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Paleontological Resource Inventory and Monitoring
Klamath Network

Natural Resource Technical Report NPS/NRPC/NRTR—2009/208



ON THE COVER
Mammut americanum molar (partial) located in the UCMP collections from Lava Beds National Monument. A thick, dark patina coats part of the tooth surface and is similar to the secondary mineralization on the floor of Fossil Cave at LABE. For more information, refer to the park's section.

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Natural Resource Technical Report NPS/NRPC/NRTR—2009/208

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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.

April 2009

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

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Abstract

Paleontological resources (fossils) are any remains of past life preserved in a geologic context. Paleontological resources are non-renewable resources found in more than 210 National Park Service (NPS) units. Despite the abundance and diversity of these resources throughout the NPS, until recently few parks have adequate baseline paleontological resource data.

The NPS National Inventory and Monitoring Program and the NPS Geologic Resources Division have developed various strategies to provide parks with the baseline paleontological resource data necessary for greater understanding and appropriate management of these resources. This report presents a paleontological resource summary for the parks of the Klamath Network. The summary was compiled through extensive literature reviews and interviews with park staff and professional geologists and paleontologists. Preliminary paleontological resource management recommendations are also included for each park. Including this report, summaries have been prepared for 24 NPS Inventory and Monitoring Networks. The National Inventory and Monitoring Program provided funding to complete paleontological resource summaries for each of the remaining networks.

The paleontological resources known from the parks of the Klamath Network are primarily limited to some isolated megafaunal remains from the lava tubes at Lava Beds National Monument (LABE), Pleistocene/Holocene fauna from Oregon Caves National Monument (ORCA), and a late Tertiary-aged flora preserved in the Gold Bluffs at Redwoods National and State Parks (RNSP). Fossils are either rare or not well documented from the other parks in the Klamath Network including: Crater Lake National Park (CRLA), Lassen Volcanic National Park (LAVO), and Whiskeytown National Recreation Area (WHIS).

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Dedication



This report is dedicated to JODA Paleontologist and NPS Pacific West Science Advisor Ted Fremd for his 30 years of contributions toward scientific research, resource management, stewardship, public education and interpretation of NPS paleontological resources. Starting his NPS career in 1979 and retiring in 2009, Ted was part of the core of NPS paleontologists that shaped NPS paleontological resource management in the late 20th and early 21st centuries.

Introduction

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

The establishment of baseline paleontological resource data is essential for the appropriate management of fossils found within National Park Service (NPS) areas. Although more than 210 NPS areas have been identified with paleontological resources, few parks have adequate baseline paleontological resource data.

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

The Klamath Network is composed of six parks in two western states (California and Oregon) as shown in Figure 1. These include Crater Lake National Park (CRLA), Lassen Volcanic National Park (LAVO), Lava Beds National Monument (LABE), Oregon Caves National Monument (ORCA), Redwood National and State Parks (REDW) and Whiskeytown National Recreation Area (WHIS). The parks that comprise the Klamath Network vary in size from 196 ha (484 acres) at ORCA to 73,775 ha (182,298 acres) at CRLA. Elevations within the network range from sea level at REDW to 3,187 m (10,456 ft) above sea level at LAVO.

The Klamath bioregion area is characterized by steep climatic, geologic, and topographic gradients. The varied disturbance regimes in the region yield biological diversity exceeded by few similar-sized areas within North America or temperate regions worldwide (Sarr et al. 2007). Within the Klamath bioregion, terrestrial habitats range from mesic coastal redwood forests with biomass accumulations among the highest recorded in terrestrial ecosystems to barren alpine tundra and xeric sagebrush steppe. Aquatic ecosystems include Pacific marine habitats, the deepest natural lake in the United States (Crater Lake), man-made reservoirs, a diverse array of wetlands, and many streams and rivers. Other unique habitats include karst and volcanic caves, hot springs, and lava flows (Sarr et al. 2007).

According to Sarr et al. (2007) the Klamath region encompasses two subregions with fundamentally different geological character. A rough line from Redding to Yreka, California and from Ashland to Roseburg, Oregon can be used to separate the complex and varied Klamath-Coastal subregion from the volcanic Cascades-Modoc subregion.

The Klamath-Coastal subregion, including Redwood, Oregon Caves, and Whiskeytown, is notable for its rugged, non volcanic topography and complex geology. The Klamath Mountains a classic example of a mountain belt formed from repeated accretion and compression of the ocean floor onto the westward edge of the North America. This accretion occurred during the last 150 million years along an active continental margin (Norris and Webb 1990). The Klamath Mountains province has been divided into four arc-shaped belts of rock of varying age. From east to west they are the Eastern Klamath, central metamorphic, western Paleozoic and Triassic, and western Jurassic belts (Snoke and Barnes 2006). The middle Jurassic (about 150 million years ago) was characterized by many igneous (molten rock) intrusions and metamorphism.

The Cascades-Modoc subregion formed during relatively recent volcanism. The Cascade Range is a classic example of subduction zone volcanism where oceanic crust is forced beneath denser continental crust. High temperatures at depth cause the oceanic crust to "sweat" water which melts surrounding

rocks. This buoyant molten material rises toward the surface, fueling volcanoes. The volcanoes of the Cascades within the KLMN include Crater Lake and Lassen Peak. Crater Lake, a spectacular 8 x 10 km caldera formed in a major eruption about 7,700 years ago from the collapse of a complex of overlapping shield and stratovolcanoes known as Mount Mazama. Lassen Peak represents the southernmost extent of the Cascade Range. A 1914-1917 explosive eruption there inspired its designation as a national park. Volcanism is also evident on the Modoc Plateau, east of the Cascades. Lava Beds National Monument, on the northern flank of Medicine Lake shield volcano, contains hundreds of lava-tube caves displaying a variety of spectacular lava-flow features (Venzke et al. 2002). Volcanic rocks from the Cascades include basalt, andesite, and dacite (Norris and Webb 1990). The eastern edge of the Cascades is bordered by the Modoc Plateau basalt flows. Continued volcanism there created geomorphic and geothermal features, including cinder cones, pumice flats, lava tubes, and hot springs (Lassen).

While the active tectonics of the region, particularly the volcanic activity, may suggest a paucity of paleontological resources within the network, there are a number of documented fossil resources. These fossils are primarily limited to some isolated megafaunal remains from the lava tubes at Lava Beds National Monument (LABE), Pleistocene/Holocene cave fauna from Oregon Caves National Monument (ORCA), and a late Tertiary-aged flora preserved in the Gold Bluffs at Redwoods National and State Parks (RNSP). Fossils are either rare or not well documented from the other parks in the Klamath Network including: Crater Lake National Park (CRLA), Lassen Volcanic National Park (LAVO), and Whiskeytown National Recreation Area (WHIS).

Collectively, the paleontological resources of the KLMN contribute to a greater understanding of the history of life on earth. Continued paleontological resource inventories will serve to expand this ever-widening base of paleontological knowledge represented throughout the National Park Service. Although more than 210 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.

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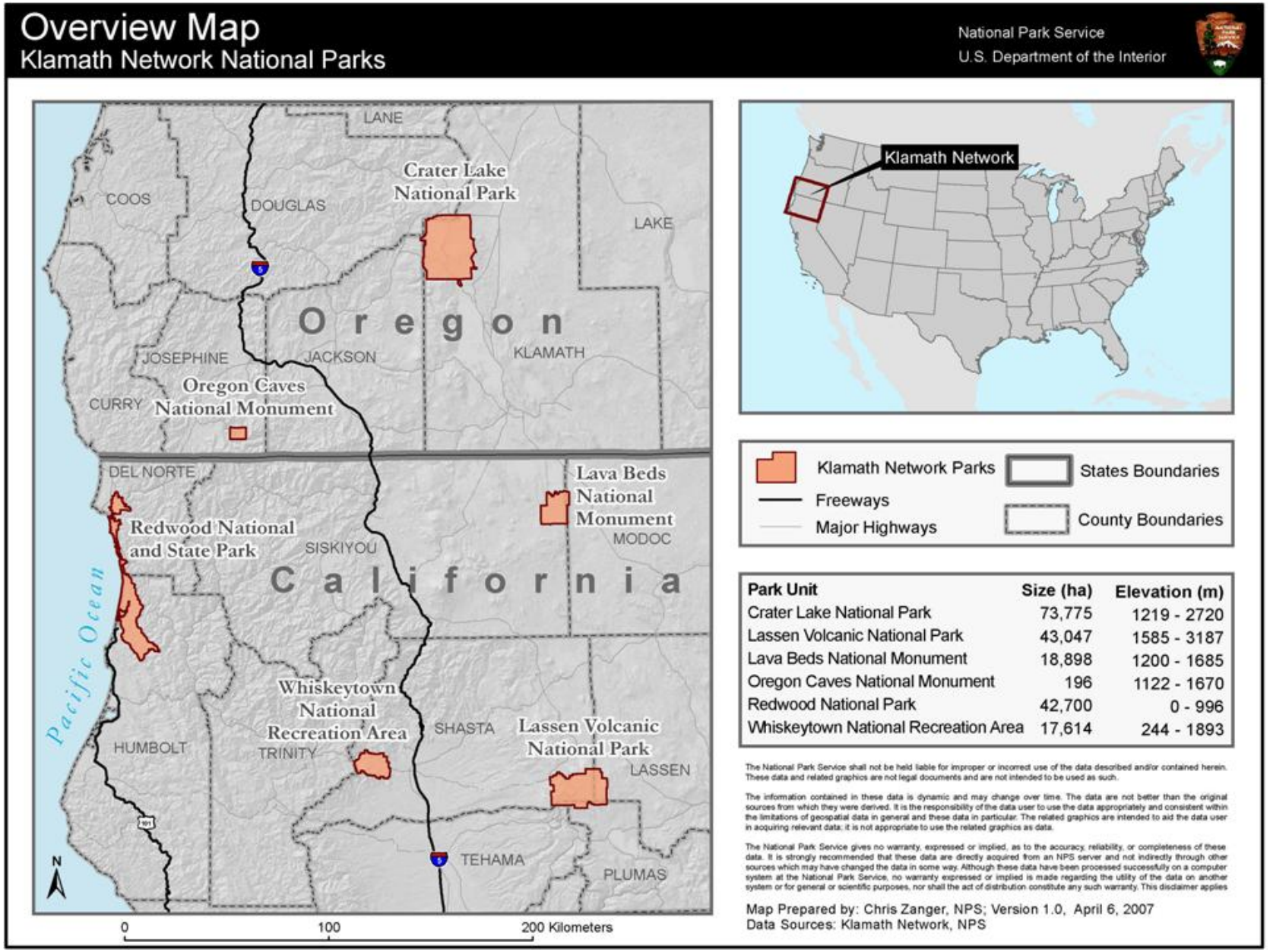


Figure 1. Map of KLMN network parks. Map courtesy of Klamath Network Inventory and Monitoring Program.

Paleontological Resource Inventory Strategies and Methodology

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

Comprehensive Park-Specific Paleontological Resource Inventories

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

Servicewide Thematic Paleontological Resource Inventories

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

Inventory and Monitoring Network Paleontological Resource Inventories

Network-based paleontological resource inventories compile baseline paleontological resource data for each of the parks within a particular network. Network-based inventories have been completed for 24 of the 32 I&M Networks including: the Appalachian Highlands, Chihuahuan Desert, Eastern Rivers and Mountains, Great Lakes, Greater Yellowstone, Gulf Coast, Heartland, Klamath (this report), Mediterranean Coast, Mid-Atlantic, Mojave Desert, National Capital Region, Northeast Coastal and Barrier, Northern Colorado Plateau, Pacific Island, Rocky Mountain, San Francisco Bay Area, Sierra Nevada, Sonoran Desert, Southeast Coast, Southeastern Alaska, Southern Plains, Southwestern Alaska, and Upper Columbia Basin networks. Research for summaries of the Arctic, Central Alaska, Cumberland Piedmont, North Coast and Cascades, Northern Great Plains, South Florida/Caribbean and Southern Colorado Plateau networks are currently underway. NPS I&M Program funding is targeted to complete paleontological resource summaries for the remaining networks by the end of FY2009. Citations for the completed reports are in the Additional References section.

I&M Network Paleontological Resource Inventory Methodology

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

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

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

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

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

Organization of the Reports

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

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

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

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

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

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

Given the tremendous diversity of past life, the existence of life for over a billion years, and the range of environments to which life has adapted, there is a broad spectrum of research interests in paleontology. It is not surprising that most of what is to be learned about the history of life remains to be discovered. Through research, more than 200 NPS areas have been identified as containing paleontological resources. However, the paleontological research for a particular park may vary widely from an incidental fossil discovery to over a century of intensive paleontological investigations. Therefore, the inventory reports include information on the history of paleontological research, identification of any museums or universities serving as repositories for park fossils, and a complete bibliography.

Paleontological Resource Management Legislation and Guidance

I&M Network reports such as this one are meant to provide network parks with sound baseline paleontological resource data that can stimulate future research, interpretation, education, or resource management projects. The proper management of resources identified through these inventories is mandated by many NPS policies. For example, the 2006 National Park Service Management Policies (§1.4.6) stipulates that paleontological resources are considered park resources and values that are subject to the "no impairment" standard set forth by the NPS Organic Act in 1916. Basic guidelines for management of paleontological resources are found in sections 4.8.2 and 4.8.2.1 of the 2006 NPS Management Policies. Another legislative protection for paleontological resources is found in the NPS Omnibus Management Act of 1998. Section 207, with the following statement, "Information concerning the nature and specific location of. . .paleontological objects within the units of the National Park System. . .may be withheld from the public source. . .," safeguards paleontological locality information from requests under the Freedom of Information Act.

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

The Geologic Resources Division and Geological Society of America is assembling a geologic resource monitoring manual that includes chapters on various geologic resources, including in situ paleontological resources, and a set of monitoring vital signs that may be applicable to a variety of parks. Monitoring represents the next phase in paleontological resource management, following the initial research inventory (represented by this report) of potential fossils and any subsequent field work to identify fossils within a park. Publication is expected by late 2009. Contact the Geologic Resources Division for more information or to obtain a copy of the report when it is available.

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

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Oregon Department of Geology and Mineral Industries: http://www.oregongeology.com
U.S. Geological Survey: http://www.usgs.gov
Geological Society of America: http://www.geosociety.org
American Geological Institute: http://www.agiweb.org

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U.S. Geological Survey Library Catalog: http://igsrglib03.er.usgs.gov:8080/#focus
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Museums

California Academy of Sciences: http://www.calacademy.org
Humboldt State University Natural History Museum: http://www.humbolt.edu/~natmus/visitUs.html
Northern Arizona University – Quaternary Studies Department: http://nau.edu/~qsp
Smithsonian National Museum of Natural History Dept. of Paleobiology: http://www.nmnh.si.edu/paleo
University of California, Berkeley, Museum of Paleontology: http://ucmp.berkeley.edu/index.php

Resource Management/Legislation Documents

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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.cfm

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National Park Service Geology and Paleontology sites

NPS Geologic Resources Division: http://www.nature.nps.gov/geology/
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http://www.paleoportal.org/
University of California-Berkeley Museum of Paleontology online paleontology exhibits:
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U.S. Geological Survey Geologic Terms Glossary:
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U.S. Geological Survey Geographic Names Information System (GNIS; search for place names and geographic features, and plot them on topographic maps or aerial photos): http://gnis.usgs.gov/
U.S. Geological Survey GeoPDFs (download searchable PDFs of any topographic map in the United States): http://store.usgs.gov (click on "Map Locator").
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Crater Lake National Park

Crater Lake National Park (CRLA) was established May 22, 1902 to preserve scenic Crater Lake which now fills the caldera of Mount Mazama. This volcano is part of the Cascade Range and climactically erupted approximately 7,700 years ago forming the caldera. The collapsed caldera is essentially a closed basin which was filled by water after the eruption. Crater Lake is the deepest lake in the United States with a maximum depth of 594 m (1,949 ft).

Geologic Background

Crater Lake National Park is located in Klamath County in southwestern Oregon and is situated in the Cascades-Modoc subregion of the Klamath Network as defined by Sarr et al. (2007). This subregion is also recognized as the southern portion of the Cascade Range and is an active plate tectonic province experiencing earthquakes and volcanic eruptions. In general the Cascades-Modoc subregion is characterized by dense basaltic rock derived from an oceanic plate which has subducted beneath less dense continental crust. Geologically the area is influenced predominantly by relatively recent (last few hundreds of thousands of years) volcanism of basalt, andesite and dacite composition (Norris and Webb 1990; Bacon 2008). Bacon (2008) recently published an updated geologic map of the park which is available online and includes a geologic summary of Mount Mazama and the formation of Crater Lake.

The Cascade Range forms a dramatic barrier to moisture carried eastward on prevailing winds from the Pacific Ocean. Because of this rainshadow effect, eastern Oregon receives approximately one-quarter of the precipitation that western Oregon receives. The Cascade Range is thought to have reached elevations close to the modern day elevations by the end of the Miocene (see the appendix for a geologic time scale) approximately 6 million years ago. However, the modern High Cascade peaks are much younger. During the Pleistocene, lava flows, primarily basalt and andesite, helped to form the lava plateaus of the Cascades. Several composite volcanic cones were formed during this period including: Mt. Bailey, Mt. Thielsen, and Union Peak.

The geologic history of Mount Mazama appears to date to the early Pleistocene with the development of shield volcanoes and a series of alternating lava flows and pyroclastic eruptions of andesitic and basaltic composition. A volcanic vent system and complex of stratovolcanoes began to form on top of the older shield volcanoes and basalt flows around 400,000 years ago. The Mount Scott vents formed a bit earlier dating to approximately 420,000 years ago and the Phantom Ship vents developed about 400,000 years ago (Bacon 2008). Most of the rocks associated with these vents are andesitic in composition and represent some of the oldest rocks from Mount Mazama. The vents form the highest elevations in the park, with the summit of Mount Scott representing the highest point in CRLA at 2,721 m (8,926 ft).

Until approximately 30,000 years ago, a series of dacite and rhyodacite lava flows and plug domes were emplaced near the summit of Mount Mazama. Eruptions of basalt and basaltic-andesite were extruded on the flanks of the mountain. After more than 20,000 years of dormancy for Mount Mazama, the Llao Rock eruption occurred about 7,800-7,900 years before present, just before the caldera-forming eruption. Evidence of the Llao Rock eruption is visible on the northwest side of the north rim of the caldera (Bacon 2008).

Williams (1942) projected that ancient Mount Mazama reached an elevation of 3,660 m (12,000 ft) prior to its eruption. The peak may have been the tallest of any Cascade Range peak in Oregon and was covered by glaciers. Episodes of glaciation before, during and after the eruptions are represented in till deposits and some glacial outwash interbedded with volcanic debris (Harris and Tuttle 1983). Munsono, Kerr, and Sun valleys are large “U” shaped valleys formed by glacial activity.

The climactic eruption resulting in the collapse of the top of Mount Mazama and formation of the caldera occurred approximately 7,700 years before present. The initial phase of the eruption involved the

production of huge ash clouds, followed by ash flows down the flanks, with large volumes of pumice, obsidian and volcanic debris. Some of these volcanic deposits developed into glass-rich rock layers known as welded tuffs as their high temperature and weight of overlying material "welded" the volcanic debris together. The pumice and ash deposits on the flanks of the mountain are evidence of the violent explosive eruption, the largest documented in the Cascade Range. Rapid melting of the peak's glaciers and significant pyroclastic debris flows (also called nuée ardentes) were generated in conjunction with the violent and explosive eruption. The eruption and subsequent collapse of the caldera greatly reduced the height Mt. Mazama from its pre-eruption estimated elevation of 3,660 m (12,000 ft) and the resultant caldera spans an average of 8 km (5 miles) in diameter and 1,219 m (4,000 ft) deep.

Volcanic activity continued after the caldera-forming eruption. Wizard Island and Merriam Cone are two cinder cones which formed on the floor of the caldera approximately 300 years after the collapse. Wizard Island is 233 m (764 ft) above the present lake level. Merriam Cone is a submerged feature on the north edge of the caldera floor. The existence of pillow lavas indicates the molten rock emerged into the lake water during the time of formation (Nelson et al. 1994).

Tall chimneys or pipe-like features called pinnacles were formed where hot trapped gases escaped to the surface through small vents in the ash deposits. The pinnacles are slender vertical features in which the ash around the pipes hardened or welded and became more resistant to erosion than the surrounding ash. Through erosion these pinnacles have become exposed and in some cases are up to 9 m (30 ft) high. These pinnacles are present in the Annie, Sand and Wheeler Creek Valley areas of the park.

The most recent volcanic activity occurred between September and December 1945 when a series of blue-gray clouds of smoke or gas were emitted from Crater Lake. The only other active volcanic features at CRLA are associated with the drowned hot springs on the caldera floor.

The high elevation mountain lake formed within the crater of Mount Mazama was known to the local Klamath Indians. The Klamath people referred to this lake as the "Lake of the Blue Waters." Archeological remains, oral histories, and legends suggest that the Klamath people were present in the area at the time of the explosion.

A young prospector named John Wesley Hillman, along with a small party of prospectors, are credited with the discovery of the lake in the volcanic caldera on June 12, 1853. The name Crater Lake was first used by newspaperman John Sutton in 1869. Judge William Gladstone Steel visited the lake in 1885 and worked towards preserving the area. Later, Steel became the superintendent of Crater Lake.

In 1886 the U.S. Geological Survey sent an exploration party led by Clarence Dutton. Members of Dutton's party were able to determine the depth of the lake to be approximately 610 m (2,000 ft). More recent measurements have determined the maximum depth of the lake to be 594 m (1,949 ft) (Bacon 2008). Crater Lake represents the deepest lake in the United States, the second deepest lake in North America, and the seventh deepest in the world. As there is no known drainage outlet for the lake, its depth is determined by relative amounts of input from precipitation and snowmelt versus water loss by evaporation and seepage.

Geologist Howel Williams studied the caldera during the 1930s and 1940s (Williams 1942). Williams determined that the caldera was formed by an inward collapse of Mount Mazama as the magma chamber beneath was emptied during the violent eruption approximately 7,700 years ago and thus developed the "classic account" of the park's geology (Bacon 2008).

Sources of Paleontological Resources

Fossils are uncommon in the park, which is not surprising given the volcanic history of the park. Nevertheless, carbonized or charcoal wood deposits are known from the glacial and eruption deposits of

the park. Examples of these fossils are on display at the Sinnott Memorial Overlook. The fossils of CRLA present opportunities for education, interpretation, and continued or future scientific research in the park.

Glacial Till Deposits (Pleistocene-Holocene)

Bacon (2008) does not assign ages to the till, although many till deposits can be constrained by prior and subsequent eruptions over the last few hundred thousand years. Glaciers, while present, were likely limited in extent during the caldera-forming eruption, which occurred after the last major glacial advance 16,000-22,000 years ago. Between eruptions there is evidence of reforestation of the area around Mount Mazama. Carbonized tree stumps and soils with charred vegetation occur within glacial till deposits. Harris and Tuttle (1983) indicate the presence of carbonized stumps preserved in a till near Discovery Point. These till deposits with carbonized plant material are covered by more recent lava flows and pumice. Till deposits below the Llao Rock pumice fall yielded charcoal that provided a date of 7,800-7,900 calendar years before present, thus constraining the age of the Llao Rock pumice fall (unit "rhp") Bacon 2008).

Climactic Eruption Deposits (Holocene)

Bacon's (2008) geologic map of CRLA differentiated deposits associated with the climactic eruption of Mount Mazama and noted charcoal or carbonized wood from the Plinian and other Holocene pumice-fall deposits unit ("cp") and the ring-vent phase ignimbrite (consolidated volcanic ash and debris flows) unit ("cf"). Bacon (2008) noted that carbonized wood was "abundant" in the ignimbrite unit deposits far enough from the source where temperatures were low enough to not completely destroy the organic material. Bacon (2008) reported radiocarbon ages of 6,845±50 radiocarbon years before present for the charcoal "twigs" from Bacon (1983). Stuiver et al. (1998) calibrated the radiocarbon ages to yield the 7,700 calendar years before present age of the eruption deposits.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following settings within CRLA. However, such settings are known to preserve fossils elsewhere, and future field investigations within the park may recover fossils from one or more (or none) of them.

The bedrock and surficial geology of CRLA is not conducive for the preservation of paleontological resources, however, there is the potential for diatoms or microfossils within lake bottom sediments. The approximately two dozen core samples previously collected at CRLA could be evaluated for the presences of microfossils which may yield information regarding past climate and sedimentation history (Covington 2004).

There are more than 40 caves within CRLA which have not been inventoried for paleontological resources (Covington 2004). Locally an important cave fauna is known from Oregon Caves National Monument suggesting the potential for similar Holocene resources at CRLA (see ORCA section in this report; for a discussion on fossil resources associated with NPS caves see Santucci et al. 2001.).

Park Collections

There are no known paleontological resources within the museum collections at CRLA (M. Benterou, CRLA Curator, pers. comm., November 2008).

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division sponsored a Geologic Resources Evaluation scoping meeting for CRLA in Ashland, Oregon, on March 3, 2004. A series of recommendations were

generated from this meeting and are contained in the Geologic Scoping Report for CRLA (Covington 2004).

- Paleolimnological studies of lake sediments would enhance the understanding of the lake's sedimentation history, climatic changes, and presence of diatoms or other microfossils. Sediment cores from the bottom of Crater Lake have been previously recovered and could be used for further analyses.
- Detailed taphonomic (dealing with processes that affect remains after an organism's death) assessment of the carbonized tree stumps and soils with charred vegetation should be undertaken to understand the effects of the volcanic activity on the ancient trees and the processes influencing their preservation.
- CRLA contains over 40 caves which are largely unexplored, mapped and inventoried. The park should seek funding or develop a partnership with a university or the National Speleological Society (NSS) to initiate inventories, including paleontological inventories, of park caves.
- The NPS Geologic Resources Division is available for consultation and assistance if any future paleontological resource issues emerge at CRLA.

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Originated by Santucci, Vincent; status: Active.

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Originated by CRLA staff; status: Active.

Lassen Volcanic National Park

Lassen Volcanic National Park (LAVO) was originally established as Lassen Peak Forest Reserve in 1905. Shortly after establishment, on May 6, 1907 the area was proclaimed as Lassen Peak and Cinder Cone National Monument. On August 9, 1916 the site was re-established as Lassen Volcanic National Park. The park has undergone a number of boundary changes between 1928 and 1972. More than half of the park was designated as wilderness October 19, 1972. The park preserves Mount Lassen Peak, a large volcano in the Cascade Range of northern California, along with active geothermal features including hot springs, fumaroles, mud pots, and sulfurous vents. Lassen Peak was one of two Cascade volcanoes to erupt in the twentieth century with the most recent eruption between 1914 and 1917.

Geologic Background

Lassen Volcanic National Park is located in Shasta, Lassen, Plumas and Tehama counties in northern California and is situated in the Cascades-Modoc subregion of the Klamath Network as defined by Sarr et al. (2007). This subregion is also recognized as the southern portion of the Cascade Range and is an active plate tectonic province experiencing earthquakes and volcanic eruptions. In general the area is characterized by dense basaltic rock derived from oceanic plate which has subducted beneath less dense continental crust. Geologically the area is influenced by relatively recent volcanism of basalt, andesite and dacite composition (Norris and Webb 1976).

Lassen Peak is 3,188 m (10,457 ft) in elevation and is the southernmost volcano in the Cascade Range. The extension of the Cascades is bound by the Sierra Nevada range to the south and Klamath Mountains to the west. The volcano was named after a Danish blacksmith, Peter Lassen, who came to California in 1830.

Paleozoic and early Mesozoic marine sediments were deposited along the western margin of the continent during the Paleozoic and early Mesozoic eras (see the appendix for a geologic time scale). These units underwent intense compressional deformation during the late Jurassic and were folded, faulted and metamorphosed (altered by high temperature and/or pressure). Today exposures of these older rocks are deeply buried by volcanic rocks, with the nearest surface exposures mapped approximately 24 km (15 miles) to the southeast of LAVO.

By the late Cretaceous a coastal plain existed south and west of LAVO. A marine sandstone known as the Chico Formation was deposited along the shoreline of the coastal plain. Isolated exposures of the Chico Formation occur in stream valleys west of the park.

A significant regional uplift occurred during the middle to late Cenozoic resulting in a westward-tilting fault block in the Sierra Nevada. Extensive volcanic activity was associated with the uplift. Massive mudflows of volcanic debris (lahars) developed on the western slope of the Sierra Nevada and accumulations have been mapped as the Pliocene Tuscan Formation (Smith et al. 2008). The Tuscan Formation reaches thicknesses up to 457 m (1,500 ft) (Norris and Webb 1976).

Some of the oldest volcanic rocks in the park are associated with the Willow Lake Basalt flows (Pliocene) which are present in the southern portion of LAVO. From the end of the Pliocene into the Pleistocene there was an extensive build-up and development of a volcanic plateau composed largely of andesitic flows, sometimes referred to Juniper Lake and Twin Lakes lavas. Pyroclastic (rock fragments formed by volcanic explosions) debris first appeared approximately 3 million years ago (Clynne 1990).

Brokeoff Cone, also known as Mount Tehama, developed during the Pleistocene (approximately 600,000 years before present) in the southwest corner of the park (Clynne 1990). The original cone is estimated to reach elevations over 3,350 m (11,000 ft) and probably 24 km (15 miles) in diameter (Williams 1932; Harris and Tuttle 1983). Brokeoff Cone was a stratovolcano which consisted of sequences of andesitic flows

(Brokeoff Andesite). Raker Peak, Prospect Peak, Red Mountain, and Mount Harkness erupted during the later stages of Brokeoff development. These peaks consisted of basaltic lavas and were probably derived from a separate magma chamber than that which fed Mount Tehama.

In the Late Pleistocene Brokeoff Cone exploded and collapsed forming an extensive caldera. There is some debate regarding whether the Brokeoff caldera was more the result of an erosional caldera rather than a collapse caldera (Kiver and Harris 1999). This was followed by a period in which there were eruptions of pre-Lassen dacites. A columnar dacite formed at the base of Lassen Peak.

Emplacement of the Lassen Peak dome is estimated to have occurred approximately 29,000 years before present (Clynne 1990; Gerstal and Clynne 1995). The dacite flows which underlie the Lassen Peak dome yield radiometric dates of approximately 31,000 years before present (Gerstal and Clynne 1995). Lassen dome is composed of dacite lava, an igneous rock type intermediate in composition between andesite and rhyolite, which accumulated around the vent. The relatively high viscosity of dacite limited how far it would flow from the vent, resulting in lava piles formed around the vent.

Glaciers covered the area during the Pleistocene and during the periods of volcanic activity. Glacial and volcanic debris were mixed together and reworked in the mudflows, lahars, landslides and moraines. Gerstal (1989) reported the occurrence of pieces of Lassen dacite within a late Pleistocene moraine. This evidence supports the emplacement of Lassen Peak dome prior to 25,000 years before present.

Approximately 11,000 years before present a large volcanic plug began to form on the northeast flank of the old Brokeoff Cone. This development resulted in the formation of the over 3,048 m (10,000 ft) tall Lassen Peak, the largest volcanic dome in the world. The development of summit craters on Lassen is somewhat unusual since these features are not normally associated with a volcanic dome. Pyroclastics and lava were ejected from these summit craters.

Crandall et al. (1974) report on the formation of Manzanita Lake due to a series of rockfall avalanche events associated with Chaos Crags. The avalanche debris dammed Manzanita Creek in the northwest portion of the park. Submerged trees in the lake at the time of the avalanche date to approximately 300 years before present, providing an age estimate for the avalanche (Crandall et al. 1974).

Cinder Cone is situated in the northeast portion of the park. This volcanic feature began violent pyroclastic eruptions several hundred years ago. A series of andesite and basalt flows originating from Cinder Cone date to approximately 250 years before present. These flows dammed drainages to form the Snag and Butte lakes. The Smithsonian Global Volcanism Program discredited the interpretation that the most recent eruptions of Cinder Cone were observed between 1850 and 1851 (L. McClelland, NPS Geologist, pers. comm., February 2009).

The most recent eruptions of Lassen Volcano occurred between 1914 and 1917. The three year period of activity began on May 30, 1914 when a dark cloud of ash emerged from the summit of Lassen. On May 19, 1915, lava emerged in the crater of Lassen Volcano, reached the rim and flowed down the northeast and southwest flanks. The heated rock caused a rapid melting of snow on the northeast flank resulting in a significant mudslide for nearly a two-day period in the Lost Creek and Hat Creek drainages.

Lava sealed the vent on Lassen causing gases to increase pressure within the vent. On May 22, 1915 an 8 km (5 mile) high column of ash and dust was emitted from Lassen Peak. The eruption generated a pyroclastic debris flow (also known as a nuée ardente) on the northeast flank.

J. S. Diller, a geologist with the U.S. Geological Survey, mapped Lassen Peak in 1883, prior to the eruptions 30 years later (Diller 1895). Diller returned to Lassen to observe and document the effects of the eruptions starting in 1914. At the time of his death in 1928, Diller was not able to complete his report on the pre- and post- eruption changes he observed at Lassen Volcano. Williams (1932), MacDonald

(1964), and Clynne (1990) provide more comprehensive publications on the geologic history of Lassen Volcano.

Today LAVO is geothermally active with hot springs, fumaroles and mudpots in Bumpass Hell, Little Hot Springs Valley, Sulphur Works and on the summit of Lassen Peak. The U.S. Geological Survey continuously monitors the volcanic activity in the Lassen Volcano area though the Cascades Volcano Observatory (Vancouver, Washington).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the geologic deposits formations within LAVO. However, these types of deposits are known to preserve fossils elsewhere, and future field investigations within the park may recover fossils from one or more (or none) of them.

Sedimentary Deposits (Pleistocene-Holocene)

There are several isolated sedimentary units in LAVO, including alluvial, colluvial and lacustrine deposits, which may be potential sources for paleontological resources.

Near Emigrant Pass in LAVO is a small exposure of sediments beneath a pyroclastic flow deposit of Kings Creek (Christiansen et al. 2002). The sediments are well-sorted, unconsolidated to partially indurated (cemented) sands, silts and interbedded peat. This unit has a maximum observed thickness of 4 m (13 ft) and is interpreted as low energy stream deposits and quiet water overbank flows or ponds (Christiansen et al. 2002). Radiocarbon dates from the peat indicate a late Pleistocene age of 37,600 years before present (Turrin et al. 1998).

Two small areas of alluvium are mapped on the surface of the andesite flow of Raker Peak. The first is adjacent to Lost Creek and the other is near Manzanita Creek, downstream from Manzanita Lake. These deposits consist of moderately to poorly sorted unconsolidated gravel and sand and appear to be coeval (of the same age) with till of Raker Peak (Christiansen et al. 2002).

Additional alluvial deposits which appear coeval with till of Anklin Meadows are mapped by Christiansen et al. (2002). These are moderately well-sorted, unconsolidated lenticular beds of sand and gravel. These are located adjacent to or between the lower courses of Manzanita, Lost and Hat creeks.

Two small localities contain Holocene lacustrine deposits. These occur on Table Mountain and near upper Manzanita Creek. The lake sediments are well-sorted, unconsolidated silt to fine sand. These appear to occur in areas underlying swampy ground within or adjacent to seasonally flooded areas. MacDonald (1964) reports a poorly consolidated white to pale gray diatomaceous earth deposited in the Butte Lake prior to the eruption of the most recent lava flows. Diatomaceous earth consists of accumulations of the silica-rich “skeletons” of diatoms (microscopic phytoplankton).

Park Collections

According to the LAVO Park Curator there are no paleontological specimens in the park collection (J. O’Barr, LAVO Curator, pers. comm., November 2008).

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division sponsored a Geologic Resources Evaluation scoping meeting for LAVO in Ashland, Oregon, on March 1, 2004. A series of recommendations were generated from this meeting and are contained in the Geologic Scoping Report for LAVO (Covington 2004).

- The NPS Geologic Resources Division is available for consultation and assistance if any future paleontological resource issues emerge at LAVO.

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Originated by Santucci, Vincent; status: Active.

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Lava Beds National Monument

Lava Beds National Monument (LABE) was originally proclaimed a monument by President Calvin Coolidge on November 21, 1925 and was administered at that time by the U.S. Forest Service. On August 10, 1933 the monument was transferred to the National Park Service. More than half of the monument was designated as wilderness on October 13, 1972. The monument preserves a rugged volcanic landscape of lava rock and contains the greatest concentration of lava tube caves in the continental United States. During the Modoc Indian War, between 1872 and 1873, American Indians used the rocky features as a natural fortress.

Geologic Background

Lava Beds National Monument (LABE) is located within Modoc and Siskiyou counties in northern California and is situated in the Cascades-Modoc subregion of the Klamath Network as defined by Sarr et al. (2007). This subregion is also recognized as the southern portion of the Cascade Range and is an active plate tectonic province, experiencing earthquakes and volcanic eruptions. In general the area is characterized by dense basaltic rock derived from oceanic plate which has subducted beneath less dense continental crust. Geologically the area is influenced predominantly by relatively recent volcanism of basalt, andesite and dacite composition (Norris and Webb 1990).

More specifically, Lava Beds National Monument is situated on the northern flank of the Medicine Lake volcano on the Modoc Plateau physiographic province. The monument boundary encompasses 18,842 ha (46,560 acres) of volcanic landscape, covering about 10 percent of the volcano's area. Medicine Lake volcano is a broad shield-shaped edifice whose flanks are dotted with cinder cones, including many within the monument. The Modoc Plateau is bounded on the north and east by the Basin and Range province, on the west by the Cascade Range, and on the south by the Sierra Nevada. Along the north boundary of the monument is farmland reclaimed from the southern portion of Tule Lake.

The lava flows in the park were produced by flank eruptions of Medicine Lake volcano (Donnelly-Nolan 1987). The monument's landscape is covered with multiple spatter cones and cinder cone volcanoes, and 30 lava flows, some of which contain lava tubes. Pleistocene and Holocene volcanics dominate the surficial geology. See the appendix for a geologic time scale. The oldest lava flow in the monument associated with Medicine Lake volcano is approximately 450,000 years old. Other geologic features in the park range in age from the approximately two million year old volcanic tuff on Gillem Bluff to the 1,100 year old Callahan lava flow emanating from Cinder Butte, just outside the southwest boundary of the monument (Donnelly-Nolan and Champion 1987).

An ash-flow tuff erupted from the center of Medicine Lake volcano about 180,000 years ago (Donnelly-Nolan et al. 2008). Exposures of the tuff are present just outside the western boundary of LABE and the tuff almost certainly underlies parts of the monument. The presence of coarse gravels and channels in the tuff suggest that rapid melting of ice during emplacement of the tuff resulted in a catastrophic flood (Nolan and Donnelly-Nolan 1984).

Donnelly-Nolan and Champion (1987) identified 39 mappable units on their geologic map of LABE. These rock units are predominantly volcanic in origin, although three sedimentary units are identified within the monument. Basaltic and andesitic lavas are the principal volcanic rock type within LABE. Higher on the volcano, andesite and high-silica lavas including Holocene rhyolites and dacites largely replace the basalts. These units are primarily outside of the monument boundaries to the south and southwest on Glass Mountain and Little Glass Mountain (Donnelly-Nolan 1987). However, pumice from these later eruptions is present in the monument and is more than 30 cm (1 ft) thick in southwestern LABE.

The basalt of Mammoth Crater is a late Pleistocene unit which covers approximately two-thirds of LABE. Mammoth Crater is a pit crater which vented a large volume of basalt and basaltic andesite. Several younger basaltic lava flows overlie the Mammoth Crater basalt. The Valentine Cave flow (dated to 10,650 years before present [ybp]), Devil's Homestead flow (10,500 ybp), and the Callahan flow (1,100 ybp) all overlie the older Mammoth Crater basalt. The Devil's Homestead basalt erupted from the Fleener Chimney spatter vents in LABE.

Extensive lava tubes developed within these more recent basalt lava flows forming the largest concentration of lava tube caves in the continental United States within and adjacent to LABE. Lava tubes are formed by differential cooling of flowing lava. Cooling and solidification proceeds more rapidly at the surface contact with much cooler air, than within the more insulated internal portions of the lava flows. The differential cooling resulted in the internal portions continuing to flow leaving a hollow tunnel or tube formed within the more rapidly cooled lava walls. Most of the lava tubes and caves are found within the Mammoth Crater basalt; these are of great interest paleontologically because they formed in late Pleistocene time and thus may contain older, pre-Holocene fossil remains.

According to Waters et al. (1990), nearly all the lava tube caves within LABE were named by J. D. Howard, an early settler and guide. Between 1917 and 1933, Howard spent considerable time exploring, measuring and naming the lava tubes and caves of the area.

Additional information regarding the geology and geologic history of LABE is documented by Stearns (1928), Peacock (1931), Powers (1932), Jones (1939), Condie and Hayslip (1975), Donnelly-Nolan et al. (1981), Waters (1981), Donnelly-Nolan and Nolan (1986), Donnelly-Nolan and Champion (1987), and Donnelly-Nolan et al. (2007).

Sources of Paleontological Resources

The fossils of LABE present opportunities for education, interpretation, and continued or future scientific research in the park. Examples of fossil material are also found in museum collections at LABE and the University of California Museum of Paleontology (Berkeley) as described below.

Lava Tubes (Pleistocene)

In March 1931, prior to the establishment of Lava Beds National Monument, a 23 cm (9.1 in) long American mastodon (*Mammut americanum*) dentary fragment with two partial molars and two camel (*Camelops hesternus*) teeth were discovered in a lava tube cave located, at that time, in Modoc National Forest (Santucci et al. 2001). The mastodon molar is figured on the cover of this report. The collector of the specimens, F.P. Cronemiller, was one of the first individuals to enter the cave later named Fossil Cave. Fossil Cave is an unusual lava tube cave with a single, large pitfall entrance (Kast 2008). The mammoth and camel remains were sent to R. A. Stirton at the University of California Museum of Paleontology (UCMP) in Berkeley, and cataloged as UCMP 134904 and 134905 (accession #148). The locality was assigned the number V3424 Fossil Cave, Modoc National Forest, Siskiyou, California.

In 1934 William S. Brown (unknown affiliation) collected two more fossil specimens from within Fossil Cave. The specimens include a camel premolar and an ursid (bear) canine fragment. The camel (*Camelops hesternus*) premolar is a cream color tooth with partial patina on the tooth surface. The ursid canine is a fragment with 2-3 mm thick dark gray encrustation covering half of the tooth surface (Kast 2008). Collection records from the UCMP reference that William Brown originally gave these specimens to James Moffett, a California Fish & Game employee. The specimens were in turn presented by Moffett to paleontologist R.A. Stirton at UCMP and assigned the catalog numbers UCMP 29492 and 134906 (accession #96). UCMP records indicate that these two specimens may have been reclaimed from the museum sometime prior to 1936.

Unlike the more recent bone material discovered within the many lava tubes of the monument, the specimens collected by Cronemiller and Brown were originally reported as embedded within the basaltic lava. If the bone material is contemporaneous with the lava it would be approximately 30,000 to 40,000 years old. The volcanic association of the fossil material raises questions regarding how the specimens survived destruction from the high temperature lava (K. Fuhrmann, LABE Resource Management Specialist, pers. comm. 2001). Another interpretation is that the bone material exhibits a "patina" which superficially resembles the surrounding lava (see cover image).

Two additional fossil specimens were collected from Fossil Cave during 1934 by Russell M. Bushey. The specimens included a badly fragmented felid carnassial molar, tentatively identified as jaguar (*Panthera onca*) and a complete bison (*Bison* sp.) upper molar. According to Kast (2008) the bison molar is approximately 5 cm (2 in) long with a creamy white enamel with some broken, dark brown patina and a carbonized root. The dentary is encrusted by a dark gray to brown secondary mineral, possibly calcite or cristobalite which are common coralloid-forming minerals in LABE caves (Rogers and Rice 1992). These specimens are maintained in the park collection as LABE 2921 (bison) and LABE 2922 (jaguar).

Within the LABE collection are nine mastodon (*Mammut americanum*) bone fragments which were discovered in 1959. Unfortunately there is no locality or collector information associated with these fossils. The remains include a nearly complete vertebra (Kast 2008). These specimens are assigned catalog numbers LABE 500 and LABE 600.

Between 1968 and 1969, U.S. Geological Survey (USGS) geologist Keith A. Howard mapped many of the lava tube caves in LABE. On July 14, 1969, Howard and LABE Supervisory Park Ranger Jerry D. Lee entered Fossil Cave through the skylight entrance with a 10 m (33 ft) overhanging drop to the floor (K. Howard, USGS, written comm., November 2008). Howard and Lee collected small bits of remaining crumbling "old" bone material from the floor of the east part of the cave, one of which was later identified in March 1970 by USGS paleontologist Charles Repenning as what "appears to be ivory," supporting the earlier identification of elephant remains (K. Howard, USGS, written comm., November 2008). Repenning identified other remains collected by Howard from the talus "breakdown" at the west end of the cave, as a jaw and tibia from a bobcat and an unidentifiable rib, possibly deer. A letter in the park archives written by Keith Howard (USGS) to Supervisory Park Ranger Jerry D. Lee in 1970 discusses the bone material collected from Fossil Cave (LABE Archives – Howard Letter 1970). The letter included some discussion about whether the material was possibly modern and the preliminary identification of bobcat remains. Currently, Howard's collection appears to be stored at the USGS collections in Denver.

In 2001, seasonal Resource Management Specialist Chris Roundtree photodocumented nine sites within Fossil Cave where bone material was observed. According to Roundtree, he observed "…bone shards strewn across the cave floor, sometimes relatively thickly" and "…points where the bone is still visibly embedded within the solid lava floor and/or covered with a thick coating of mineral deposits (cave coral)" (C. Roundtree, LABE Park Ranger, written comm., 2001). Roundtree's photos, particularly from one location (Site 9), shows bone material which is clearly eroding from beneath either lava or mineral deposits. During 2001 there was some discussion between park staff and geologists at the U.S. Geological Survey about this unusual occurrence and possible radiocarbon evaluation of the bone.

According to Kast (2008) a letter in the LABE archives indicated that additional fossil material may have been removed from Fossil Cave due to unauthorized activities. In a 1962 letter to the LABE Superintendent, Park Ranger Picco described a conversation with a Modoc National Forest employee who worked during the 1920s (LABE Archives – Picco Letter 1962). The retired employee, Reuel Methvin, indicated there were fossils taken from a cave determined to be Fossil Cave. According to the letter the specimens were later identified as mastodon and given to a state senator sometime in the past.

Lava Tube and Cave Deposits (Holocene)

During the 1890s, rancher E. L. Hopkins was credited with the discovery of 36 bighorn sheep skulls in one of the lava caves (Waters et al. 1990). J. D. Howard rediscovered this cave in 1918 and named it Ovis Cave based upon the scientific name for Bighorn Sheep (*Ovis canadensis*). Ovis Cave is part of a complex lava tube system located on the southern end of the Cave Loop Road in the south-central portion of the monument. The cave is difficult to traverse due to partial roof collapse.

Skull Cave was discovered in 1898 within a long collapse trench near Crescent Butte. An upper and lower level occur within this cave representing two large lava tubes which are superposed upon one another (Waters et al. 1990). Within the lower level of the cave are the remains of two human skeletons embedded in ice, along with bones of antelope, bighorn sheep, mountain goats and a broken log. One interpretation is that the human remains were of American Indians who had attempted to position the log into the cave to serve as a ladder to descend into this opening. Evidence suggests that the two individuals fell from the balcony to their death (Waters et al. 1990).

In 2008 Geologist-In-Park intern Sophia Kast was recruited to conduct a paleontological resource inventory for LABE (Kast 2008). Kast focused her work on identification of additional fossils associated with lava tubes and caves in LABE. According to Kast (2008) many of the LABE lava tubes and caves contain bighorn sheep remains, in particular skulls.

Radiocarbon testing of skull fragments from four different caves in LABE was undertaken by Kast in 2008. The Dragon Head Cave specimen dated to 6,370 years before present (ybp), the Natural Bridge specimen dated to 3,700 ybp, the Ovis Cave specimen dated to 4,930 ybp , and the Bighorn Cave specimen dated to 4,800 ybp. (Kast 2008).

Potential Sources of Paleontological Resources

Although most of LABE is covered by volcanic rock, there is potential for occurrence of paleontological resources from within Pleistocene glacial and lacustrine deposits in the park. There are numerous fossil localities near the monument within Modoc and Siskiyou counties in California. Brief descriptions of those local fossil localities are worth presenting given the potential for discovery of similar resources in the future, especially if erosion or construction activities result in the exposure of underlying rock units.

Fossil-Bearing Deposits (Cretaceous-Pleistocene)

A large number of paleontological localities in Siskiyou County, California are described on the University of California Museum of Paleontology (UCMP) paleontology locality database (http://ucmpdb.berkeley.edu/loc.html; UCMP 2008). Hagerdon Ranch is a Late Cretaceous locality with exposures of the Hornbrook Formation which yield the remains of the gastropod taxa *Acteonina bellavistana* and *Turritella hearni* (UCMP 2008). Another Late Cretaceous locality is referred to as the Siskiyou Mountains locality from which collections of bivalves (*Yaadia leana*) and cephalopods (*Sciponoceras baculoide*) have been made from the Chico Formation. Several localities occur within Siskiyou County that have yielded Pleistocene vertebrates. A *Mammuthus* molar was collected by Sam Welles in 1936 at a Rancholabrean locality near Hornbrook (UCMP 2008). A specimen identified as *Euceratherium* collinum was collected from the Gottville locality.

Similarly, there are a large number of sites in Modoc County, California. Badger's Nose is an important paleobotanical locality occurring in the Eocene Steamboat Formation. The flora are dated to between 34-35 million years old and represent a transitional latest Eocene–Oligocene assemblage (Myers 2006). This is an important global transition from very warm ("greenhouse") to colder ("ice house") climates. A large collection of fossil plant specimens have been collected and reposited at the UCMP. The dominant plant taxon is the gymnosperm *Metasequoia occidentalis*. The Badger's Nose flora also includes the following genera: *Alnus, Cedrelospermum lineatum, Cercidiphyllum, Litseaphyllum, Magnolia dayana, Osmunda, Parrotia brevipetiolata, Plafkeria obliquifolia, Platanus, Pterocarya, Ternstroemites,* and *Ulmus*. Cooks

Canyon North and South are other plant producing localities in the Eocene Steamboat Formation in Modoc County. The remains of *Metasequoia occidentalis, Platanus exaspera,* and *Sequoia affinis* have been documented from this locality. One specimen of the perissodactyl *Trigonias* was collected from Eocene deposits in the Lower Cedarville Flora locality.

The Old River Pit locality is within an unnamed Miocene formation which has yielded a number of type paleobotanical specimens now in the collections of the University of California Museum of Paleontology (UCMP 2008). The flora includes the following taxa: *Abies parviseminis, Arbutus matthesii, Castanea lewquereuxi, Ptelea miocenica, Quercus hannibali, Q. eoprinus,* and *Rosa hilliae*.

Alturas (1-8) is an important Miocene through Pliocene paleontological locality within the Alturas Formation in Modoc County, California (UCMP 2008). Collectively the sites preserve fossil plants, fish, and mammals. The mammals that occur within the Miocene portion of the Alturas Formation include: two carnivores (*Felis atrox* and *Tephrocyon* sp.), several artiodactyl genera (*Tayassu, Ticholeptus, Pliauchenia, Megatylopus, Aepycamelus,* and *Procamelus*) and the perissodactyl genera (*Aphelops,* and *Hiipparion*). The plants and fish occur in the early Pliocene portion of the Alturas Formation. The fish are all osteichthys including the genus *Acrocheilus* sp. The fossil plants consist of angiosperms including the following taxa: *Populus alexanderi, P. payettensis, P. pliotremuloides, Salix truckeana, S. vanorensis, S. wildcatensis,* and *Ulmus moragensis*.

Signal Butte is another important Pliocene locality within the Alturas Formation in Modoc County in which the remains of fish, amphibian, reptile, birds and mammals have been collected (UCMP 2008). Several Signal Butte sites, identified as Signal Butte 1-4, have produced fossil vertebrates and are cataloged at the University of California Museum of Paleontology. The predominant mammal is *Mimomys sawrockensis* with dozens of individual specimens collected. The remains of the frog *Rana* sp. and the reptile *Sceloporus* sp. have also been identified from the locality.

Canby Bluffs is an additional locality in the Pliocene Alturas Formation which has produced the remains of osteichthyes and one specimen of *Mimomys sawrockensis* (UCMP 2008).

The fossil remains of *Bison, Symbos,* and *Equus* have been collected from several Pleistocene deposits in Modoc County, California.

Glacial Deposits (Pleistocene)

Interlayered gravel and sand deposits in two localities within LABE are interpreted as late Pleistocene glacial outwash (Donnelly-Nolan and Champion 1987). The valley floor just east of Mammoth Crater, along the southern boundary of the monument, is filled with glacial sediment. Additionally, discontinuous beds of moderately sorted and graded deposits of gravel and sand were exposed in a quarry southeast of Caldwell Butte in the extreme southeast portion of LABE. The quarry was eventually filled in by the National Park Service in order to restore disturbed lands in the monument. These glacial deposits at LABE have not been surveyed for paleontological resources, but there is potential for paleontological remains in these glacial sediments.

Lacustrine Deposits (Pleistocene)

Three small and isolated lacustrine deposits are mapped within LABE (Donnelly-Nolan and Champion 1987). One locality identified with lake sediments is approximately 2 km (1.24 miles) southwest of Captain Jack's Stronghold in the north-central portion of the monument. This locality consists of a closed depression formed within the late Pleistocene basalt of Mammoth Crater. Donnelly-Nolan and Champion (1987) report thin unmapped deposits of gravel, sand and clay on the northern limit of the Pleistocene Mammoth Crater basalt where this unit flowed into Tule Lake.

A second small lacustrine deposit in LABE is mapped in the extreme northeast corner of the monument (Donnelly-Nolan and Champion 1987). A layer of gravel and cobbles or scoria are interpreted as a

possible beach deposit. This unit is underlain by pillow basalt within the Pleistocene Gillem Bluff basalt and is overlain by a palagonite tuff.

The third and largest lacustrine deposit within LABE is located in the Petroglyph Section of the Monument. The Petroglyph Section is an isolated portion of the monument to the northeast of the rest of the park. The lake sediments are exposed to the west and northwest of Petroglyph Point (Prisoners Rock) and consist of gravel, sand and clay. Presumably these sediments are associated with Tule Lake which covered a larger area prior to human use and development of the area.

Park Collections

According to the park curator there are five cataloged paleontological specimens within the LABE collections (M. Benterou, LABE Curator, pers. comm., September 2008). A description for these specimens is provided earlier in this report.

Additionally, there is a small collection of Pleistocene vertebrates from Fossil Cave in LABE housed at the University of California Museum of Paleontology. These were collections made prior to LABE being transferred to the National Park Service.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division sponsored a Geologic Resources Evaluation scoping meeting for LABE on March 4, 2004 in Ashland, Oregon. The participants of the LABE geologic scoping meeting developed a series of recommendations for future work (Covington 2004).
- Park staff should continue to be made aware of the potential for discovery of fossil material during other field work or construction activities, particularly in association with the lava tubes, gullies, and other erosional features within the park.
- Known paleontological localities at LABE should be formally documented and regular monitoring the site condition should be established.
- An inventory of the bone material collected from Fossil Cave during 1969 by USGS geologist Keith Howard should be undertaken and cross cataloged with the LABE collection.
- Undertake radiocarbon dating of the *in situ* bone material present in Fossil Cave which appears to be embedded within either the lava or mineral deposits. U.S. Geological Survey scientists should be involved with the sampling and evaluation.
- Pleistocene lacustrine sediments identified in three localities of LABE may contain pollen and other paleontological resources which may enable better age-dating and paleoclimatic data. The U.S. Geological Survey could assist with geologic core sampling and analysis.
- The NPS Geologic Resources Division is a source of assistance to LABE staff regarding any paleontological resource issues.

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

Lava Beds National Monument Collections
1933–present. (museum specimens; associated field notes; collection records; maps; photographs).
Originated by LABE staff; status: Active.

University of California Museum of Paleontology (UCMP) Collections
1931-present. (fossils and field notes).
Originated by Stirton, R.A.; status: Active.

U.S. Geological Survey, Denver - Paleontology Collections
1968-present. (fossils and field notes).
Originated by Howard, K. and C. Repenning; status: Inactive.

Oregon Caves National Monument

Oregon Caves National Monument (ORCA) was originally proclaimed a monument on July 12, 1909 under the administration of the U.S. Forest Service. The enabling legislation states, "…certain natural caves, known as the Oregon Caves…are of unusual scientific interest and importance, and it appears that the public interests will be promoted by reserving these caves with as much land as may be necessary for the proper protection thereof, as a National Monument." The monument was transferred to the National Park Service on August 10, 1933. Oregon Caves consists of a series of interconnected subterranean chambers that together form a single large cave developed in marble. The monument also preserves a remnant old growth Douglas fir forest. A National Historic District is designated within the monument which includes structures exhibiting northwest rustic architecture.

Geologic Background

Oregon Caves National Monument (ORCA) is located within Josephine County in southwest Oregon and is situated in the Klamath-Coastal subregion of the Klamath Network as defined by Sarr et al. (2007). This subregion is characterized by rugged topography and complex geology. The monument consists of 197 ha (488 acres) located in the Siskiyou Range within the Klamath Mountains physiographic province. ORCA is situated within the upper portion of the Cave Creek watershed which drains into the Illinois River and then in turn the Rogue River.

The caves were originally discovered in 1874 by Elijah J. Davidson. Early visitors to the cave often broke off and removed speleothems to take home as souvenirs. This vandalism generated discussion regarding the need to protect the cave and its features. In 1909, the Oregon Caves were proclaimed a national monument to be managed and protected by the federal government.

Geologically the rocks in and around ORCA consist of terranes which formed elsewhere and were transported by plate movement and subsequently accreted to the western edge of the North American continental plate (Orr et al. 1992). Irwin (1960) mapped and named two belts in the Cave Junction area: the Western Jurassic Belt and a small area of the Western Paleozoic and Triassic Belt. The complex is predominantly comprised of the lower Rattlesnake Creek terrane, which consists of marble, argillite, metasediment and metachert (Barnard 2007). The Josephine Ophiolite (oceanic crust) complex is exposed in areas of uplift by thrust faulting and is composed of peridotite, serpentinite, skarn, metamorphic basalt and gabbro (Barnard 2007). Diorite dikes derived from the Greyback Pluton (mass of molten material that was emplaced and subsequently cooled beneath the surface) intrude the ophiolite and other local rock units.

The Applegate Group is a prominent and complex sequence which occurs within the Rattlesnake Creek terrane. This unit was originally a Triassic marine limestone and underwent metamorphism during the Nevadan (Sevier) Orogeny about 150 million years ago (See the appendix for a geologic time scale). Barnes et al. (1993) recognize two lithologic units within the Applegate Group: an interbedded volcanogenic (formed by processes associated with volcanism) metamorphosed sandstone and argillite, and a block-on-block ophiolite mélange (a large complexly deformed body of many rock types) that contains a variety of metamorphic rocks such as metaserpentinite, marble, metabasalt, metagabbro and siliceous metasedimentary rocks. The volcanogenic rocks of the Applegate Group are lithologically and compositionally identical to those of the western Hayfork terrane, which structurally overlies the Rattlesnake Creek terrane in California.

The regional uplift was followed by extensive erosion during the middle Tertiary. By the early Quaternary, the marbles of the Applegate Group emerged relatively close to the surface and groundwater was able to permeate this unit sometimes referred to as the "Oregon Cave Marble."

Cave development has been ongoing for hundreds of thousands of years at ORCA. Dissolution and chemical precipitation has resulted in the formation of cave speleothems including: flowstone, stalagmites, stalactites, helictite, soda straws, cave popcorn (globulite) and other features. The subterranean River Styx continues to enlarge the cave.

Sources of Paleontological Resources

The fossils of ORCA present opportunities for education, interpretation, and continued or future scientific research in the park. They are found in two contexts within the caves of the park: *in situ* within the rocks of the cave-forming Hayfork Terrane and as much younger Pleistocene-Holocene remains of organisms that lived, died, and/or were transported into the cave.

Hayfork Terrane (Mesozoic)

ORCA consists of a series of interconnected chambers that together form a single large cave within the marble of the Jurassic Hayfork Terrane. Local mountain building events have substantially influenced cave development. The rocks of the Hayfork Terrane are one of a number of mapped terrane deposits in southwestern Oregon and northwestern California. The rocks in this region have produced significant fossils that have been invaluable for dating the deposits (Irwin and Blome 2004). While none of Irwin and Blome's localities are within ORCA, their locality 16 is approximately 4.8 km (3 miles) to the southwest and yielded Mesozoic-aged echinoid spines from limestone of the Rattlesnake Creek Terrane. Their Hayfork Terrane fossils were all described from localties 119-126 in an arc from southwest to east of the park. Fossils were primarily of Late Triassic age and included radiolarians, a gastropod, crinoids, conodonts and shark teeth (Irwin and Blome 2004).

The low-grade metamorphic marble of the Hayfork does not contain an abundance of fossils, although a few poorly preserved crinoids and foraminifera have been found within the park (J. Roth, ORCA Resource Management Specialist, pers. comm., 2001).

Cave deposits (Pleistocene-Holocene)

Cave sediments, primarily alluvial and fluvial, occur in multiple levels within the cave. These sediments range in age from less than 10,000 years old to strata at least 120,000 years old. Some cave sediments are speculated to be even older, maybe extending back 1.5 million years.

More than 50 Pleistocene and Holocene fossil vertebrate occurrences within ORCA are derived from slope wash-in, owl roost pellet wash-in, natural trap capturing of select microfauna, and some cave denning activities (Mead et al. in preparation).

A preliminary assessment of the fossil megafauna associated with ORCA was undertaken by National Park Service Paleontologist Greg McDonald in 1995. The remains of a jaguar and *Ursus americanus* (black bear) were identified. A limb bone, possibly belonging to *Ursus arctos* (grizzly bear) yielded a radiocarbon date greater than 50,000 years old (G. McDonald, NPS Senior Curator for Natural History, pers. comm., 2001). This represents the oldest known remains of grizzly bear from North America.

A jaguar skeleton was collected from ORCA that represents the most complete North American jaguar skeleton outside of Appalachia (K. Seymour, paleontologist, written comm., February 2009) and the northernmost discovery of a fossil jaguar skeleton ever found. The cave formations suggest the skeleton may be Irvingtonian in age, however, the size of the skeleton suggests a Rancholabrean age.

Between 1997 and 2000 a field crew coordinated by Jim Mead from Northern Arizona University conducted an inventory of paleontological resources within ORCA. Approximately 270 kg (600 lbs) of sediments, in addition to isolated vertebrate skeletal remains, were removed from several localities within the cave (Mead et al. 2000). The cave sediments were sieved, cleaned, dried and any fossil remains sorted from the sediment.

Jim Mead focused screen washing of cave sediments to inventory fossil material from one locality in the cave referred to as G3d. The faunal remains recovered from the G3d locality are quite extensive with salamanders being the most common fossil. The majority of the salamander remains were identified as taxa belonging to the large and complex group of plethodontids (lungless salamanders), including the genera *Aneides* and *Dicamptodon* (Mead et al. 2000).

Other remains recovered through screen washing at the G3d locality include snails, small birds, and a rare anuran. *Elgaria* (western alligator lizard), *Plestiodon* (western skink), *Sceloporus* (?fence lizard), *Charina* (rubber boa), colubrids, bats, *Sorex*, *Neurotrichus, Zapus* (jumping mouse), *Peromyscus, Reithrodontomys* (harvest mouse), *Neotoma, Aplodontia* (mountain beaver), *Thomomys*, sciurids, *Cleithrionomys* (vole), *Microtus, Phenacomys / Arborimus* (vole), *Lepus, Sylvilagus, Ursus, Spilogale, Cervus,* and *Odocoileus* were specifically identified in the cave deposits. Many of the fossil species are known to live in the area around the cave today. Radiocarbon dates of charcoal from the cave locality date to approximately 1,820 years before present (ybp) (Mead et al. 2000).

Vertebrate trace fossils have also been documented in Oregon Caves. A single 11 cm (4.5 in) bear paw print is preserved in the cave sediments. There are at least 20 distinct claw scratch marks in the sediments, tentatively identified as bear claws. One such trace is exceptionally preserved, showing five claw points pushed into the mud (S. Knutson, pers. comm., 1998; Santucci et al. 2001).

Potential Sources of Paleontological Resources

Although more than 50 paleontological localities have been documented within the cave passages of ORCA, the potential for additional localities and collections is high. Rubble piles from previous cave excavations remain in the park and have yielded the remains of a human tooth suggesting additional archeological resources along with the paleontological material. These rubble piles have been disturbed by visitors engaged in theft and vandalism of these cave sediment resources.

Park Collections

The fossils collected between 1997 and 2000 by the field crew under the direction of Dr. Jim Mead are temporarily cataloged at the Quaternary Studies Program Laboratory at Northern Arizona University in Flagstaff, Arizona (M. Benterou, ORCA Curator, pers. comm., November 2008).

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division sponsored a Geologic Resources Evaluation scoping meeting for ORCA on March 4, 2004 in Ashland, Oregon. The participants of the ORCA geologic scoping meeting developed a series of recommendations for future work (Covington 2004).
- Park staff should continue to be made aware of the potential for discovery of fossil material during other field work or construction activities, particularly in association with the cave sediments, stream banks, gullies, and other erosional features within the park.
- Screen washing of the rubble and sediment piles of material excavated from ORCA may yield additional paleontological and possibly archeological remains.
- Known paleontological localities at ORCA should be formally documented and regular monitoring of the site conditions should be established.
- The NPS Geologic Resources Division is a source of assistance to ORCA staff regarding any paleontological resource issues.

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1997 – present (fossils, field notes, photographs)
Originated by Mead, Jim I., status: Active.

Department of Geosciences - East Tennessee State University
1997 – present (fossils, field notes, photographs)
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Redwood National and State Parks

Redwood National Park was established by Congress on October 2, 1968 to preserve significant examples of the primeval coastal redwood forests with virgin groves of ancient trees. These forests include the world's tallest trees, known as coastal redwoods, which thrive in the foggy and temperate climate in coastal northern California. Coast Redwoods (*Sequoia sempervirens*) are some of the oldest living organisms on earth, some living more than 2,000 years. A boundary expansion on March 27, 1978 increased the park size by about 50%. The park includes four units: Redwood National Park and three California State Parks—Jedediah Smith (established 1929), Del Norte (established 1925), and Prairie Creek (established 1923) state parks. Since 1994, the federal and state parks, known as Redwood National and State Parks (RNSP) are managed cooperatively and include approximately 56 km (35 miles) of scenic Pacific coastline in Humboldt and Del Norte counties, California. The western portion of the park consists of sandy beaches to the south and a steep, rocky coastline to the north and the eastern portion climbs the Coastal Range. The park was designated a World Heritage Site on September 5, 1980 and a Biosphere Reserve on June 30, 1983.

Two famous vertebrate paleontologists were directly related to the history of preservation of the California Redwood trees. Henry Fairfield Osborn (American Museum of Natural History) and John Campbell Merriam (University of California, Berkeley) were co-founders of the Save the Redwoods League in 1918.

Geologic Background

Redwood National and State Parks is located within Humboldt and Del Norte counties along the Pacific coast of northern California and is situated in the Klamath-Coastal subregion of the Klamath Network as defined by Sarr et al. (2007). This subregion is characterized by rugged topography and complex geology. The park includes portions of the Coast Range which is a northwest trending mountain chain of nonvolcanic coastal mountains. The underlying rocks of the coast range were deposited and deformed in an active tectonic setting along the western margin of North America. Elevations within RNSP range from sea level along the coast to 944 m (3,097 ft) at School House Peak. Along the coastline are sandy beaches, steep and rocky coastline with pocket beaches, and offshore sea stacks.

The oldest rocks are part of the Franciscan Rock Complex (also referred to as Franciscan Assemblage, Franciscan Group, Franciscan Series, and Franciscan Formation) which range in age between Middle Jurassic and Late Cretaceous (see the appendix for a geologic time scale;Bailey et al. 1964). The Franciscan Complex is more than 15 km (50,000 ft) thick and underlies most of the RNSP area. The Franciscan Complex is bounded on the east by the coast range thrust fault. The Franciscan rocks represent accreted terranes from a subduction complex and were ocean floor sediments scraped off and appended under the edge of North America. These rocks form arcuate belts of north-northwest trending heterogenous rocks which are oldest to the east and progressively younger to the west. These Mesozoic accumulations represented extensive deep water marine sedimentation on the continental slope and on oceanic crust in deep trenches off the western edge of North America. Sediment accumulations consisted of sand, silt, limey muds, radiolarian ooze (a soft rock composed of the skeletal remains of microscopic organisms known as radiolarians), sediments derived from rocks on land (terrigenous), and submarine basalt flows (Underwood 1984). This deep trench is associated with a subduction zone. The mixture of sediments moved down the steep slopes of the continental shelf forming turbidity currents (Kiver and Harris 1999).

The Franciscan Complex has been subdivided into various units based upon lithology, mineralogy and degree of metamorphism. In Redwood Creek near Orick, California, the Franciscan Complex includes two quartz-mica schist (a metamorphic rock derived from clays or muds) units—Redwood Creek schist (west of Redwood Creek), and the South Fork Mountain Schist and two sandstone and mudstone units—Inconherent Unit of Coyote Creek and the Conherent Unit of Lacks Creek (both east of Redwood Creek) (Harden et al. 1981; Cashman et al 1995; Covington 2004). Several other unnamed units include the

metamorphosed sandstone and mudstone of the Grogan Fault Zone, along with the sandstone and mélange unit of Snow Camp Mountain (Harden et al. 1981).

During subduction, the Franciscan Complex rocks underwent tectonic mixing. Metamorphism altered the basalts to rocks referred to as greenstones and the sedimentary rocks were altered to metasediments. Some phyllites and schists (metamorphosed sedimentary rocks) were generated in areas where higher grade metamorphism led to recrystallization. Metamorphism resulted in the destruction of fossils within some portions of the Franciscan Complex.

Alt and Hyndman (2000) suggest the subduction of the Franciscan trench terminated sometime between 30 and 15 million years ago. Sediments stuffed into the trenches rose to become the Franciscan rocks of the Coast Range. The Franciscan Complex rocks are extremely fractured and sheared, resulting in these deposits being highly susceptible to mass wasting and landslides.

An early Tertiary uplift and erosion was followed by a middle Tertiary (Miocene) subsidence. During the early Miocene the sea advanced over the coastal range area. This resulted in the development of isolated marine basins with some volcanism, predominantly submarine. Marine sedimentation continued during the Miocene with the deposition of gravels. Tectonism influenced the development of the northern Coast Range during the Late Miocene. Down-warping created basins defined by northwest trending anticlinal arches.

During the Pliocene the Coastal Range orogeny resulted in uplift, stream cutting and valley fill. Most of the uplifted areas existing today were in place by the Late Pliocene (Stone 1992). Rocks and sediment eroded and redeposited during the uplift are evident, especially to the south of the park, with thick stream gravels deposited in valleys. The Franciscan rocks were covered by coarse gravels transported down the Klamath River. Continued uplift and erosion occurred throughout the Pleistocene with the development of marine terraces during the middle to late Pleistocene. However, the extensive erosion has resulted in a limited amount of Quaternary coastal deposits overlying the Franciscan Complex in the RNSP area. This sediment outwash led to the development of a delta where the Klamath River entered the Pacific Ocean. Pleistocene sediments at Gold Bluffs Beach represent the progradation of an ancient Klamath River onto the continental shelf, and are situated 12 km (8 miles) south of the current mouth (Kelsey and Trexler 1989). The Klamath River has shifted north since the Pleistocene. Fossil plants and clams in the delta sediments date approximately between 1 to 4 million years ago (Kiver and Harris 1999).

During the Holocene there was extensive coastal erosion along with continued faulting. The deposits are largely alluvial and the remains of mass wasting. The moist climate supports dense forest and vegetation growth. Thus most of the geology is covered by vegetation. However, logging has increased surface erosion. The best exposures of the geology occur in the exposed sea cliffs, and road cuts.

More detailed information regarding the geology of the RNSP and surrounding area can be found in Anderson (1938), Irwin (1957, 1960), Strand (1962), Irwin (1964), Bailey et al. (1964), Bailey (1966), Blake and Jones (1981), Aalto and Harper (1982), Blake (1984), Fraticelli et al. (1987), Aalto (1989), Stone (1992), Cashman et al. (1995), and Irwin (1997).

Sources of Paleontological Resources

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

Franciscan Complex (Middle Jurassic to Late Cretaceous)

Fossils are relatively rare in RNSP with a few occurrences in the Mesozoic Franciscan Complex. Late Jurassic (Tithonian) radiolarian microfossils are documented with cherts at the mouth of the Klamath River (Aalto et al. 1983). Green and red bedded radiolarian cherts were utilized to date the Franciscan

rocks at the mouth of the Klamath River as late Jurassic (Tithonian) (Aalto et al. 1983; Pessagno 1973, 1977). Sliter (1984) described foraminifera from a Cretaceous limestone unit within the Franciscan Complex at RNSP.

Cashman et al. (1995) indicated the eastern half of the Redwood Creek Basin is predominantly underlain by massive sandstone and interbedded sandstone and mudstone, with some minor amounts of conglomerate, greenstone and chert. Two middle Cretaceous (Cenomanian) ammonites, *Desmoceras (Pseudouligella) japonicum* and *Calycoceras* sp., were discovered in the Franciscan Complex on the east side of the Redwood Creek Basin (Harden et al. 1981; V. Ozaki, RNSP Geologist, pers. comm., 2005).

Wimer Formation (late Miocene - early Pliocene)

The western estuarine facies of the Wimer Formation is composed of fossil-bearing mudstones containing invertebrate macrofossils, fragmental leaf impressions and diatoms (Stone 1992). A paleobiological study of fossil molluscan communities of the Wimer Formation was conducted by Watkins in 1974. Based on the fossil assemblages, Watkins defined two communities: a *Cryptomya californica* community and a *Macoma balthica* community. The *Cryptomya californica* community is defined by the coexistence of *Cryptomya californica* , *Macoma nasuta*, and a berbardinid bivalve. This community is found in the Bald Hills area of the parks. The *Macoma balthica* community is typified by *Macoma balthica* and *Mya arenaria* and is found east of the Bald Hills outside of the parks. Two other fossil assemblages occur in the Bald Hills area—*Solen perrini* (*Lamelliconcha* sp.) and a transported assemblage (Watkins 1974).

An assemblage of marine diatoms from Wimer siltstones in the Bald Hills area provides an age estimate of early Pliocene (Stone 1992) and includes: *Paralia sulcata, Thalassionema nitzschioides, Thalassiosirea kryophilia, T.temperie,T.* aff. *grunowii, T. oestrupii, Rhaphoneis fatula, Denticulopsis hustedtii, Delphineis simbirskiana, Actinocyclus divisus, Navicula optima, Cocconeis* sp., *Stephanopysix* sp., *Lithodesmium minusculum, Rhizosolenia miocenica,* and *Coscinodiscus asteromphalus.*

Prairie Creek Formation (late Pliocene to Pleistocene)

The Prairie Creek Formation represents coastal plain deposits including fluvial, near-shore marine, beach and estuarine sediments (Cashman et al. 1995). This unit is best exposed at the Gold Bluffs beach and in the Prairie Creek drainage basin. These sediments contain fragmentary Pliocene plant fossils, carbonized wood/logs, and petrified wood, pelecypod bivalves, and radiolarians (Moore and Silver 1968; Harden et al. 1981).

Harden et al. (1981) reported that, "In addition, pelecypod bivalves from genera not diagnostic of age occur in the unit (Prairie Creek Formation) together with late Miocene or Pliocene radiolarians." Cashman et al. (1995) identified one age-diagnostic fossil (*Protothaca hannabali*) near the base of the Prairie Creek Formation which helped to determine the lower age limit as Plio-Pleistocene. Kelsey and Trexler (1989) also found *Mytilus* sp. cf. *M. edulis* and sand filled burrows and *Macoma* sp. *in situ* in the same approximate stratigraphic level near the base of the Prairie Creek Formation.

Chase (1874) reported on a specimen of an unidentified fossil vertebra that he collected from the Gold Bluffs between 1872 and 1874. Two pelecypod bivalve taxa were also recovered from within this unit. The precise locality or stratigraphic occurrence of these fossils was not indicated.

Criswell (1968) described a late Pliocene-early Pleistocene flora from the Gold Bluff area within Prairie Creek Redwoods State Park. The flora includes 18 paleobotanical taxa including logs, leaf impressions, carbonized leaves, cones, and peat-like deposits. The flora occurs in at least six horizons with the 244 m (800 ft) thick coastal cliffs comprised of conglomerate, sandstone, and siltstone beds. Criswell developed a stratigraphic column for the fossil rich Fern Creek area of the park. The lithology consists of poorly sorted conglomerate with cobbles and pebbles embedded in a sandy matrix. Angular carbonized wood fragments range in size from less than 2.5 cm (1 in) to more than 61 cm (2 ft) in diameter occur in the more silty beds.

Criswell consulted with paleobotanist H. D. MacGinitie in 1966 regarding the flora which was compared to similar fossil plant producing localities in the area (Criswell 1968). MacGinitie (1937) interpreted the Gold Bluffs flora as a late Pliocene to earliest Pleistocene assemblage. Additional fossil plant localities were documented from several roadcuts east of Prairie Creek Redwoods State Park (J. C. Young, Humboldt State University Professor, pers. comm., December 2008), the south side of Big Lagoon and a locality approximately 13 km (8 miles) south of the mouth of the Klamath River.

Trexler (1989) mapped tree and root casts in the cliffs at Gold Bluffs Beach. He found tree casts about 50 cm (1.6 ft) in diameter with the tree roots preserved as original wood (V. Ozaki, RNSP Geologist, pers. comm., December 2008).

Prior to the establishment of RNSP, a collection of petrified wood was made from the area by Sam Morrison, one of the original U.S. Geological Survey mappers for the Redwoods area, during the 1970s (V. Ozaki, RNSP Geologist, pers. comm., December 2008).

Potential Sources of Paleontological Resources

Although there are abundant paleontological resources in northern California, there is no current evidence to support the presence of fossils from other units at RNSP. The Wildcat Group (late Miocene to Pleistocene) is a fossil-bearing unit which is exposed south of the park. Locally the Bear River Beds contain volcanic ash which dates to late Miocene or early Pliocene. This unit may correlate to the ash beds in the Wildcat Group exposed along the Van Duzen River. The sediments near the Bear River have mollusks indicating a Pliocene age for the beds (McLaughlin et al. 2000).

St. George Formation (late Miocene to early Pliocene)

The St. George Formation is a sandstone and shale unit containing a shallow marine invertebrate fauna and diatoms (Maxson 1933; Back 1957; Moore and Silver 1968). The formation has a limited exposure near St. George Point north of Crescent City and is located north of RSNP.

Battery Formation (Pleistocene)

The Battery Formation is exposed in and around Crescent City and extends south towards Crescent Beach. This unit is an unconsolidated sand and shale covering the southern part of Crescent City Platform (Maxson 1933; Irwin 1997). Locally this unit may be as much as 20 m (66 ft) thick (Back 1957) and contains shells of marine mollusks approximately 100,000 years old based on amino acid dating (Wehmiller et al. 1977).

Falor Formation (Pleistocene to late Pleistocene)

The Falor Formation is a shallow marine sandstone and conglomerate which contains an abundant molluscan fauna (Manning and Ogle 1950). The Falor is exposed south of RNSP.

Park Collections

According to the RNSP Curator, there are no paleontological specimens in the park museum collection that have been obtained from within the park boundaries (J. O'Barr, RNSP Museum Curator, pers. comm., October 2008).

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division sponsored a Geologic Resources Evaluation scoping meeting for RNSP in Ashland, Oregon, on March 2-3, 2004. A series of recommendations were

generated from this meeting and are contained in the Geologic Scoping Report for RNSP (Covington 2004).

- The location of the paleobotanical collection made by Robert Criswell (Humboldt State College) in 1968 is unknown. Research should be undertaken to relocate this collection and incorporate either the curatorial records or the actual fossil specimens into the RNSP museum collection.
- Park staff should be encouraged to observe exposed cliffs, other erosional bedrock, rivers and streams (especially during times of low river/stream levels) for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- The NPS Geologic Resources Division is available for consultation and assistance if any future paleontological resource issues emerge at RNSP.

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

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1968–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by RNSP staff; status: Active.

Whiskeytown National Recreation Area

Whiskeytown National Recreation Area (WHIS) was originally authorized on November 8, 1965 and established on October 21, 1972. WHIS is administered by the National Park Service and the nearby Shasta and Trinity recreation areas are administered by the U.S. Forest Service. Collectively the official name for the recreation areas is the Whiskeytown-Shasta-Trinity National Recreation Area. The recreational area consists of a mountainous backcountry and large reservoir which provide outdoor recreational opportunities for the public. The park preserves historic buildings and structures associated with the California Gold Rush. The name Whiskeytown comes from an early incident involving a team of donkeys that lost their footing on a local trail spilling a load of whiskey into a nearby ravine (Thornberry-Ehrlich 2007).

Geologic Background

Whiskeytown National Recreation Area (WHIS) is located in Shasta and Trinity counties in northcentral California and is situated in the Klamath-Coastal subregion of the Klamath Network as defined by Sarr et al. (2007). This subregion is characterized by rugged topography and complex geology. The park includes a man-made lake and rich history of mining activities.

During the 1849 California Gold Rush, the Klamath Mountains were the focus of miners and prospectors seeking gold, silver, copper and other metals present in placer and massive sulfide deposits. Placer gold was first discovered in the region's streams and rivers in 1848, and the lode gold was found in nearby French Gulch in 1852 (Clark 1970). Remnants of their settlements still dot the landscape at Whiskeytown, preserved as part of the park's historical legacy. Exploration and mining in the area has continued ever since. From 1900-1914, and again in 1930, gold mining activity was at its peak. Mining in the French Gulch area continued until 1942. During the 1970s and 1980s, there was a resurgence of mining interest for lode gold, copper, silver, zinc, and iron from massive sulfide deposits (Albers 1965; Thornberry-Ehrlich 2007). Whiskeytown NRA is one of three National Park Service units open to federal mineral leasing. Because of this extensive history of mining, the region is the second most productive gold district in California.

Geologically WHIS is dominated by igneous and metamorphic rocks and contains some of the oldest rocks in the region. The Abrams Mica Schist and the Salmon Hornblende Schist are pre-Silurian in age occur as basement rock at WHIS (See the appendix for a geologic time scale). Although these units are not exposed in the national recreation area, they are present at the surface to the south and southwest and nonconformably contact at the Shasta Bally Batholith (B. Rasmussen, WHIS Geologist, pers. comm.., February 2009). The Copley Greenstone and Balaklala Rhyolite are overlapping and interlocking Devonian-aged pyroclastic (composed of rock fragments from volcanic explosions) units. The Copley Greenstone and Balaklala Rhyolite, along with the overlying Kennett Formation, are part of an accreted terrane added on to the western edge of North America. The Mule Mountain Stock represents another Devonian unit in WHIS which has an age date of 400 million years based on zircons (Albers 1964; Irwin and Wooden 1999). The Mule Mountain Stock has undergone the process of albitization which alters the calcium-rich mineral plagioclase (anorthite) to sodium-rich plagioclase (albite). One theory is that the rhyolite and greenstone formed at the same time as the emplacement of the Mule Mountain Stock. Relative and absolute ages, and the process of albitization support this theory (B. Rasmussen, WHIS Geologist, pers. comm., February 2009).

The recreation area's most prominent geologic feature is a large northwest trending Shasta Bally batholith which reaches an elevation of 1,893 m (6,209 ft). A batholith is a large igneous intrusion that has more than 100 sq km (40 sq miles) surface exposure and no known bottom. The Shasta Bally is primarily composed of light-colored quartz diorite ranging to granodiorite (Albers 1965). Several satellite plutons of identical composition are exposed around Shasta Bally. One of the largest is the Clear Creek plug which covers more than 2.5 sq km (1 sq mile). Sharp contacts exist between the batholith and the surrounding foliated gneissic bedrock.

The Shasta Bally batholith intruded an older assemblage of quartz-mica schists, silica-rich (felsic) and silica-poor (mafic) volcanic rocks, conglomeratic and shaly sedimentary rocks which range in age from the Precambrian to the Mississippian (Albers, 1965; Irwin, 1999). This intrusive event occurred during the Late Jurassic and/or Early Cretaceous and was contemporaneous with the Nevadan orogenic (mountain building) event. During this time, igneous intrusion was also occurring in the area that became the Sierra Nevada Mountains, southeast of Whiskeytown (Thornberry-Ehrlich 2007).

Deposited atop these bedrock units are a variety of unconsolidated Quaternary units (less than 2 million years old). These include soils, landslide material, talus, slope wash, colluvium, terrace and alluvial gravels, silts, sands, and clays. Semi-consolidated and correlative sands and gravels of the Quaternary Red Bluff Formation also appear locally. Most of these units are the weathered remnants of igneous, metamorphic and sedimentary bedrock units.

Sources of Paleontological Resources

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

Bragdon Formation (Mississippian)

The Bragdon Formation consists of two clastic sedimentary units. The upper unit is predominantly conglomerate and sandstone with interbedded siltstone and shale. The lower unit consists of mostly shale, mudstone, and siltstone, with minor amounts of tuff and conglomerate. The Bragdon Formation is mapped in the northern portions of the park. This unit is intruded by the Shasta Bally batholith and contact metamorphism is evident by the presence of metamorphic rock called phyllite.

According to the WHIS park geologist, a single fossil specimen has been collected from the Bragdon Formation in the park. The specimen appears to be the fragmentary remains of an invertebrate preserved in a black shale unit within the Bragdon (B. Rasmussen, WHIS Geologist, pers. comm., October 2008).

Potential Sources of Paleontological Resources

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

Kennett Formation (Devonian)

The Kennett Formation is a gray to black cherty shale with two distinct lithologic units. The lower portion consists of tuffaceous sedimentary rock. The upper portion is more predominantly a limestone which contains the remains of Devonian corals and brachiopods.

Albers' (1964) geologic map of the French Gulch quadrangle does not indicate the presence of the Devonian Kennett Formation within WHIS. According to WHIS Geologist Brian Rasmussen, although the Kennett Formation has not been mapped or identified in the park, this may be a function of scale, as this unit is very thin (as little as 30 cm or 1 ft) in some areas (B. Rasmussen, WHIS Geologist, pers. comm., October 2008).

Pleistocene/Holocene Surficial Deposits and Caves

Potter Creek Cave and Samwell Cave are two well known and important paleontological localities in the Shasta Unit of the national recreation area administered by the U.S. Forest Service. These caves are miles outside of the National Park Service administered lands, but reflect a significant local Pleistocene fossil site. These caves were first studied in the early twentieth century (Sinclair 1903, 1904, 1905). The fossil

fauna is dominated by Pleistocene mammals. Similar fossil remains may occur in other caves or surficial deposits within and around WHIS.

Park Collections

According to the curator for WHIS, there are no cataloged fossil specimens in the park's museum collection (J. O'Barr, WHIS Curator, pers. comm., September 2008). There is one possible fossil specimen which was collected from the Mississippian Bragdon Formation within WHIS. This specimen appears to be a fragmentary invertebrate (possibly trilobite) preserved in a black shale. The specimen is currently uncataloged and in the resource management office at WHIS (B. Rasmussen, WHIS Geologist, pers. comm., October 2008).

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division sponsored a Geologic Resources Evaluation scoping meeting for WHIS in Ashland, Oregon, on March 2, 2004. A series of recommendations were generated from this meeting and are contained in the Geologic Scoping Report for WHIS. A detailed Geologic Resource Inventory report was subsequently completed for the park (Thornberry-Ehrlich 2007).
- Park staff should be encouraged to observe exposed cliffs, other erosional bedrock, rivers and streams (especially during times of low river/stream levels) for fossil material while conducting their usual duties. Staff should document any observations with photographs using a common item (e.g. pocketknife) for scale. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- The fossil invertebrate specimen collected from the Bragdon Formation should be evaluated by a invertebrate paleontologist in order to determine which taxonomic group it belongs. The locality in which this specimen was collected should be revisited for other potential paleontological remains.
- The NPS Geologic Resources Division is available for consultation and assistance if any future paleontological resource issues emerge at WHIS.

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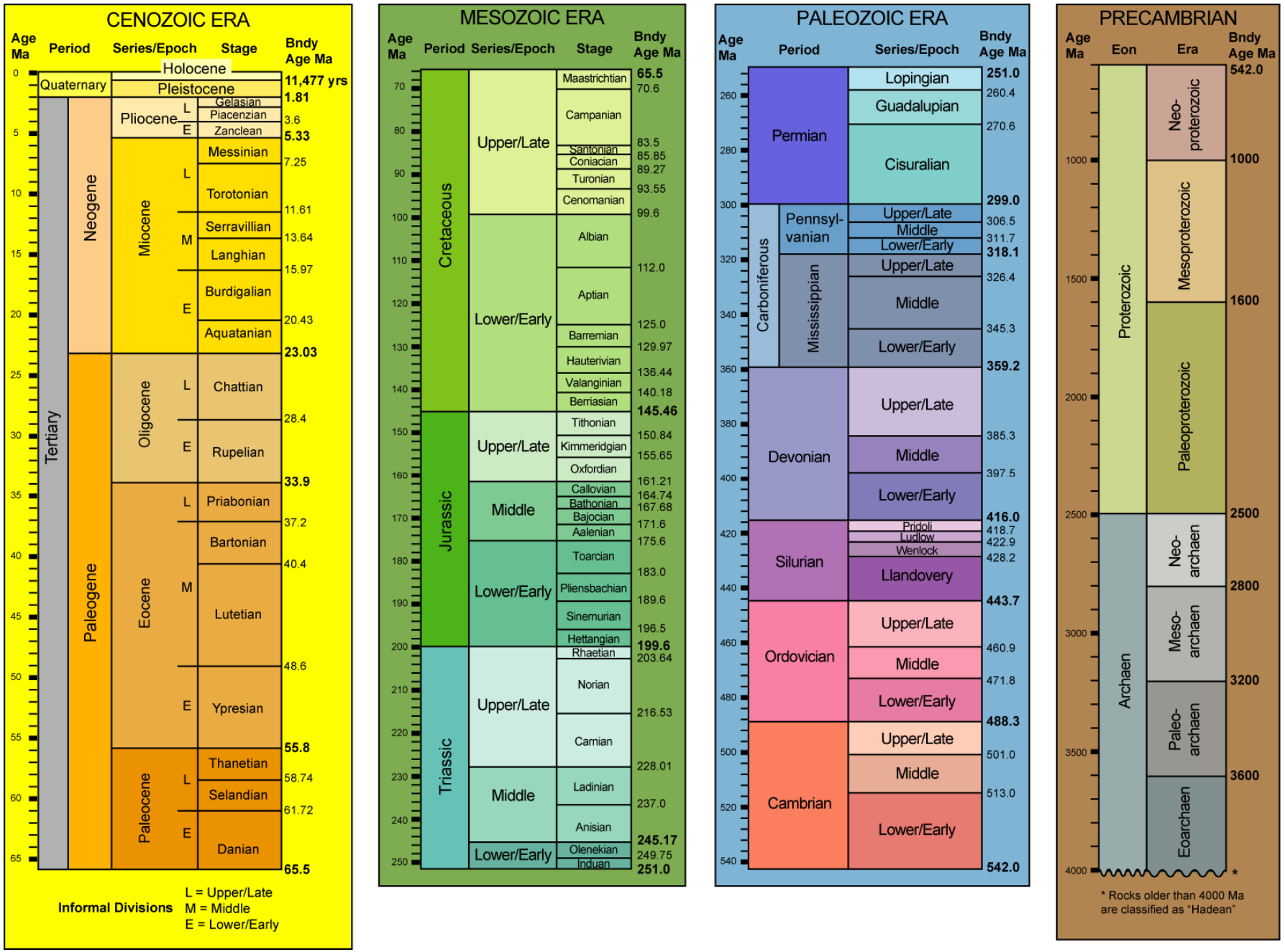
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Data Sets

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

Whiskeytown National Recreation Area Collections
1972–present. (museum specimens; associated specimen notes; collection records; maps; etc.).
Originated by WHIS staff; status: Active.



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

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