc.). Originated by Santucci, Vincent; status: Active.

HALEAKALA NATIONAL PARK

Effective July 1, 1961, the detached portion of Hawaii National Park, on the island of Maui, was established as a separate National Park System unit, now known as Haleakala National Park (HALE). HALE was established to protect fragile native Hawaiian ecosystems, rare and endangered species, and cultural sites. The park now protects 30,183 acres of land, of which 24,719 acres are designated as Wilderness and managed under the Wilderness Act of 1964.

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

In March 2003, the NPS Geologic Resources Division sponsored a geological resource scoping session for Haleakala National Park and the other PACN parks. Formal paleontological inventories have not yet been completed for HALE. Nevertheless, avian fossils are known from the lava tubes within HALE and were summarized briefly in an inventory of paleontological resources associated with NPS caves (Santucci et al. 2001). Tree molds, found in the lava flows of other PACN parks, are not yet documented within HALE. The park's boundary ends at mean high tide and there are no submerged marine resources or coral reefs within the park (Daniel and Minton 2006). No emerged (exposed) marine fossils were noted on the island of Maui by Jones (1993). Fossiliferous Pleistocene limestones are present on the northwest side of Maui 10 km southeast of Lahaina and are described by Ostergaard (1939). Similar resources are not documented near HALE. There are three small ponds associated with bog ecosystems within HALE (Aruch 2006). It is unknown whether these ponds may produce paleoecological material similar to the fishponds within KAHU and PUHO.

Haleakala National Park is located on eastern side of Maui, the second largest island in the Hawaiian Islands, formed by the connection of two shield volcanoes 2-1.3 million years ago (Wood and Kienle 1990). Haleakala is an ancient shield volcano formed by eruptions of basaltic lava starting around 800,000 years ago on the ocean floor. The most recent eruption may have occurred about 1750. The older lavas on the island are composed of tholeiitic basalts and olivine basalts from the Honomanu and Kumulihi Formations. These mafic rocks grade upward without a break in sequence into the andesitic rocks of the Kula Formation (Macdonald 1978). Caves and lava tubes are documented in the Kipahulu Valley of HALE (Santucci et al. 2001).

Avian Fossils (Pleistocene-Recent)

At Haleakala National Park fossils of both extinct and extant birds were found in the lava tubes between 1984 and 1988 (Medeiros et al. 1989; James et al. 1987; Santucci et al. 2001). Bird fossils were collected from Luamanu ("bird pit") and Pukamoa ("chicken-like bird hole") caves at Haleakala. These remains include an undescribed genus of flightless goose-like bird, a honeycreeper with affinities similar to *Chloridops* sp., along with a flightless ibis *Apteribis* sp., a goose *Branta* sp., and a flightless rail *Porzana* sp. (Medeiros et al. 1989). Other prehistoric fossil remains known from Maui include *Akialoa* cf. *lanaiensis*, *Akialoa* aff. *upupirostris*, *Drepanis funerea*, *Orthospiza howarthi*, *Rhodacanthis forfex*, and *Rhodacanthis litotes* (James 2004; James and Olson 2005). This fossil avifauna increases the endemic terrestrial bird fauna on the island of Maui from 10 to at least 29 species. The drop in avian diversity is attributed to the arrival of humans on the island, which has experienced more than 50 percent extinction of its native species (Burney et al. 2001; Olson and James 1982b, 1991; Olson 1989; James and Olson 1991). The first Polynesian colonizers arrived during the fifth to eighth centuries. The first European naturalists arrived in the late 1700s. Interestingly, these fossils preserve original biomolecules but are also permineralized (pore spaces filled with minerals; H. James, personal communication, 2006).

Fossils in Museum Collections

Fossils known from Haleakala National Park are repositied at the National Museum of Natural History (Washington D.C.) and the Bishop Museum (Honolulu, Hawaii) as cited within Medeiros et al. (1989), James et al. (1987, 1991), and Olson and James (1982, 1991). The Bishop Museum has a collection numbering more than 30,000 bird fossils, many of which are still being added to the museum's catalog.

This collection began in the 1970s and continues today. Most of these specimens have been collected by Dr. Helen James and Dr. Storrs Olsen of the National Museum of Natural History. Remains from the island of Molokai (see KALA section of this report) were collected by Mrs. Joan Aidem and other Bishop Museum staff (C. Kishinami, personal communication, 2007).

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DATA SETS

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

DS-HALE- Smithsonian Institution National Museum of Natural History Museum Collections. 1970s-
XXX present. (museum specimens; associated specimen notes; collection records; publications,
maps; etc.). Originated by Helen James and Storrs Olson; status: Active.

DS-HALE- Bernice P. Bishop Museum (Honolulu, HI) Collections. (museum specimens; associated
XXX specimen notes; collection records; maps; etc.). 1970s-present. Originated by museum staff
and other researchers; status: Active.

HAWAII VOLCANOES NATIONAL PARK

On August 1, 1916, President Woodrow Wilson signed into law the country's thirteenth national park, Hawaii Volcanoes National Park (HAVO). The park, located on the island of Hawaii, consists of 976 square km of volcanic summits, flows and craters, along with forest, deserts, and archaeological resources. In 1980, the United Nations Educational, Scientific, and Cultural Organization (UNESCO) named Hawaii Volcanoes National Park an International Biosphere Reserve because of its outstanding scenic and scientific values. The park was recognized for its important volcanic sites; its volcanic island ecosystem, which preserves one of the largest significant ecosystems on the Hawaiian Islands; and its cultural and historic sites. Hawaii Volcanoes National Park was named a World Heritage Site by UNESCO in 1987. (Hamilton 2005)

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

A geological resources scoping session, sponsored by the NPS Geologic Resources Division was held for HAVO and the other PACN parks in March 2003. Formal paleontological inventories have not yet been completed for the park. However, tree molds, a fern impression, and human footprint fossils are known from the volcanic deposits within HAVO, the latter two being preserved in ash fall. Other fossils are known from ash beds outside of the park, including a fossil goose described below, and may indicate the potential for additional fossils within similar deposits of HAVO. Lava tubes and caves are known from within the park (Rutherford and Kaye 2006) but fossil resources within those caves are not yet known. The park's boundary ends at mean high tide and there are no submerged marine resources or coral reefs within the park (Daniel and Minton 2006). Jones (1993) did not report emerged (exposed) marine fossils from the east side of the island of Hawaii near HAVO, although they are found along the western shore of the island. Brackish water anchialine ponds are documented within HAVO (Perry 2006). It is unknown whether these ponds may produce paleoecological material similar to the fishponds within KAHU and PUHO.

All of the mapped geological formations at HAVO are igneous; therefore *in situ* fossils would not be expected. However, trace fossils (tree molds and human footprints) and a fern impression are present within the park as described below. Avian fossils known from the island of Hawaii outside of the park include the birds *Loxioides* sp., *Akialoa* sp., *Telespiza* sp., *Hemignathus vorpalis*, and 3 species of birds from Umii Manu Cave: *Porzana* sp., *Corvus* sp., and *Hemignathus* sp. (Griffin 1993; James 2004; James and Olson 2005). Wetmore (1943) described the “good-sized” fossil goose *Geochen rhuax* from material collected within the Pahala Ash (see below) near Kaumaikeohu summit 14.5 km west of HAVO. Olson and Wetmore (1976) compared this material to other fossil geese from Molokai (see KALA section).

Map coverage for HAVO consists of 21 quadrangles of interest (scale 1:24,000): Puu Makaala, Kulani, Puu Ulaula, Kokoolau, Kalalua Volcano, Kilauea Crater, Kipuka Pakekake, Mauna Loa, Sulphur Cone, Kalapana, Makaopuhi Crater, Kau Desert, Wood Valley, Keaiwa Reservoir, Alike Cone, Naliikakani Point, Pahala, Punaluu, and Puu O Keokeo. The U.S. Geological Survey has produced maps (Miscellaneous Geologic Investigations) I-2524-A and I-2524-B (Wolf and Morris 1996a-f). An online geologic map of the island of Hawaii is available (Trusdell et al. 2005). For the shoreline component of the park, the U.S. Geological Survey has produced Miscellaneous Geologic Investigations I-2761 (Fletcher et al. 2002).

HAVO is located on the central and southeastern portions of the island of Hawaii. The southeastern portion of Hawaii developed from the eruptive activities of Kilauea and Mauna Loa volcanoes. Both are vigorously active shield volcanoes. Kilauea is the youngest and most active of the five distinctive volcanoes located on the big island of Hawaii.

The volcanoes of Hawaii typically evolve through a sequence of four eruptive stages: preshield, shield, postshield, and rejuvenated stages (Clague and Dalrymple 1987). Each stage is distinguished by lava composition, eruptive rate and style, and stage of development (Wolfe and Morris 1996a).

The Kilauea volcanics are predominantly basaltic lavas with some ash deposits. The older Pleistocene Hilina Basalt consists of lava flows with intercalated ash deposits exposed in kipukas south of Kilauea Crater (Wolfe and Morris 1996a). The Hilina Basalt dated to approximately 23,000 years before present (Wolf and Morris 1996a). Both aa and pahoehoe lava flows occur within this 300 m thick formation. Intercalated ash layers are approximately 4 m thick. Major ash units or groups of ash units have been assigned to the Moo, Pohakaa, Kahele, and Halape Ash Members of the Hilina Basalt (Easton 1987).

The Puna Basalt is a sequence of Holocene lava flows, vent deposits, littoral deposits, and tephra deposits. The Puna Basalt consists of eruptions which date back to nearly 10,000 years before present and persist through the recent. Both aa and pahoehoe lava flows are largely associated with fissure eruptions. Pyroclastic vent deposits are associated with spatter or tuff cones (Wolf and Morris 1996a). Cone-building littoral deposits developed where lava flows entered the ocean and were violently fragmented by ensuing steam explosions (Wolf and Morris 1996a). Ash, lapilli, and bombs of dense glassy basalt occur along the shoreline where these eruptions enter the ocean.

Tephra deposits include local air-fall deposits of ash and lapilli, lithic tuff with basaltic lava fragments, and relatively widespread air-fall and surge deposits that record violent explosive steam-driven eruptions (Wolf and Morris 1996a).

The Mauna Loa volcanics consist of three distinct basalt sequences, from oldest to youngest: Ninole Basalt, Kahuku Basalt and Kau Basalt. The Ninole Basalt is a Pleistocene unit exposed as erosional remnants on scattered hills on the southeast flank of Mauna Loa (Wolf and Morris 1996a). The Ninole consists of both aa and pahoehoe lava flows with thin interbeds of tuffs. Potassium-Argon dating yields dates of between 300,000 to 100,000 years before present (Lipman et al. 1990).

The Kahuku Basalt overlies an ash unit known as the Pahala Ash of the Kau Basalt. The Pahala Ash dates between 31,000 and 10,000 years before present. Therefore the underlying Kahuku Basalt is at least 31,000 years old. The Pahala Ash preserved Wetmore's (1943) fossil goose skeleton.

The Kua Basalt, the youngest of the Mauna Loa basalts, consists of lava flows, vent deposits, littoral deposits, and tephra deposits. Pyroclastic vent deposits form prominent cones which consist of spatter and minor scoria. The Kua Basalt dates from 31,000 years old to recent (Wolf and Morris 1996a).

Aloi Crater Tree Molds (Recent)

In 1962 the floor of Aloi Crater within HAVO was flooded with lava. The native ohia trees (*Metrosideros collina* var. *polymorpha*) that had been growing within the crater were engulfed, but not immediately consumed by the lavas (Hamilton 1964; Hazlett 1981). As the trees were engulfed, their moisture content was released as steam, allowing enough time for the outside of the tree to leave an impression in the surrounding lava. Surface details, such as leaf attachments and bark patterns, are often preserved, even after the tree has decayed or succumbed to the lava's heat. When the lava receded a few hours later, many of the trees smoldered and died, leaving the hollow molds of their trunks along with many unburned trunks. These tree molds are examples of trace fossils. Tree molds are also known from Puuhonua o Honaunau National Historical Park (Island of Hawaii), Lava Tree State Park (Island of Hawaii), Craters of the Moon National Monument and Preserve (Idaho), Lava Beds National Monument (California), and El Malpais National Monument (New Mexico).

Fern Leaf Impression (Recent)

HAVO's museum collections include a 3.2 cm fern leaf (figured on the cover of this report) discovered by Dr. Thomas Jaggar one of the founding fathers of the Hawaiian Volcano Observatory (administered by the U.S. Geological Survey within HAVO). Dr. Jaggar collected the fern leaf on July 25, 1940, during

Civilian Conservation Corps excavations for the then new observatory building; now the park headquarters (K. Awong, D. Hu; J. Moniz-Nakamura; T. Laqua; D. Swanson, personal communication, 2007). The ash layer was deposited in the late 17th-early 18th century (D. Swanson, personal communication, 2007). Additional organic debris was discovered in the ash layer in 2001 during drainfield pit excavations at the park entrance station (D. Swanson, personal communication, 2007). Additional paleontological resources might be discovered within this layer during future construction activities.

Human Footprints at Keonehelelei (Recent)

Human footprints were found within the hardened Keanakakoi Ash deposits of the Kau Desert within HAVO. These footprints occur in two layers, separated by 90 cm of dune sands (Cruikshank 1974; Hazlett 1981). During a Kilauean eruption in 1780 a base surge rolled out across the north-eastern part of the Kau desert, depositing the yellow pisolitic tuff (Swanson and Christiansen 1973; Hazlett 1981). While these footprints are managed as an archaeological resource, they demonstrate a process that can also preserve footprints of other organisms. Additional trace fossils may be found in the preserved ash layers within the park. Nakamura (2003) details previous research, the results of new studies and new conclusions regarding the footprints of soldiers in the army of Hawaiian chief Keoua.

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DATA SETS

- DS-HAVO- Hawaii Volcanoes National Park Paleontological Archives. 5/1985–present. (hard copy data; XXX reports; electronic data; photographs; maps; publications, etc.). Originated by Santucci, Vincent; status: Active.
- DS-HAVO- Hawaii Volcanoes National Park Museum Collection. 1916–present. (museum specimens, XXX specimen notes, photographs; maps; publications, etc.). Originated by HAVO staff; status: Active.

KALAUPAPA NATIONAL HISTORICAL PARK

Kalaupapa National Historical Park (KALA) was established December 22, 1980 to preserve the unique cultural, historic, educational, and scenic resources of Kalaupapa Peninsula. KALA sits on the northern shore of the island of Molokai, Hawaii. The park preserves and interprets the Kalaupapa settlement, community, and the residents' current lifestyle. The park also maintains important historic structures, traditional Hawaiian sites, and natural features. Limited visitation by the general public is allowed. Preservation and interpretation of the settlement is to be managed and performed by residents and Native Hawaiians to the extent practical. The park contains the Kalaupapa Hansen's Disease (formally known as Leprosy) Settlement, which is listed on the National Register of Historic Places as a National Historic Landmark. A section of the park is included within the North Shore Cliffs National Natural Landmark. The Puu Alii plateau is a designated state Natural Area Reserve (NAR) and is also included within the authorized boundary of the park. The Molokai Lighthouse is listed separately on the National Register of Historic Places (Aruch 2006).

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

Geologic resource scoping sessions, sponsored by the NPS Geologic Resources Division were held for KALA and the other PACN parks in March 2003. Formal paleontological inventories have not yet been completed for the park and future discovery of fossils within KALA may be possible. As described by Aruch (2006), KALA contains lava tubes and caves and offshore marine resources such as coral reefs (Daniel and Minton 2006). Fossils are known in these settings from other PACN parks but have not yet been documented within KALA. Outside of the park, molluscan fossils are known from the southern coast of Molokai. Avian fossils are known from the northwestern shore of the island as described below. Stone buildings within KALA may display fossils as described below. An anchialine pool, historically utilized as a fishpond, is documented within the park (Aruch 2006). Sediment cores from ponds within KAHO and PUHO produced valuable paleoecological data. Similar data has not yet been collected from KALA.

Kalaupapa National Historical Park consists of two quadrangles of interest (scale 1:24,000): Molokai West and Molokai East. The park contains both terrestrial and marine resources as the boundary extends one 0.4 km (0.25 mile) off shore. Therefore producing both types of geologic maps is necessary for proper resource management. A terrestrial geologic map has been produced (Stearns and MacDonald 1947). Geologic Resource Evaluation staff has derived the digital geologic data for the terrestrial portion of the park.

Molokai is the fifth largest of the Hawaiian Islands formed from two separate shield volcanoes: West Molokai Volcano (also known as Mauna Loa, 1.9 million years old) and East Molokai Volcano (also known as Kamakou, 1.75 million years old). The north coast of the eastern half of the island faces the ocean with sheer cliffs, the result of a giant landslide more than 400,000 years ago. Deep, steep valleys were subsequently cut into the cliffs by stream erosion. About 230,000 years ago, long after Mauna Loa and Kamakou became extinct, another small shield volcano rose from the sea floor and joined against the north cliffs. This volcano, named Puu Uao, formed a relatively flat triangle of land through continuous flows of pahoehoe lava. The Kalaupapa Peninsula is 3.2 km from the cliffs to the tip, and 4.1 km wide at the base of the cliffs, an area of approximately 13 square km. Its isolation led to its being chosen as Kalaupapa Hansen's Disease Settlement. The rim of the volcano remnant rises over 137 m, forming Kauhako Crater with a crater lake at the bottom more than 244 m deep (Cochran et al. 2002). All of the mapped geological formations within the park are igneous; therefore fossils are not likely to occur *in situ*. Tree molds similar to those found in other PACN parks, such as HAVO and PUHE are not known from KALA. While lava tubes within HALE have produced fossils as described in this report and for the NPS by Santucci et al. (2001), the lava tubes and caves of KALA are not known to produce fossils, or they have not yet been documented.

Molluscan and Avian Fossils on Molokai (Pleistocene)

While paleontological resources are not likely within KALA boundaries, significant molluscan and avian fossils are known from the island of Molokai. Ostergaard (1939) described Pleistocene marine mollusks from the leeward shore of Molokai (opposite shore from KALA) near Kaunakakai. The fossils are found in nine nearshore limestone terrace levels ranging from 3 m to 59 m in the Kalamaula Stream area. Because gastropod and pelecypod fossils are similar throughout the terraces, the discoveries indicate a relatively rapid sea level change during the Pleistocene (Ostergaard 1939). Similar fossils are not documented from the KALA area. However, there are modern coral reefs within the 0.4 km (0.25 mile) of submerged lands along the KALA boundary with the Pacific Ocean.

Olson and Wetmore (1976) described a significant collection of fossil bird bones from the Pleistocene dunes of western Molokai. In fact most of the Hawaiian bird bones identified by Smithsonian Institution (Washington, DC) ornithologists in the late 1970s were from this Molokai locality outside of KALA. Two of the specimens were particularly significant when first discovered in 1975 and are described by Olson and Wetmore (1976). The ibis *Apteribis glenos*, for example was at the time the only known ibis from all of Oceania and possessed morphological characteristics unlike typical ibises and was named a new genus and species based on Molokai material. *Thambetothen chauliodus* (flightless goose) was another new genus and species named from Molokai material and is much larger than material from the island of Hawaii described by Wetmore (1943). Stearns (1973) described the geologic setting of the *Thambetothen* discovery. Beneath (older than) the avian bone bearing layer, fossil land snail shells were discovered and radiocarbon dated to more than 27,000 years before present. Land snail shells found in association with the *Thambetothen* specimen provided a radiocarbon age of approximately 25,150±1000 years before present (Stearns 1973). Fossil tree trunks (less than 10 cm in diameter) were also recorded from the locality (Stearns 1973).

KALA Fossils in Cultural Contexts

Nearly 1,500 historic structures comprise the historic settlement administered as KALA. “Stone” was utilized as a building material within some of these structures. As described by Ostergaard (1939) limestones on Molokai can display Pleistocene marine (primarily molluscan) fossils. Depending on the stone used, stone structures such as the Old Stone Church, or stone walls and grave markers may display fossils. However such an occurrence has not yet been documented. Many historic structures in the National Park Service display fossils in their building stones (Kenworthy and Santucci 2006). Such structures present easily accessible fossil “exposures” and unique interpretive and resource management opportunities.

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KALOKO-HONOKOHAU NATIONAL HISTORICAL PARK

Kaloko-Honokohau National Historical Park (KAHO) was established on November 10, 1978 for the preservation, protection and interpretation of traditional native Hawaiian activities and culture. The park is an 1,160 acre area, including 596 acres of marine resources, and is located on the western shore of the youngest and largest island in the Hawaiian chain, Hawaii, at a latitude of 19°N. It is the site of an ancient Hawaiian settlement which encompasses portions of four different ahupuaa, or traditional sea to mountain land divisions. Resources include fishponds, kahua (house site platforms), kii pohaku (petroglyphs), holua (stone slide), and heiau (religious site).

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

Geologic scoping sessions, sponsored by the NPS Geologic Resources Division were held for KAHO and the other PACN parks in March 2003. Formal paleontological inventories have not yet been completed for the park. Recent (approximately 1400 years old) pollen and gastropods were described from a fishpond sediment core within the park as described below and are important tools for paleoenvironmental reconstruction. Lava flows, which can preserve tree molds, as documented in other PACN parks, are potentially present within KAHO (Rutherford and Kaye 2006). Likewise, lava tubes and caves, which produce paleontological resources in other parks within PACN, are potentially present within KAHO but not yet documented (Rutherford and Kaye 2006). The park contains extensive submerged marine resources including coral reefs (Daniel and Minton 2006). Jones (1993) summarized a number of radiometrically dated marine fossils from the west side of the island of Hawaii; however, none were within or near KAHO. Jones (1993) does note that marine fossils are sometimes found associated with Hawaiian temples (heiaus), small fishing shrines, and trail cairns. He does not list specific examples however.

Map coverage for KAHO consists of one quadrangle of interest (scale 1:24,000): Keahole Point. The park contains both terrestrial and marine resources; therefore, producing both types of geologic maps is necessary for proper resource management. The U.S. Geological Survey has produced maps for the terrestrial component (Wolf and Morris 1996a-f) and the marine component (Fletcher et al. 2002). A digital geologic map of the island is available online (Trusdell et al. 2005).

KAHO is located on the west-central coast of the Island of Hawaii, which developed from the eruptive activity of Hualalai, one of five distinctive volcanoes on the island (Wolfe and Morris 1996a). The volcanoes of Hawaii typically evolve through a sequence of four eruptive stages: preshield, shield, postshield, and rejuvenated stages (Clague and Dalrymple 1987). Each stage is distinguished by lava composition, eruptive rate and style, and stage of development (Wolfe and Morris 1996a). The Hualalai volcanics are predominantly basaltic lavas. The older Waawaa Volcanics have been Potassium-Argon (K-Ar) dated to between 100,000 to 105,000 years old (Clague 1987). The more recent Hualalai Volcanics Basalt span the Pleistocene and Holocene, yielding K-Ar dates between 13,000 and the recent (Wolf and Morris 1996a).

KAHO is located on a combination of flat basalts and rough volcanic deposits from Hualalai, which last erupted in 1801 (DeVerse 2006). All of the mapped geological formations within the park are igneous; therefore in situ fossils are not expected. There is a chance that other remains, such as trace fossils (tree molds) may be found. However tree molds such as those at HAVO and PUHO have not been documented within KAHO (F. Klasner, personal communication, 2007). Body fossils are also known from the Island of Hawaii, but not within KAHO: the birds *Loxioides* sp., *Akialoa* sp., *Telespiza* sp., *Hemignathus vorpalis*, and 3 species of birds from Umii Manu Cave: *Porzana* sp., *Corvus* sp., and *Hemignathus* sp. (Griffin 1993; James 2004; James and Olson 2005).

Aimakapa Fishpond Paleoenvironment (Recent)

Athens and Ward (2006) studied three sediment cores from Aimakapa Fishpond to recreate the local paleoenvironment over the last 1400 calendar years (as determined via radiocarbon dating). While recent in scope, this core study revealed a history of subsidence and its affects on pond water depth, salinity, and oxygen level (Athens and Ward 2006). The report documents pollen changes from open forest and shrubby understory to a more open environment following Polynesian settlement. Changes in the pond's gastropod assemblage likely reflect changes in salinity and oxygen. Fishponds are present in a number of PACN parks and may provide similar opportunities for paleoenvironmental reconstruction. A similar report was prepared for PUHO.

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NATIONAL PARK OF AMERICA SAMOA

The National Park of American Samoa (NPSA) was established in 1988 by PL 100-571 with park units on the islands of Tutuila, Ofu and Tau in the Territory of American Samoa, located south of the equator in the central South Pacific Ocean approximately 3,700 km southwest of Hawaii and about 4,345 km northeast of Australia. The park's purpose is to "preserve and protect the tropical forest and archeological and cultural resources of American Samoa, and of associated reefs, to maintain the habitat of flying foxes, preserve the ecological balance of the Samoan tropical forest, and, consistent with the preservation of these resources, to provide for the enjoyment of the unique resources of the Samoan tropical forest by visitors from around the world." Because the Park could not purchase land outright due to the traditional communal land system, it was not until 1993 that the park became legally established with a 50-year lease agreement. This agreement, involving lands within eight villages, enabled the NPS to begin managing lands and waters within the leased premises for National Park purposes. The park consists of 7,970 acres of land and 2,550 marine acres (NPSA's boundary extends 0.40 km (0.25 miles) offshore where water depths are about 30.5 m). In 2002, Congress approved a 30% expansion on Olosega and Ofu islands (Hart 2006).

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

The NPS Geologic Resources Division sponsored geologic resource scoping sessions for NPSA and the other PACN parks in March 2003. Formal, paleontological inventories have not yet been completed for the park. Nevertheless, there is potential for fossil discovery. Lava flows, which can preserve tree molds, as documented in other PACN parks, are potentially present within NPSA (Rutherford and Kaye 2006). Likewise, lava tubes and caves, which preserve paleontological resources in other parks within PACN, are potentially present within NPSA but not yet documented (Rutherford and Kaye 2006). The park contains extensive submerged marine resources as its boundary extends 0.40 km (0.25 mile) offshore (Daniel and Minton 2006). Hart (2006) does not mention fish ponds from within NPSA. Fishponds within KAHŌ and PUHO yielded sediment cores with valuable paleoecological data.

National Park of American Samoa consists of one quadrangle of interest on Samoa (scale 1:24,000): Manua Islands. NPS Geologic Resource Evaluation staff derived the digital geologic data of this quadrangle from Wingert and Pereira (1981a-d). This compiled geologic map is available for downloading from the NR-GIS Metadata and Data Store at <http://science.nature.nps.gov/nrdata> (Chappell 2004).

The Territory of American Samoa is composed of five high volcanic islands, one coral atoll, one low coral islet, and several seamounts. The main volcanic islands form a chain created as the ocean floor (Pacific Plate) moved over a stationary "hotspot" beneath the earth's crust. Secondary volcanism occurred as recently as 2003 when the submarine volcano Vailuluu (between Tau and Rose islands) erupted (L. McClelland, personal communication, 2007). The islands are small and steep, ranging in size from the populated island of Tutuila (135 square km) to the smaller and sparsely populated islands of Ofu, Olosega, and Tau in the Manua Group (Hart 2006). The majority of the geological formations on American Samoa are igneous (basalt, trachyte, and andesite); therefore fossils are not likely to occur *in situ*. Fossil plants, however, have been noted from tuffs (volcanic ash) on the island of Tutuila, with no further information (Stearns, 1944). Fossils from Pleistocene coral reefs are not yet known or documented within or near the park.

Ana Peapea Cave—Outside of NPSA

The only source of prehistoric remains in the American Samoan islands was Ana Peapea cave on the southern coast of Tutuila east of Pago Pago Harbor. The barn owl *Tyto alba* is thought to be responsible for the 13,700 bones found in this cave due to several factors. *Tyto alba* is the most commonly represented bird (including the remains of nestlings), nearly all (more than 95%) of the remains belong to its preferred prey, the Polynesian rat *Rattus exulans*, there was no cultural evidence found at the site, and the other bones recovered from the site included smaller prey such as the Pacific sheath-tailed bat *Emballonura*

semicaudata, the geckos *Gehyra oceanica* and *Nactus pelagicus*, the skink *Emoia* spp., an unidentified lizard, and the small boa *Candoia bibroni*. Nine species of birds were also identified from the cave, none of which are extinct: the chicken *Gallus gallus*, the rail *Gallirallus philippensis*, the tern *Procelsterna cerulea*, the kingfisher *Halcyon chloris*, the starlings *Aplonis tabuensis* and *A. atrifusca*, the honeyeater *Foulehaio carunculata*, an unidentified bird and the aforementioned barn-owl *Tyto alba*. Only one bird found at the site is extirpated on Tutuila, the rail *Porzana tabuensis*. The remains in the cave are probably less than 2,800 years before present in age (Steadman and Pregrill 2004; Steadman 2006).

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PUUHONUA O HONAUNAU NATIONAL HISTORICAL PARK

Puuhonua o Honaunau National Historical Park (PUHO) was originally established by Congress as City of Refuge National Historical Park on July 26, 1955. The site was renamed its current designation in 1978. The park area was the seat of power for the Kona chiefs and includes many archaeological sites. The 182-acre park is located seaward of Honaunau village on the shoreline of Mauna Loa volcano, on the western shore of Hawaii (Else 2006).

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

Geologic resource scoping sessions, sponsored by the NPS Geologic Resources Division were held for PUHO and the PACN parks in March 2003. Formal paleontological resource inventories have not yet been undertaken for PUHO. Nevertheless, tree mold fossils are known from within the park and sediment cores provided paleoenvironmental data for the park as described below. Lava tubes and caves, which preserve fossils in other PACN sites are potentially present within PUHO especially within the park's sea cliffs (Rutherford and Kaye 2006), however they have not been documented. The PUHO boundary ends at mean high tide, therefore submerged resources are not extensive at PUHO (Daniel and Minton 2006).

Map coverage for Puuhonua o Honaunau National Historical Park consists of one quadrangle of interest (scale 1:24,000): Honaunau. The park contains both terrestrial and marine resources; therefore, both types of geologic maps are necessary for proper resource management. The U.S. Geological Survey has produced terrestrial and marine geological maps. Geologic Resource Evaluation staff will derive the digital geologic data for the terrestrial and marine portions of the park (from Wolf and Morris 1996a-f and Fletcher et al. 2002, respectively).

Puuhonua o Honaunau National Historical Park is located on the shoreline of Mauna Loa volcano, which most recently erupted in 1975 and 1984. Several of the lava flows found within the park are between 750 and many thousands of years old (Else 2006). The mapped geological formations within PUHO are composed entirely of Kau Basalts (tholeiitic basalts) of Holocene and Pleistocene age.

Puuhonua o Honaunau Tree Molds (Pleistocene-Holocene)

Trace fossils are preserved within PUHO on the Kona coastline as tree molds. These trace fossils form when a tree is surrounded by lava, preserving the outer surface of the tree. As the tree is engulfed, its moisture content is released as steam, allowing enough time for the outside of the tree to leave an impression in the surrounding lava. This can often preserve surface details, such as leaf attachments and bark patterns; even after the tree has decayed or succumbed to the lava's heat. There are nearly three dozen molds found at PUHO (Woodcock and Kalodimos 2005). The tree molds typically extend horizontally across flows, which indicate trees that fell into the lava and were transported with the flow. Vertical molds indicate the life position of these trees and can give insight into the flow direction of the lava, establish locations of vents, and the force of the flow. Lava often infill portions of these hollow molds when breached from below, creating a "squeeze up" formation. The surface detail of the tree is often lost during this process. These tree molds appear to be loulu palms, most likely *Prichardia* sp. (Woodcock and Kalodimos 2003, 2005). The *Prichardia* sp. has been dated to approximately 1,000 years before present via a charcoal layer beneath the flow. Therefore the native loulu palm was an important floral component during the early period of Polynesian settlement (Woodcock and Kalodimos 2005). Introduced palms now dominate the flora of the area; however there are loulu palms still present within the park, including a specimen near the park offices (Woodcock and Kalodimos 2005). Tree molds are also known from around the Hawaiian Islands and in other NPS areas including: Hawaii Volcanoes National Park (Island of Hawaii), Lava Tree State Park (Island of Hawaii), Craters of the Moon National Monument and Preserve (Idaho), Lava Beds National Monument (California), and El Malpais National Monument (New Mexico).

Kaloko Fishpond Paleoenvironment (Recent)

Athens et al. (2006) studied sediment cores from the two Kaloko Fishponds within PUHO to provide paleoenvironmental information to the park. The sediment cores produced pollen up to approximately 900 years old (AD 992-1149). The report documented environmental changes as a response to subsidence and human activity. Pollen assemblages within the core show a change from native vegetation to dominated by coconut approximately 500 years ago following increased settlement. Increased salinity within the pond may have contributed better conditions for raising fish (Athens et al. 2006). The study also included diatoms and mollusks. Fishponds are present in a number of PACN parks and may provide similar opportunities for paleoenvironmental reconstruction. A similar report has been produced for KAHŌ and is described in that park's section.

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PUUKOHOLA HEIAU NATIONAL HISTORIC SITE

Puukohola Heiau National Historic Site was designated in 1928 when it was commemorated as a Historical Landmark by the Hawaiian Territorial Government. In the 1960s, the Queen Emma Foundation and the Queen's Medical Center, the Waimea and other Hawaiian Civic Clubs, and local community groups were instrumental in getting Puukohola Heiau designated as a National Historic Landmark. The Queen Emma Foundation donated 34 acres of land in 1972 encompassing Puukohola Heiau and the John Young Homestead making possible the establishment of Puukohola Heiau National Historic Site (PUHE) through an act of Congress on August 17, 1972.

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

The NPS Geologic Resources Division sponsored geologic resource scoping sessions for PUHE and the other PACN parks in March 2003. As fossils are not yet known from within PUHE, no paleontological resource inventories have been conducted for the park. Lava flows and lava tubes or caves are not documented within PUHE (Rutherford and Kaye 2006). These features preserve fossils within other PACN parks. Submerged lands adjacent to the park are managed by the state of Hawaii (Daniel and Minton 2006). Jones (1993) listed a Pleistocene age (110,000 years old) for emerged fossil coral reef near Keawanui Bay approximately 14.5 km northwest of PUHE. Similar resources are not yet documented within the park. However, Jones (1993) does note that marine fossils are sometimes found associated with Hawaiian temples (heiaus), small fishing shrines, and trail cairns. He does not list specific examples however. Given the proximity of the Keawanui Bay exposures to the park, similar resources might be found within PUHE but are not yet documented. Else (2006) noted the presence of a small pond within the park. Sediment cores from fishponds within KAHO and PUHO yielded important paleoecological data, a similar study has not yet been undertaken for the pond within PUHE.

Puukohola Heiau National Historic Site is located on the northwest coast of the Island of Hawaii. The northwest portion of Hawaii developed from the eruptive activity of Kohala volcano, one of five distinctive volcanoes on the big island. Kohala is the first of the five volcanoes to emerge from the ocean (Wolfe and Morris 1996a), so is the source of the oldest rocks on the island. The volcanoes of Hawaii typically evolve through a sequence of four eruptive stages: preshield, shield, postshield, and rejuvenated stages (Clague and Dalrymple 1987). Each stage is distinguished by lava composition, eruptive rate and style, and stage of development (Wolfe and Morris 1996a). Kohala is capped by postshield lavas. The Kohala volcanics are predominantly basaltic lavas. The older Pololu Volcanics have been Potassium-Argon (K-Ar) dated to between 400,000 to 250,000 years old (Dalrymple 1971). The more recent Hawi Volcanics yield K-Ar dates between 230,000 and 120,000 years old (McDougall 1969; McDougall and Swanson 1972).

Map coverage for PUHE consists of one quadrangle of interest (scale 1:24,000): Kawaihae. The historic site contains both terrestrial and marine resources; therefore, producing both types of geologic maps is necessary for proper resource management. The U.S. Geological Survey has produced maps for the terrestrial (Wolf and Morris 1996a-f) and marine (Fletcher et al. 2002) components, respectively.

No fossils are known to occur within PUHE. Basaltic rocks were used in the construction of the temples, walls, and other structures now preserved as cultural resources at the site. Fossil birds *Loxioides* sp., *Akialoa* sp., *Telespiza* sp., *Hemignathus vorpalis*, and 3 species of birds from Umii Manu Cave: *Porzana* sp., *Corvus* sp., and *Hemignathus* sp. are all known from the island of Hawaii (Griffin 1993; James 2004; James and Olson 2005). Baseline soil and soil geochemistry studies have been performed in the Kohala and Kawaihae areas of PUHE (Gardiner 1967; Giza 1979; Halbig et al. 1985).

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USS ARIZONA MEMORIAL

The USS Arizona Memorial (USAR) is the final resting place for many of the battleship's 1,177 crew members who lost their lives on December 7, 1941. Located on the island of Oahu, the national memorial commemorates the site where World War II began for the United States. There is no congressionally authorized enabling mandate for the USS Arizona Memorial. In 1978 the Military Construction Authorization provided the transfer of operation from the United States Navy to the National Park Service, which was finalized in 1980 (Daniel 2006).

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

Due to the limited ground area of the USS Arizona Memorial, geological scoping sessions have not been performed for USAR. No formal paleontological inventories have been undertaken for the park and fossils are not known, and not likely within USAR. The park does not preserve natural resources that have produced fossils in other PACN parks such as lava flows or lava tubes and caves (Rutherford and Kaye 2006). Fishponds, which have produced paleoenvironmental data for PUHO and KAHO, are likewise not found within the park. The park boundary ends at mean high tide, and does not include the submerged lands surrounding the USS Arizona and USS Utah (Daniel and Minton 2006). Jones (1993) summarized fossiliferous marine terraces and the dozens of radiometric dates obtained along the Oahu coastline. A number of these terrace dates were obtained near Honolulu, but none near Pearl Harbor. Fishponds, which produced paleoecological data within KAHO and PUHO are not documented within USAR (Daniel 2006).

The island of Oahu is composed of basalts and other volcanics, the occasional tephra and ash deposits, with unconsolidated alluvium restricted to the valleys and coastlines. USS Arizona Memorial is located in Pearl Harbor, on the south-central side of the Island of Oahu. Most of the park is located on artificial fill. Depending on the source of the fill material, it may be fossiliferous. However exposures of the fill within the park are not known.

USAR Building Stones—Vermont Marble

Vermont Marble was used in the construction of the memorial (D. Martinez, personal communication, 2007). Ordovician-aged Vermont Marble has been a popular memorial stone in the United States since the early 1800s. In fact it was chosen for USAR to form connections between the memorial and other government buildings and memorials in Washington D.C. that utilize Vermont Marble, such as the Jefferson Memorial (D. Martinez, personal communication, 2007). Marbles are metamorphosed (altered under high temperature and/or pressure) limestones. Limestones frequently preserve fossils, but metamorphism typically destroys them. As such, fossils are probably not visible in the high grade Vermont Marble of USAR.

Plant Fossils (Middle Pleistocene)—Outside of USAR

An interesting fossil flora assemblage was found approximately three km east of USAR near the Salt Lake Crater. Woodcock and Maekawa (2006) described leaf galls (“wounds” associated with piercing/sucking insects) on *Metrosideros* leaves from the Salt Lake volcanics. The lahar deposits, dated to approximately 250,000-474,000 years before present, preserve an fossil flora assemblage that represents some of the oldest fossil material associated with igneous rocks in the Hawaiian Islands. Woodcock et al. (1998) also reported fossil cotton of the *Gossypium* genus from an ash layer below the lahars.

Avian Fossils (Middle Pleistocene)—Outside of USAR

Middle Pleistocene age bird fossils are known from the island of Oahu, outside of NPS land, within the lacustrine units of Ulupau Crater. These fossils may represent the oldest known birds from the Hawaiian archipelago (Hearty et al. 2005). Other prehistoric bird remains known from the island of Oahu include *Rhodacanthus litotes*, along with *Ciridops* sp, *Akialoa upupirostris*, *Chloridops regiskongi* (James 2004; James and Olson 2005).

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WAR IN THE PACIFIC NATIONAL HISTORICAL PARK

War in the Pacific National Historical Park (WAPA) is located on the tropical island of Guam, approximately 13 degrees north of the equator and about 5,300 km southwest of Hawaii. While Guam is only 550 square km, the island is rich in history. Only hours after Pearl Harbor was attacked, the Japanese began aerial bombings on Guam. After two days of strafing, the Japanese came ashore and hours later the naval governor surrendered the American territory. The island remained under Japanese control for 31 months until July 21, 1944 when the United States returned and liberated the island. In order to remember the involvement of the United States and Guam in World War II, War in the Pacific was established in 1978. The site commemorates the bravery and sacrifice of those participating in the campaigns of the Pacific Theater of World War II and conserves and interprets outstanding natural, scenic, and historic values and objects of the island of Guam.

BASELINE PALEONTOLOGICAL RESOURCE INVENTORIES

Geologic resource scoping sessions, sponsored by the NPS Geologic Resources Division were held in March 2003 for WAPA and the other PACN parks. Formal paleontological resource inventories have not yet been completed for WAPA. Nevertheless, fossils are known from within the park as described below. Lava flows which preserve tree molds in other PACN parks are not documented within WAPA (Rutherford and Kaye 2006). Lava tubes and caves, however, are documented within the park (Rutherford and Kaye 2006). These tubes preserve fossils such as avian bones in other PACN parks but are not yet known to contain fossils within WAPA. The park contains over 1,000 acres of submerged lands including extensive coral reefs (Daniel and Minton 2006). Fishponds, which produced paleoecological data within KAHO and PUHO are not documented within WAPA (Daniel 2006).

The U.S. Geological Survey produced a map of the entire island in 1964 (Tracey et al. 1964). These maps may be available digitally (D. Minton, personal communication, 2006). Invertebrate fossils are known from the park and were likely found in the Alutom, Alifan and/or Mariana Formations as described below. Fossils may also be found in the “coralline limestone” incorporated in many of the park’s historic fortifications.

Guam is the largest and southernmost of the Mariana Island chain, in the western Pacific Ocean. These islands are typical of an island arc system, consisting of stratovolcanoes rising from the floor of the Pacific Ocean. Origins of the Mariana Islands can be attributed to subduction of the Pacific Plate underneath the Philippine Plate. Volcanic activity that initiated the growth of the islands began some 10 to 45 million years ago. Guam was built by sedimentary and igneous processes. Central and northern Guam is composed of a relatively flat plateau of raised coralline limestones, often exhibiting karst features, with some sections exposed as steep coastal cliffs. Southern Guam is a mix of high volcanic hills and valleys of pillow and basaltic flows, intermingling with the limestone (Daniel 2004).

Fossiliferous Limestones (Eocene-Pleistocene)

The sedimentary rocks of Guam are limestones, with eight named formations, including three within War in the Pacific National Historical Park (Alutom, Alifan and Mariana; Tracey et al. 1964). Six of the eight formations are known to contain fossils of foraminifera and/or other calcareous algae: Eocene-Oligocene Alutom Formation (14 known species), Miocene Bonya Limestone (13 known species), Miocene Maemong Limestone member of the Umatac Formation (36 known species), Miocene-Pliocene Alifan Limestone (19 known species), Miocene-Pliocene Barrigada Limestone (9 known species), Pliocene-Pleistocene Mariana Limestone (7 known species) (Cole 1963; Johnson 1964). Foraminifera are fossils that are often used to correlate rock units, also assisting in age determination.

The Alutom formation can be found in the Asan Inland, Fonte Plateau, Mt. Chachao, Mt. Tenjo and Piti Guns Units of the park. The Mahlec member of the Alutom Formation contains fourteen known species of planktonic Foraminifera, with the most common forms belonging to *Bolivinitis* sp., *Nonion*

maoricum, *Bolivina choctawansis*, *Angulogerina vicksburgensis*, and *Angulogerina cooperensis*. The Mariana and Alifan Limestone formations may also be present in the Asan Inland Unit. The Mariana Limestone is the most fossiliferous and extensive formation on Guam, preserving reef and lagoon deposits. It contains several different facies, many of which contain the remains of sea urchins, mollusks (*Ostrea*, *Tridacna*, and *Turritella*), foraminifera (*Operculina*, *Marginipora*, *Amphestigina*, *Gypsina*, and *Cycloclypeus*) and corals (*Acropora*, *Seriatopora*, *Porites*, and *Favia*). The Mt. Alifan Unit is located on the Alifan Limestone; a formation known to contain remains of the foraminifera *Rotalia atjehensis*. The Asan Beach Unit is composed of small amounts of Mariana Limestone, Alifan Limestone and Alutom Formation, and larger amounts of alluvium and beach deposits. The Agat Unit is composed almost entirely of alluvium, with smaller outcroppings of Mariana and Alifan Limestone (Johnson 1964; Tracy et al. 1964).

Crustaceans are another well-known fossil from Guam, found as isolated remains that tend to wash onto beaches, most notably Dadi Beach less than 1.6 km north of the park's Agat Unit. Similar fossils have or could wash up on the beaches within the Agat Unit, although this is currently undocumented. In 1958 four species of crab were identified (Kesling 1958). Since then many hundred of fossil crabs, along with shrimp, barnacles, mollusks, corals and ray teeth have been collected (Scott-Smith 2004). To date, twelve species of fossil crabs have been identified, with two of Kesling's 1958 identifications being placed into different taxa (Schweitzer and Feldmann 2000; Schweitzer et al. 2002; Scott-Smith 2004). No fossils have been reported from the Asan (Miocene), Sumay (Pleistocene), or Merizo Limestones (Holocene) (Johnson 1964).

Avian Fossils (Pleistocene-Recent)

Extinction is a persistent problem for the avian species on Guam today, which have been greatly reduced by non-native brown tree snakes. Guam's avian fossil record is very poorly known, and limited to only 28 known bones, including the heron *Egretta sacra*, the duck *Anas oustaletii*, the megapode (a chickenlike bird) *Megapodius laperous*, the rails *Gallirallus owestoni*, *Poliolimanas cinereus*, and *Gallinula chloropus*, the dove *Gallicolumba xanthonura*, the swift *Collocalia vanikorensis*, the starling *Aplonis opaca*, the monarch *Myiagra freycineti*, and the honeyeater *Myzomela rubrata* (Steadman 2006).

WAPA Fossils in Cultural Contexts

Numerous natural and manmade caves, and defensive emplacements are located throughout the park. Structures are typically constructed of concrete and local limestone. Some of the limestone is described as "coral limestone" or "crushed coral" in NPS Classified Structure reports (e.g. Japanese Emplacement and 1961 Mabini Memorial) and may display identifiable Pleistocene or older invertebrate fossils. Many historic structures in the National Park Service display fossils in their building stones (Kenworthy and Santucci 2006). Such structures present easily accessible fossil "exposures" and unique interpretive and resource management opportunities.

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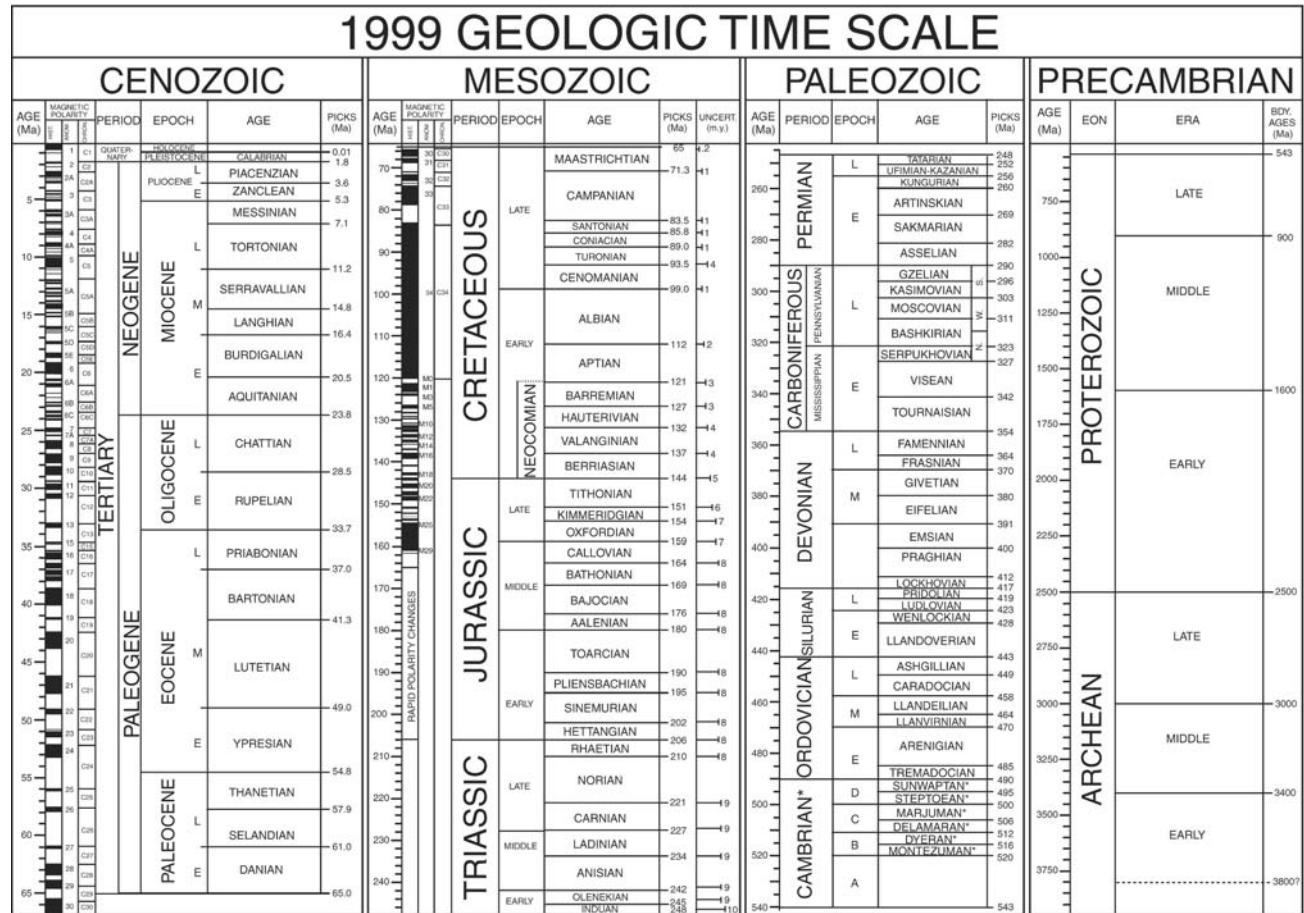
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APPENDIX A: GEOLOGIC TIME SCALE

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*International ages have not been established. These are regional (Laurentian) only. Boundary Picks were based on dating techniques and fossil records as of 1999. Paleomagnetic attributions have errors. Please ignore the paleomagnetic scale.

Sources for nomenclature and ages: Primarily from Gradstein, F., and Ogg, J., 1996, *Episodes*, v. 19, nos. 1 & 2; Gradstein, F., et al., 1995, *SEPM Special Pub. 54*, p. 95–128; Berggren, W. A., et al., 1995, *SEPM Special Pub. 54*, p. 129–212; Cambrian and basal Ordovician ages adapted from Landing, E., 1998, *Canadian Journal of Earth Sciences*, v. 35, p. 329–338; and Davidek, K., et al., 1998, *Geological Magazine*, v. 135, p. 305–309. Cambrian age names from Palmer, A. R., 1998, *Canadian Journal of Earth Sciences*, v. 35, p. 323–328.

Note: Picks (Ma) = age of the geologic time unit boundary in millions of years (Ma).

This timescale is available online as a PDF: <http://www.geosociety.org/science/timescale/timescl.pdf>