



Paleontological Resource Inventory and Monitoring

North Coast and Cascades Network

Natural Resource Technical Report NPS/NRPC/NRTR—2009/250



ON THE COVER

Unidentified starfish (Phylum: Echinodermata, Class: Asteroidea) discovered and collected from Olympic National Park in 2009. The specimen is very significant as the only starfish known from the Hoh Formation, and one of very few known from the Pacific Northwest. The Hoh Formation ranges in age from late Eocene through Miocene.

Photo by Elizabeth A. Nesbitt (Burke Museum).

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NOTE:

This report provides baseline paleontological resource data to National Park Service administration and resource management staff. The report contains information regarding the location of non-renewable paleontological resources within NPS units.

It is *not* intended for distribution to the general public.

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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 at least 219 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 North Coast and Cascades 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 27 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 North Coast and Cascades Network come from marine, terrestrial, glacial, and glacial deposits, and range from Late Paleozoic to Holocene in age. All NCCN parks (EBLA, FOVA, LEWI, MORA, NOCA, OLYM, and SAJH) have been the subject of glacial chronology studies and Pleistocene-Holocene paleoenvironmental reconstructions. These studies analyze pollen and microfossils, plant fragments, and marine and terrestrial invertebrates (especially mollusks). Trees preserved in Holocene mass wasting deposits at MORA help scientists to understand potential hazards associated with Mount Rainier. Paleontological resources occur in cultural contexts at EBLA, FOVA, LEWI, NOCA, OLYM, and SAJH. Evidence of early human occupation in these areas comes from home sites and kitchen middens. These sites contain the remains of marine and terrestrial invertebrates (mostly mollusks) as well as remains of vertebrates including fish, terrestrial mammals, birds, and marine mammals. Many cultural sites also contain objects like “worked” bone and shell material and in some cases, tools. In the case of FOVA, paleontological resources also include historic objects such as personal curios, trade objects, and building materials. Marine microfossils and marine invertebrates (especially mollusks) examined from rocks at NOCA, OLYM, and LEWI help geologists to understand the ages and relationships of Mesozoic and Cenozoic rocks; similar studies based on plant fossils have been conducted in and around MORA. Evidence of unusual chemosynthetic communities are preserved in the rocks of OLYM and LEWI; deposits such as these preserve the earliest known examples of a myriad of genera and species, and therefore they are significant to paleontological studies. The majority of the paleontological discoveries within NCCN parks have not appeared in popular literature but may be found in geological publications and unpublished theses, if reported or studied at all.

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Dedication



We dedicate the North Coast and Cascades Network Paleontological Resource Inventory and Monitoring report to (from left to right): Lisa Norby (National Park Service), Wesley Hill (Geological Society of America), and Maggie Toscano (Association for Women Geoscientists) in appreciation for their longstanding support of the National Park Service Geoscientists-In-the-Parks (GIP) program. GIP program participants contribute to numerous paleontology projects throughout the NPS, including this and many other I&M paleontological resource summaries.

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 219 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 North Coast and Cascades I&M Network.

The North Coast and Cascades Network (NCCN) is composed of seven parks in two western states (Washington and Oregon) as shown in Figure 1. These include Ebey's Landing National Historical Reserve (EBLA), Fort Vancouver National Historic Site (FOVA), Lewis & Clark National Historical Park (LEWI), Mount Rainier National Park (MORA), North Cascades National Park Service Complex (NOCA), Olympic National Park (OLYM) and San Juan Island National Historical Park (SAJH). The parks that comprise the North Cascades Network vary in size from 85 ha (210 acres) (FOVA) to 373,384 ha (922,651 acres) (OLYM). Elevations within the network range from sea level (EBLA, LEWI, OLYM, and SAJH) to 4,392 m (14,410 ft) above sea level (MORA).

In a broad sense, the geologic setting of the NCCN is well understood. Due to plate tectonics, dense oceanic crust that comprises the Pacific Ocean Basin is pushed beneath the buoyant and comparatively less-dense continental crustal rocks that comprise the North American continent. This process, called subduction, has been shaping the region since the Mesozoic Era. It is important to note that several striking geologic features have formed as a result of the subduction of oceanic crust.

Like a conveyor belt carrying groceries to the checkout line, the subducting oceanic crust transports marine sediments closer to the continental margin. At the subduction zone, where the oceanic crust plunges beneath the continental margin, marine sediments are scraped off the downgoing slab, resulting in a jumbled and chaotic group of marine rocks (sometimes called "mélange"—a French word meaning "mixture") that form an accretionary prism. The Olympic Mountains (OLYM) are such an accretionary prism. Other diverse rock suites, called "terrane" are also transported by the conveyor belt, until they are compressed, sutured, and welded to the continent in a process called accretion. The San Juan Island Archipelago (SAJH), portions of the Olympic Peninsula (OLYM), and a large part of the North Cascade Range (NOCA) are underlain by terranes. The complex rock suites found in this region gave rise to the accretionary tectonic model (e.g. Saleeby 1983). Specific examples of accretionary terranes within NCCN include the Easton and Chelan terranes of NOCA, the Turtleback Complex, Deadman Bay Terrane, and Decatur Terrane of SAJH, and the Crescent Terrane of OLYM. Deeper inside the earth, the subducting rocks actually sweat moisture, which melts the overlying rocks and forms the tall, steep-sided volcanoes of the Cascade Range, including Mount Rainier (MORA).

Rivers drain the mountainous area, washing volumes of sediment into the ocean, where the sediment is then deposited to form submarine fans. Ancient submarine fans formed beyond the mouth of the ancestral Columbia and other rivers, and are visible in the fossiliferous marine rocks that outcrop at LEWI, such as the Astoria Formation. Eventually, the Columbia River carved its way into the slowly-uplifting rocks of the Columbia River Basalt. Because of its favorable location as a trading outpost, a terrace above the Columbia River was settled and became a hub for regional commerce, leading to the

establishment of FOVA. However, it is important to note that westward expansion, at least in the geologic sense, has been taking place in the NCCN for more than 100 million years, as a direct result of plate tectonic processes.

More recently, continental ice sheets and alpine glaciers have sculpted the regional landscape. The Cordilleran Ice Sheet deposited thick blankets of sediment during its initial advance (in the form of glacial till deposits), and during its final retreat (in the form of glacial outwash deposits). Such deposits dominate the geology at SAJH and EBLA. Continental glaciation has contributed to the geology of OLYM and NOCA, but alpine glaciation is more dominant in those areas.

In a more technical sense, the details of the region's geologic history remain somewhat elusive. Precise reconstructions of the geologic history of the Pacific Northwest are controversial, due in part to the complexity of the geologic processes operating in this area, but also due to the dense vegetation, and the rugged topography. Although the larger pieces of the geologic puzzle are firmly in place, some of the smaller pieces are still not well understood. Questions about the timing of certain glacial events remain unanswered, as are questions on the timing of certain structural and metamorphic events and how certain rock units formed in relation to one another. Each and every park within the NCCN contains a record of these geologic events. Paleontological clues within these rocks provide a rare window into the geologic past and may contribute a solution to some of these long-standing geologic conundrums.

The majority of the paleontological discoveries within NCCN parks have not appeared in popular literature but may be found in geological publications and unpublished theses, if reported or studied at all. The paleontological resources known from the parks of the North Coast and Cascades Network come from marine, terrestrial, glacial, and glacial deposits, and range from Late Paleozoic to Holocene in age. See the appendix for a geologic time scale. All NCCN parks (EBLA, FOVA, LEWI, MORA, NOCA, OLYM, and SAJH) have been the subject of glacial chronology studies and Pleistocene-Holocene paleoenvironmental reconstructions. These studies analyze pollen and microfossils, plant fragments, and marine and terrestrial invertebrates (especially mollusks). Trees preserved in Holocene mass wasting deposits at MORA help scientists to understand potential hazards associated with Mount Rainier. Paleontological resources occur in cultural contexts at EBLA, FOVA, LEWI, NOCA, OLYM, and SAJH. Evidence of early human occupation in these areas comes from home sites and kitchen middens. These sites contain the remains of marine and terrestrial invertebrates (mostly mollusks) as well as remains of vertebrates including fish, terrestrial mammals, birds, and marine mammals. Many cultural sites also contain objects like "worked" bone and shell material and in some cases, tools. In the case of FOVA, paleontological resources also include historic objects such as personal curios, trade objects, and building materials. Marine microfossils and marine invertebrates (especially mollusks) examined from rocks at NOCA, OLYM, and LEWI help geologists to understand the ages and relationships of Mesozoic and Cenozoic rocks; similar studies based on plant fossils have been conducted in and around MORA. Evidence of unusual chemosynthetic communities are preserved in the rocks of OLYM and LEWI; deposits such as these preserve the earliest known examples of a myriad of genera and species, and therefore they are significant to paleontological studies.

Collectively, the paleontological resources of the NCCN 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 219 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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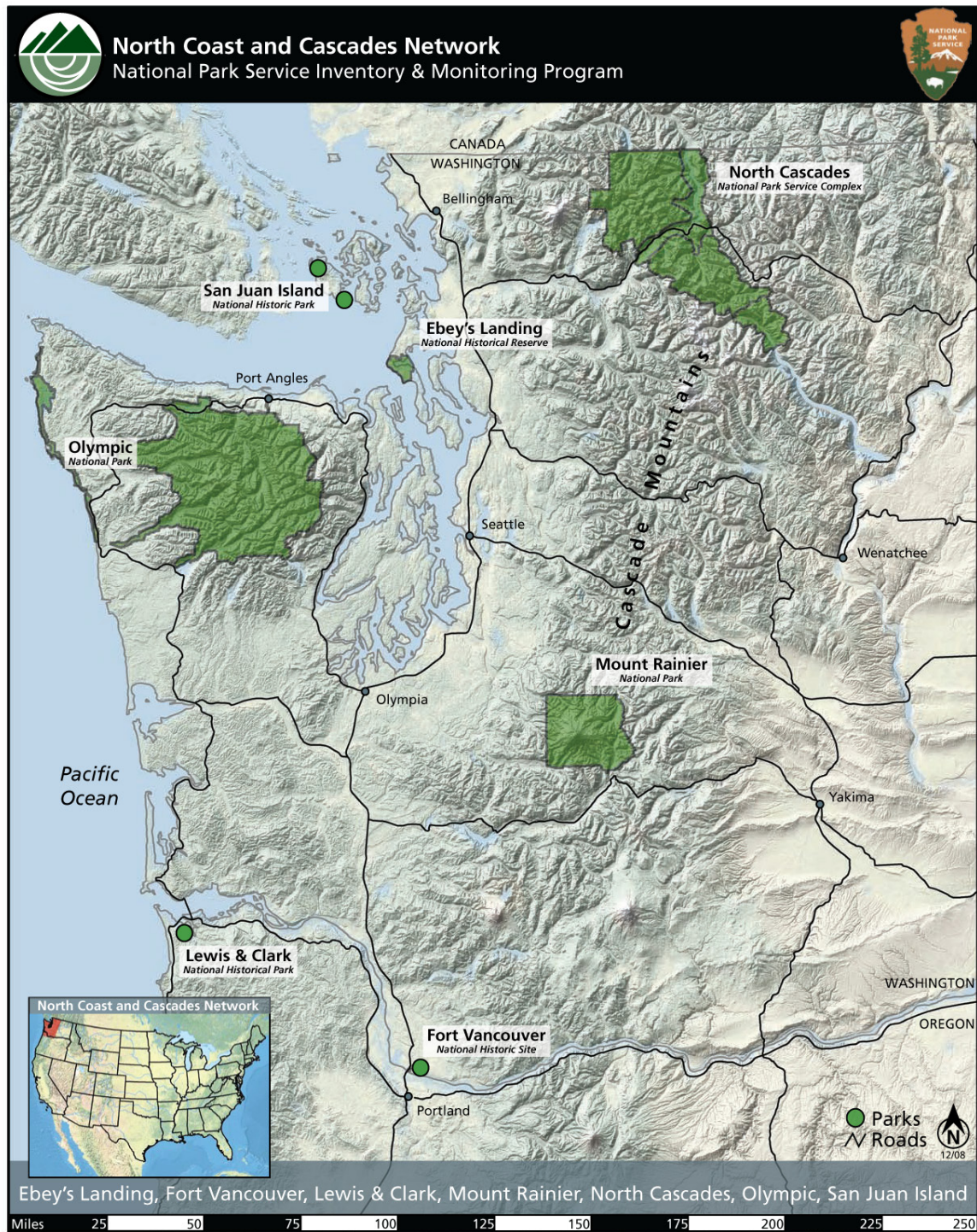


Figure 1. Map of North Coast and Cascade Network parks. Courtesy NCCN.

Paleontological Resource Inventory Strategies and Methodology

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

Comprehensive Park-Specific Paleontological Resource Inventories

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

Servicewide Thematic Paleontological Resource Inventories

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

Inventory and Monitoring Network Paleontological Resource Inventories

Network-based paleontological resource inventories compile baseline paleontological resource data for each of the parks within a particular network. Network-based inventories have been completed for 27 of the 32 I&M networks including: Appalachian Highlands, Chihuahuan Desert, Cumberland Piedmont, Eastern Rivers and Mountains, Great Lakes, Greater Yellowstone, Gulf Coast, Heartland, Klamath, Mediterranean Coast, Mid-Atlantic, Mojave Desert, National Capital Region, North Coast and Cascades (this report), Northeast Coastal and Barrier, Northern Colorado Plateau, Pacific Island, Rocky Mountain, San Francisco Bay Area, Sierra Nevada, Sonoran Desert, Southeast Coast, Southeastern Alaska, Southern Colorado Plateau, Southern Plains, Southwestern Alaska, and Upper Columbia Basin networks. Research for summaries of the Arctic, Central Alaska, Northeast Temperate, Northern Great Plains, and South Florida/Caribbean networks are currently underway. NPS I&M Program funding is targeted to complete paleontological resource summaries for the remaining networks in FY2010. Citations for the completed reports are in the Additional References section.

I&M Network Paleontological Resource Inventory Methodology

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

The most valuable component of any paleontological resource inventory is an intensive literature search. Various databases contain citations for geology or paleontology themed publications. The American Geological Institute's GeoRef is the primary database for geology references and contains more than three million 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 many 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 (<http://www.stategeologists.org/>) are also excellent sources of information, as are geologists familiar with local geology and paleontology.

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

Bibliographic searches include a search for geologic maps associated with each park. The NPS Geologic Resources Division maintains a database of geological map coverage for many parks (current contact is Tim Connors). A digital geologic map for each park is one product of the NPS GRD Geologic Resource Inventory program. In addition, the USGS National Geologic Map Database (NGMDB; <http://ngmdb.usgs.gov>) lists maps for a given geographic area or place name and provides information on how to obtain maps. Geologic maps show the types of rocks and the associated geological formations within a park area. These maps alone can often suggest 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. This lexicon provides a basic summary for each formation, summarizes current and past usage of the various formation names found in the literature, and provides an annotated bibliography for each formation.

Organization of the Reports

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

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

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

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

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

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

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

Paleontological Resource Management Legislation and Guidance

I&M Network reports such as this are meant to provide network parks with sound baseline paleontological resource data that can stimulate future research, interpretation, education, or resource management projects. The proper management of resources identified through these inventories is mandated by many NPS policies including the newly enacted Paleontological Resource Preservation Act.

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

§6302 calls for the management and protection of paleontological resources using scientific principles and expertise. The NPS should develop plans for inventory, monitoring, and the scientific and educational use of paleontological resources. Planning should emphasize interagency coordination and collaboration and where possible include non-federal partners, the scientific community and the public.

§6303 calls for the establishment of education programs to increase public awareness about the significance of paleontological resources.

§6304 calls for the development of a specific permit for the collection of NPS paleontological resources. The new legislation and other existing authorities clarify and reaffirm issues of property ownership, accountability, access and confidentiality of locality information associated with the management of NPS paleontological resources.

§6305 calls for the curation of NPS paleontological resources, along with any associated data or records, in approved repositories.

§6306 provides clarity regarding prohibited acts involving paleontological resources and specifies criminal penalties associated with these prohibited acts.

§6307, along with other existing authorities, enables the NPS to seek civil penalties and restitution for the violation of any prohibited activities involving paleontological resources.

§6308 provides the NPS a confidentiality provision with an exemption from the disclosure of any information associated with the nature and specific location of NPS paleontological resources.

§6310 directs the Secretaries of the Interior and Agriculture to issue regulations appropriate to carry out the Act

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

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

implementation and continuation of paleontological resource management programs. Links to the above documents are listed in the “Additional References” section.

The Geologic Resources Division and Geological Society of America are assembling a geologic resource monitoring manual that includes chapters on various geologic resources, including in situ paleontological resources (Santucci et al. in press), 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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General NCCN Information

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Oregon Department of Geology and Mineral Industries (DOGAMI):

<http://www.oregongeology.org/sub/default.htm>

Washington State Division of Geology and Earth Resources:

<http://www.dnr.wa.gov/ResearchScience/GeologyEarthSciences/Pages/Home.aspx>

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

Geological Survey of Canada: http://gsc.nrcan.gc.ca/index_e.php

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

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

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Library catalogs

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Burke Museum of Natural History and Culture (Seattle): <http://www.washington.edu/burkemuseum/>.

Canadian Museum of Nature (Ottawa): http://nature.ca/nature_e.cfm

Makah Cultural and Research Center (Neah Bay, WA): <http://www.makah.com/mcrchome.htm>

University of Oregon Museum of Natural and Cultural History (Eugene):

<http://www.uoregon.edu/~mnh/>

University of California Museum of Paleontology (Berkeley): <http://www.ucmp.berkeley.edu/>

Western Washington University (Department of Geology; Bellingham):

<http://geology.wvu.edu/dept/index.shtml>

Smithsonian Institution National Museum of Natural History (Department of Paleobiology; Washington,

DC): <http://paleobiology.si.edu/>

Resource Management/Legislation Documents

NPS 2006 Management Policies (§1.4; Park Management): <http://www.nps.gov/policy/mp/chapter1.htm>

NPS 2006 Management Policies (§4.8.2.1; Paleontological Resources):

<http://www.nps.gov/policy/mp/chapter4.htm>

NPS 1998 Omnibus Management Act (paleontological resource summary):

http://www.nature.nps.gov/geology/paleontology/paleo_5_1/index.htm

NPS Natural Resource Management Reference Manual #77 (paleontology section):

<http://www.nature.nps.gov/rm77/paleo.cfm>

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

National Park Service Paleontology Program Sites

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

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

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

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

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

NPS Technical Information Center (Denver, repository for technical (TIC) documents):
<http://etic.nps.gov/>

Other Geology/Paleontology Tools

Bates, R. L. and J. A. Jackson, editors. American Geological Institute dictionary of geological terms (3rd Edition). Bantam Doubleday Dell Publishing Group, New York.

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

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

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

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

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

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

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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Ebey's Landing National Historical Reserve

Ebey's Landing National Historical Reserve (EBLA) was established "to preserve and protect a rural community which provides an unbroken historic record of nineteenth-century exploration and settlement in Puget Sound to the present time." Accordingly, today's land use patterns are similar to when the land was settled under the Donation Land Claim Act of 1850. EBLA was designated one of the first national historical reserves by Congress on November 10, 1978. After boundary expansions in 2000 and 2002, EBLA now encompasses 7,820 hectares (19,324 acres); 1,096 ha (2,709 acres) of which are under federal administration. The reserve operates under a unique management framework, the Trust Board of Ebey's Landing National Historical Reserve, which is a partnership of local, state, and federal governments and private landowners. The reserve encompasses two state parks and the historic town of Coupeville.

Geologic Background

EBLA is located on Whidbey Island of the San Juan Archipelago, Washington State. The reserve is bounded by the Strait of Juan de Fuca to the west. EBLA is located approximately 25 km (roughly 15 mi) southeast of San Juan Island National Historical Park (see SAJH summary in this report), on San Juan Island. Just over 85% of the land within EBLA's administrative boundary is held by private owners, Washington State Parks (Fort Ebey and Fort Casey state parks), The Nature Conservancy, and the municipality of Coupeville. The remaining portion is held by NPS. Adjacent land-use is primarily residential and agrarian, and includes an outlying airfield of Whidbey Island Naval Air Station.

EBLA is situated in the Puget Lowland (or Puget Trough) Physiographic Province, which is seismically active. The Olympic Mountains lie to the southwest and the Northern Cascade Mountains lie to the east; the Fraser Lowland lies to the north in the Canadian province of British Columbia.

Whidbey Island is mantled by a thick blanket of loosely-consolidated to unconsolidated sediments that were derived from glacial and fluvial processes which prevailed there during the Quaternary Period (see the appendix for a geologic time scale). Local geomorphic features, which rarely rise more than 60 m (200 ft) above sea level, are comprised of these deposits. Bedrock is not exposed in the vicinity of EBLA because the overlying sediments are approximately 300-800 m (1000-2500 ft) in thickness (e.g. Mosher et al. 2000).

The deposits at EBLA record several intervals of glaciation and the intervening nonglacial periods. Generally speaking, glacial sediments (sometimes called "drift") were deposited directly by the ice sheet or were transported by meltwater. Most of the geomorphic features at EBLA were formed from glacial meltwater. These features formed at a time when Ebey's Prairie was flooded by seawater while an ice sheet remained over Coupeville and Penn Cove, with the ice front running east and west from Coupeville (M. Polenz, pers. comm. April 4, 2009). Voluminous meltwater emanated from the ice front and formed braided stream deltas east and northwest of Ebey's Prairie, which built the flat-topped hills (e. g. Smith Prairie) that define the width of the prairie (M. Polenz, pers. comm. April 4, 2009). Nonglacial sediments were deposited in terrestrial and freshwater environments, when rivers flowed from the eastern highlands, shedding large volumes of sediment into aggrading flood plains, deltas and fans, in an environment similar to the flat lands that surround the lower Skagit River (20 km or 15 mi northeast of EBLA) today. Deposits of the Double Bluff Glaciation are the oldest strata exposed within EBLA, estimated to have been deposited between 125,000 and 185,000 years ago. Nonglacial deposits representing the Whidbey Interglacial interval overlie deposits of the Double Bluff. Where present, field relations of the Possession Drift, deposited during the Possession Glaciation, help to distinguish Whidbey Interglacial deposits from the overlying but similar looking deposits of the younger Olympia nonglacial interval. A majority of Whidbey Island's surficial deposits were deposited more recently during the Fraser Glaciation, which at EBLA is divided into the Vashon Stade (advance and glacial maximum) and the Everson Interstade (glacial retreat), and perhaps a subsequent minor glacial readvance that could have

returned an ice front to the northern fringe of the EBLA area. The Everson Interstade ended prior to approximately 12,500 radiocarbon years ago (Swanson 1994).

All of the deposits found within the park are potentially fossiliferous, and may contain the remains of marine and terrestrial invertebrates, birds, or mammals. However, within EBLA, fossil occurrences have only been documented from Olympia-age and younger (post-60,000 years ago) deposits.

Sources of Paleontological Resources

Fossils have been documented from the following geologic formations and museum collections within EBLA. These fossils present opportunities for resource management (including field surveys, inventory, and monitoring), education, interpretation, and continued or future scientific research in the park.

Deposits of the Olympia Nonglacial Interval (Pleistocene)

Though not a formally recognized geochronologic unit, deposits of the Olympia nonglacial interval (approximately 60,000-20,000 years old) were emplaced after the retreat of the Possession Glaciation. The term “nonglacial” is applied to the Olympia beds because during Olympia-age, the climate did not become stabilized and warm at a global scale (global climatic stability being a characteristic of true “interglacial” period). Freshwater mollusk shells were collected within EBLA, and analyzed for geochronology studies. The shells yield radiocarbon ages ranging from $16,790 \pm 70$ to $22,160 \pm 90$ radiocarbon years before present (^{14}C ybp) (uncorrected and uncalibrated dates; uncertainty statements are one sigma; Polenz et al. 2005a, 2005b).

Pollen studies from sites in the Fraser Lowland of British Columbia describe the Olympia-age climatic succession. The climate during the Olympia nonglacial interval began as cold and unstable more than 48,000 years ago (indicated by Polypodiaceae fern spores and grass pollen), then became cool, like a dry parkland (dominated by grass and *Pinus*). A cool and moist climate dominated approximately 33,000 years ago, as indicated by spruce and mountain hemlock (*Picea* and *Tsuga mertensiana*) from sedge and *Myrica* wetlands, and by flowering plants (*Valeriana*, *Gentiana*, and *Sanguisorba*). A cooler, dryer climate indicated by grass, shrubs (*Artemisia*), and club moss (*Lycopodium*) may represent the end of the Olympia nonglacial interval and the onset of Fraser Glaciation (Hebda et al. 2007). In addition to excellent pollen preservation, other localities of Olympia beds preserve diatomites, pine cones, needles, branches, leaf prints, and in-situ tree roots, and mammoth teeth, representing a diverse paleoecosystem (Troost 2002).

Deposits of the Everson Interstade (Pleistocene)

Fraser-age deposits are the most widespread deposits on Whidbey Island. After the initial advance (Vashon Stade) of the Fraser Glaciation, recessional deposits of the Everson Interstade were emplaced. The type section for Everson Drift is located on Whidbey and Camano islands (Easterbrook 1968). Marine shells, collected from deposits of Everson Drift within EBLA, were used in geochronology studies. Reported ages range from $11,850 \pm 240$ to $13,230 \pm 90$ ^{14}C ybp (uncorrected and uncalibrated ages; Easterbrook 1966; Swanson 1994; Dethier et al 1995; Polenz et al. 2005a, 2005b).

Post-glacial deposits (Pleistocene-Holocene)

Post-glacial deposits include modern environments including: beach, dune, marsh, and soil horizons. A variety of fossils have been collected and identified from the recent deposits within EBLA. Wood, possibly representing a Douglas fir, obtained from an estuary yielded a radiocarbon date of AD 1740-1790 or AD 1810-1960 (Polenz et al. 2005a, 2005b). Marine shells, recovered from late Holocene sands, were radiocarbon dated to 935 ± 110 ^{14}C ybp (uncorrected and uncalibrated ages; Trautman and Willis 1966).

Interestingly, a kettle that was subsequently filled with eolian dune sands includes a concentrated bone-bed of disarticulated skeletal remains representing a variety of taxa. The site, originally identified by Mustoe and Carlstadt (1995), includes abundant land snails (*Modade niafidelis*), numerous birds (Canada goose- *Branta canadensis*, lesser snow goose- *Chen hyperborea*, an unidentified hawk- cf. *Accipiter* sp., black-legged kittiwake- *Rissa tridactyla*, Clark’s nutcracker- *Nucifraga columbiana*, and tufted puffin-

Fratercula cirrhata), and a variety of mammals (deer mouse- *Peromyscus*, voles- *Microtus* spp., gray wolf- *Canis lupus*, brown bear- *Ursus arctos*, and Columbian black-tailed deer- *Odocoileus*). Bones from a deer (Mustoe et al. 2005) and a vole (Polenz et al. 2005a, 2005b) were radiocarbon dated to $8,840 \pm 50$ ^{14}C ybp and $8,280 \pm 40$ ^{14}C ybp, respectively (uncorrected, uncalibrated). This EBLA site contains “the only known record of (continental) animals that inhabited the Pacific Northwest coast during the early Holocene” (Mustoe et al. 2005), and marks the faunal transition from late Pleistocene fauna to more modern Holocene fauna.

During subsequent field studies by a different researcher, human skeletal remains were discovered from a nearby site. The local Sheriff's department determined that the material is not of “modern” character; the remains were subsequently released to a local tribe (G. Mustoe, Western Washington University, pers. comm., March 2, 2009). The ownership and management status of this particular faunal site were not identified during this baseline inventory. Similar landforms exist within EBLA in the area of central Whidbey Island, and it is reasonable to infer that these features also contain significant and diverse faunal assemblages.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within EBLA. However, future field investigations within the park may yield fossils from one or more (or none) of the following geologic units. Fossils may be documented from these units outside of the park.

Deposits of the Double Bluff Glaciation (Pleistocene)

The oldest described geologic unit exposed within EBLA is Double Bluff Drift, which was emplaced approximately 185,000-125,000 years ago during the Double Bluff Glaciation. Within EBLA, the only exposure of Double Bluff Drift can be found along the bluffs to the southeast of Ebey's Landing. The type section of the Double Bluff Drift is located less than 25 km (15 mi) southeast of EBLA, along the sea cliffs at Double Bluff, Whidbey Island (Easterbrook et al. 1967). Although the Double Bluff Drift was deposited at a time when Pleistocene megafauna flourished throughout the region, such fossil finds have not been recorded from the unit.

Whidbey Formation (Pleistocene)

After the retreat of the Double Bluff Glaciation, fluvial processes dominated the landscape (approximately 125,000-80,000 years ago) during a climatic period that was probably slightly warmer than the present-day. North of Penn Cove, thick beds of sorted sand, silt, and clay-sized particles of the Whidbey Formation represent a broad floodplain. Horizons which include high concentrations of pumice and pebbles with dacitic composition (volcanic rock with moderately-high silica) are interpreted as lahar runouts (large landslide-derived debris flow or flood deposits originating from a volcano. In the case of the Whidbey Formation, the volcanic material may have originated from Glacier Peak or Kulshan-Mt. Baker of the Cascade Volcanic Arc).

Although no fossil finds have been recorded from exposures of the Whidbey Formation within EBLA, mammoth tusks, teeth, and bones are known from this unit outside of the reserve. Fossils are documented from the type section, which is located 25 km (15 mi) southeast of EBLA at West Useless Bay, Whidbey Island (Easterbrook et al. 1967; Easterbrook et al. 2003), and farther to the south at Scatchet Head, Whidbey Island (Barton 1999). Geochronology studies have been conducted on amino acids obtained from woody material found within EBLA at West Beach (Blunt 1982; Blunt and Kvenvolden 1982). Bivalves identified as *Macoma calcara* and *Saxidomus giganteus*, collected outside of EBLA, have yielded dates of approximately $77,000 \pm 6,000$ calendar years before present (Kvenvolden et al. 1980). It is possible that woody material and peat is present in deposits the Whidbey Formation and Partridge Gravel within EBLA, but occurrences are not documented in the literature because radiocarbon dates obtained from material of that age is unreliable (M. Polenz, pers. comm., April 4, 2009.)

Possession Drift (Pleistocene)

Subsequent to the deposition of the Whidbey Formation, a cooling climate brought another glacial advance, represented by deposits of Possession Drift, a discontinuous, mostly unsorted deposit which overlies the Whidbey Formation in several exposures. In fact, the appearance of the underlying Whidbey Formation and overlying Olympia deposits are so similar that, in many cases, the presence of Possession Drift is all that distinguishes the two nonglacial sedimentary packages in outcrop. The type section is located at Possession Point, at southernmost Whidbey Island (Easterbrook et al. 1967). It is estimated to have been deposited approximately 80,000 to 60,000 years ago, based on an amino acid analysis of wood collected from an area within EBLA near Blowers Bluff (Polenz et al. 2005a, 2005b).

According to the Polenz et al. (2005a, 2005b) map unit description, Possession Drift commonly contains shells, but no additional information on the variety, quality, or distribution of the shells is provided in the 2005 report. Shells preserved in the Possession Drift would most likely be marine because, like the glacio-marine deposits from the more recent Everson Interstade, the glacio-marine drift from the Possession resulted from the disappearance of glacial ice from the area at the end of the glaciation. Because the weight of the ice mass had depressed the crust of the earth in the region, land levels were much lower than today, so that marine water inundated the area despite the fact that global sea level was also much below the modern sea level. Later, the crust rebounded, causing the land to emerge. (M. Polenz, pers. comm., April 4, 2009.)

Deposits of the Vashon Stade (Pleistocene)

Deposits representing the initial advance of the Fraser Glaciation, known as the Vashon Stade, are not recognized to be fossiliferous within EBLA. However, outwash deposits preceding the Fraser advance in areas such as Vancouver Island, British Columbia, yield quantities of mammoth remains (Keddie, no date; Barton 1999).

Park Collections

There are no known paleontological resources within the museum collections at EBLA (K. Cahill, EBLA-NOCA Curator, pers. comm., February 9, 2009.)

External Collections

According to Mustoe et al. (2005), Western Washington University manages approximately 124 specimens, and the Canadian Museum of Nature manages two specimens collected from EBLA. However, personal communication with the lead author indicates that three specimens (brown bear skull, vole skull, and deer vertebra) are displayed in cabinets at Western Washington University's Geology Department. The remainder of the collection was turned over to the Canadian Museum of Nature in Ottawa, Canada (G. Mustoe, Western Washington University, pers. comm., March 2, 2009).

According to the museum's collection records, the Mustoe collection at the Canadian Museum of Nature includes 38 items which have been identified as various aves (lesser snow goose- *Chen hyperborea*, Canada goose- *Branta canadensis*, hawk- cf. *Accipiter* sp., black-legged kittiwake- *Rissa tridactyla*, Clark's nutcracker- *Nucifraga columbiana*, and tufted puffin- *Fratercula cirrhata*), rodents such as deer mice and voles (described as Microtinae), and deer (*Odocoileus*). (Canadian Museum of Nature collection records.)

An apparent discrepancy exists between the number of specimens identified from this important faunal site, and the number of specimens currently residing in the known collections at Western Washington University and the Canadian Museum of Nature. One specimen in particular, the *Canis lupus* cranium is presently unaccounted for.

A search of the online database of collections managed by University of California Museum of Paleontology at Berkeley reveals that two of Berkeley's catalogued specimens were collected from Island County: a Recent gastropod (*Haliotis kamtschatkana*) from Oak Harbor, and a Pleistocene mammoth

(*Mammuthus primigenius*) from Whidbey Island. Unfortunately, a minimum of ancillary information is provided.

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division (GRD) sponsored a Geologic Resources Inventory (GRI) scoping meeting for EBLA and other NCCN parks on September 10, 2002 in Seattle, Washington. GRI map data was discussed at the meeting; other geologic needs were not identified at that time. GRD has not yet prepared a GRI scoping report and final report for EBLA; however, a geologic map of EBLA was supported by GRI and published by the Washington Department of Natural Resources, Division of Geology and Earth Resources (Polenz et al. 2005).
- Mixed land ownership (federal, state and private) at EBLA may have contributed to some issues regarding management of paleontological discoveries. As a result, numerous fossils recovered from the park area in the past now reside in Canada. Establishment of a paleontological resource management protocol or a fossil “point-person” by the Trust Board would help to clarify and resolve this issue.
- The management status (e.g. ownership and administration) of the known vertebrate faunal site is unclear at this time and should be determined. If possible, the site should be managed in a way that is consistent with its significance. If the known vertebrate faunal site is located on federally-owned or controlled land, the NPS should strive to resolve fossil collection discrepancies, particularly regarding the cranium of *Canis lupus*.
- Due to the potential for new fossil discoveries in landforms similar to that of the known vertebrate faunal site, park staff should consider potential adverse impacts to fossil resources when evaluating future development and research projects proposed on or near such landforms.
- Public outreach and education as to the ethical handling of paleontological resources should be initiated or continued in order to preserve the scientific integrity of future paleontological discoveries.
- All known paleontological specimens should be cross referenced into the NPS Museum Catalog (ANCS+) if they were collected from an NPS area (Kelly Cahill, NOCA, is current contact).
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should photodocument and potentially monitor any occurrences of paleontological resources.
- The park should consider future field inventories for paleontological resources to more fully document *in situ* occurrences of fossils. The park may consider a formal site documentation and condition assessment for significant fossil localities. Monitoring of significant sites should be undertaken at least once a year in the future. A forthcoming (2009) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring (Santucci et al. in press).
- Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts. Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

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Data Sets

Ebey's Landing National Historical Reserve Paleontological Archives.

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

Ebey's Landing National Historical Reserve Museum Collections.

1978–present. (museum specimens; associated specimen notes; collection records; maps; etc.).
Originated by EBLA staff; status: Active.

University of California Museum of Paleontology at Berkeley.

Unknown – present. (museum specimens; associated specimen and collections records; field notes; etc.)
Originated by UCMP staff; status: Active.

Canadian Museum of Nature.

1995 – present. (museum specimens; associated specimen and collections records; field notes; etc.)

Originated by CNM staff; status: Active.

Geology Department, Western Washington University.

1995 – present (museum specimens; associated specimen and collections records; field notes; etc.)

Originated by George Mustoe, WWU; status: Active.

Ebey's Landing National Historical Reserve Digital Geologic Map

2006-present. (geologic map data; electronic files; GIS metadata). Originated by NPS-Geologic Resource

Inventory staff; status: Active. Online. <http://science.nature.nps.gov/nrdata/datastore.cfm?ID=41509>.

Fort Vancouver National Historic Site

Fort Vancouver National Historic Site (FOVA) served as the base of Hudson's Bay Company's (HBC) western operation. HBC developed a trade network from this site during the 1820s and the U.S. Army established its presence in 1849. HBC withdrew in 1860, leaving the Army in control of the fort and village. The Civilian Conservation Corps operated an induction camp at the site (Vancouver Barracks) from 1933 to 1942. FOVA consists of two units: The primary unit protects a village and fort that preserve the history of the region's most important commercial, cultural, and political hub. A smaller unit preserves the homes of John McLoughlin (Chief Factor of HBC and "Father of Oregon") and Dr. Forbes Barclay (physician). The site was designated as a national monument in 1948 and was redesignated as a national historic site, June 30, 1961. The boundary was modified in 1958, 1961, 1972, and 2003. FOVA now encompasses 85 hectares (210 acres), 82 ha (202 acres) of which are under federal administration.

Geologic Background

FOVA is situated within the Portland Basin, at the southern terminus of the Puget Trough section of the Pacific Border Physiographic Province. The Oregon Coast Range lies to the west and the middle Cascade Range lies to the east. FOVA's fort and village unit is located in the city of Vancouver, in southern Washington, on a flood plain terrace on the northern bank of the Columbia River. The surrounding area is dominated by metropolitan land use and a U.S. Army military installation. FOVA's McLoughlin House unit is approximately 30 km (20 mi) south in Oregon City, Oregon, near the confluence of the Willamette and Clackamas rivers.

The low lying Portland Basin originally formed during the uplift of the nearby Oregon Coast Range. Extraordinary thicknesses of basaltic lavas (Miocene Columbia River Group) accumulated in the topographic depression (see the appendix for a geologic time scale). Through time, the ancestral Columbia River alternately filled and incised the landscape. At some point, the river became dammed. Subsequent ponding in the area of the Portland Basin caused the older fluvial deposits (Sandy River Mudstone) to be covered by graded channel and lacustrine deposits (Miocene-Pliocene Troutdale Formation). Shortly after the basin drained, local volcanic vents produced relatively minor amounts of basaltic and andesitic lavas (Pliocene-Pleistocene Boring Lava). The modern Columbia River carved terraces into these strata, establishing its current course during recent crustal fluctuations associated with Cascadian volcanism. Today, FOVA occupies flat lying river terraces, which are blanketed by up to 50 m (165 ft) of undifferentiated alluvium consisting of recent overbank deposits of the Columbia and Willamette Rivers. Small amounts of artificial fill were added during modern urban development. (e.g. Trimble 1963; Beeson et al. 1991; Evarts 2007).

In situ fossil occurrence is extremely unlikely within FOVA for several reasons: the dominant geology of the area is not conducive to fossil preservation. The land has been worked over many times throughout its long history of development, farming, and redevelopment, which largely precludes future paleontological discoveries; furthermore, no rock outcrops exist within FOVA.

Sources of Paleontological Resources

Paleontological resources have been documented from alluvial and artificial deposits at FOVA and are cataloged into the park's museum collection. These fossils present opportunities for resource management, education, interpretation, and continued or future scientific research in the park. Some of the paleontological resources are known from various cultural resource contexts as described in the "Cultural Resource Contexts" section and "Park Collections" section below.

Quaternary deposits (Holocene or recent)

FOVA's recent alluvium and artificial fill have been analyzed during palynological investigations. An unpublished study conducted in 2001 by a professor at University of Washington examined pollen that

dates between 160-500 years old (Bob Cromwell, FOVA Archeologist, pers. comm. April 1, 2009). Elaine Dorset (graduate student, Portland State University) presented the status of her investigation of pollen from an HBC garden site at the 62nd Annual Northwest Anthropological Conference in April 2009 at Newport, Oregon. Susan A. Jacobucci (University of Massachusetts, Boston) delivered her resource management report, “An analysis of Pollen from Fort Vancouver, WA” to FOVA in 2008.

Park Collections

FOVA does not maintain paleontological collections (B. Cromwell, FOVA Archeologist, pers. comm., April 1, 2009.) However, FOVA maintains an archeology collection consisting of roughly 2,000,000 specimens. As mentioned in the “Cultural Resource Contexts” section, numerous paleontological resources occur within cultural contexts. Several occurrences are described in detail below.

Eight specimens within the FOVA collection contain the descriptor “fossil;” these specimens probably belonged to personal collections of HBC employees. Five specimens (FOVA 412, 95024, 114620, 114621, 114622) are similar in character (H. Pierson, FOVA Museum Technician, pers. comm., April 6, 2009), and are described as impressions of “univalve or bivalve shells.” A photograph of several fossils cataloged as FOVA 412 appears to depict concretions containing bivalves of the family Pectinidae, most likely of the genus *Patinopectin*. A specific identification may be possible with more detailed examination (A. Hendy, Post-doctoral Associate, Yale Peabody Museum, pers. comm., April 4, 2009). *Patinopectin* (and other Pectinidae genera, including *Vertipectin*) are well known from Eocene-Miocene sedimentary strata of the coastal Pacific Northwest. Many of these strata (e.g. Astoria Formation) contain abundant concretions as well. It is highly probable that the aforementioned specimens were collected from the Eocene or Miocene strata of the Pacific Northwest coast.

Three other “fossil” specimens were reported by Heidi Pierson [FOVA 157308 (a fossil fragment), 186315 (shell, fossilized?), 191877 (partially fossilized faunal tibia, marrow replaced with calcium carbonate)] but were not further identified during the course of this baseline inventory. FOVA 191877 measures 23.5 cm (9.25 in) and weighs 125 g (4.4 oz); it is a large fragment of a tibia that was collected from Kanaka Village site during a 1974 excavation (H. Pierson, pers. comm., April 22, 2009.)

Approximately 700 archeological specimens recovered from FOVA consist of or incorporate invertebrate shells. Some specimens (e.g. FOVA 65) may have belonged to an individual resident’s personal curio collection. Specimens representing ornamental, imported, or traded objects are often embellished with shell material. Objects include buttons, hair accoutrements, knife handles, and American Indian beads (e.g. FOVA 20843, 79718, 47506, 16009, respectively). Shell material includes mother of pearl, tortoise shell, *Haliotis* (abalone), “dentalium” (family Dentaliidae), whelk, and cockle shells. While these may be modern representatives, American Indians throughout the country are known to incorporate paleontological material into jewelry and other items. Although such an occurrence has not yet been definitively documented from FOVA, it is known in other NPS areas as explored by Kenworthy and Santucci (2006).

More than 5,000 specimens consist of or incorporate bones or animal teeth. Artifacts, including knife handles, spoons, gaming pieces, buttons, beads, spear points, fishing points, and a whistle, were fashioned from bone or animal teeth (e.g. FOVA 17507, 522, 276, 134639, 112343, 810, 11654, 16358, respectively.) Fully articulated skeletons of dogs, cats, and horses are interpreted to represent burial sites (e.g. FOVA 17153). Disarticulated bones of poultry, fowl, and ungulates are associated with kitchen refuse sites (e.g. FOVA 17170). While most likely modern, the antiquity and paleontological value of some of this material is unknown.

Approximately 1,000 specimens contain coral. A large number of these specimens consist of ground coral used as mortar in the construction of the foundation of the Powder Magazine (e.g. FOVA 16310), largely represented by the genera *Porites*, *Pocillopora*, and *Leptastrea*.

Other coral specimens, such as FOVA 9879, may have belonged to an individual resident's personal curio collection. A photograph of specimen 9879 depicts a branching coral, commonly known as "elkhorn" coral. *Pocillopora* (*P. eydouxi*) is an elkhorn of Pacific provenance; *Acropora* (*A. palmata*) is an elkhorn of Caribbean provenance (C. Moses, U.S. Geological Survey, pers. comm. April 3, 2009.) Without further examination, it is unclear whether 9879 represents a Pacific or Caribbean taxa. Preliminarily, the specimen appears to have been collected from a modern beach environment (i.e. during beachcombing).

Cultural Resource Contexts

As the base of Hudson's Bay Company's vast western operations, and later as a military installation, FOVA has always been a cultural crossroads. Traders and soldiers brought to the site diverse items originating from throughout the Pacific, North America, and England. FOVA's archeological collections include approximately 2,000,000 specimens. Many of these items trace HBC's extensive trading networks.

Paleontological resources are known to occur in several cultural contexts within FOVA. Some fossil specimens recovered from FOVA were apparently the personal collections of former inhabitants. An abundance of artifacts (items that are notched, drilled, or incised), or ornaments (e.g. sculpted items, inlay in metal work or wood work) were crafted from bones, shells, and teeth. Fully articulated skeletal remains may represent buried domesticated animals. Bones and shells (e.g. chicken bones and oyster shells) are commonly associated with kitchen refuse, though these types of remains are of minimal paleontological significance. Specimens are described in detail in the "Park Collections" section above. Such items are just one example of fossils found in cultural resource contexts. Kenworthy and Santucci (2006) present an overview and cite selected examples from throughout the NPS.

Fossils recovered from FOVA may have originally been maintained by HBC or informally gathered by the fort's residents. According to Bob Cromwell (FOVA Archeologist), HBC records indicate the existence of fossil collections housed in a "curio room." The collection was dispersed when HBC abandoned the site, and no further indication as to the whereabouts of its specimens is known to exist (B. Cromwell, pers. comm. April 1, 2009). John A. Hussey's 1957 NPS report, "The History of Fort Vancouver and its physical structure," may contain the only mention of a "curio room," which may have been located in the "Bachelors' Quarters" structure. A later report by Hussey (1976) gives a detailed description of the Bachelors' Quarters building which primarily served as both long-term and short-term housing for the subordinate employees of HBC, visitor's accommodations, as well as a social gathering place; but the author does not mention the existence of a "curio room" therein. Although the accommodations and furnishings of the Bachelors' Quarters were generally considered austere, the atmosphere may have depended upon an individual occupant's penchant for style. H. M. Robinson gives a personal account of the décor of the place, indicating that occasionally a "gentlemen of independent taste...graces the useful with more or less of the ornamental... (Natural and 'aboriginal' objects) impart a certain barbaric splendor to the apartment" (Hussey 1976, pg. 175). Hussey indicates that "natural curiosities such as rock specimens" were recovered from the site, among the personal effects of the tenants (Hussey 1976, pg. 193). According to John Dunn, the "public sitting room" of the structure (also known as "Bachelors' Hall proper" and "the smoking room") "presents the appearance of an armory and a museum. All sorts of weapons...and curiosities of civilized and savage life...may be seen there." Information provided in Hussey's 1976 report suggests that the items were of a personal nature and probably were accumulated informally rather than having been formally acquisitioned or otherwise conscientiously managed. The Bachelors' Quarters may have also contained a reference library and a subscription library (Hussey 1976, pg. 187), the holdings of which may have been informally accumulated.

The Powder Magazine is the only building at FOVA constructed with a stone and mortar foundation (B. Cromwell, FOVA Archeologist, pers. comm. April 1, 2009). The mortar was manufactured from ground coral which may have been brought to FOVA as ships' ballast. The coral was ground to a rubbly powder, calcined (removing CO₂ and water, leaving only calcium oxide), then slaked, to create a workable mortar (Virginia Lime Works, no date). An study conducted in 2006 by Lummio and Tissot (Washington State University) examined nearly 12,000 coral mortar samples recovered from the Powder Magazine;

approximately 4,000 samples of coral fragments were identifiable to the genus-level. Nearly 99% of the identifiable specimens belong to the genus *Porites*; the remainder consists of *Pocillopora* and *Leptastrea*. Though the authors note that selective harvesting or the vulnerability of certain genera to calcination may account for subtle differences in the abundance of the genera represented in the mortar compared to the abundance in the live reefs of Hawaii, the proportions of genera are rather similar to live Hawaiian reefs (Lummio and Tissot in review).

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service – Geologic Resources Division will sponsor a Geologic Resources Inventory (GRI) scoping meeting for FOVA during October, 2009.
- Known specimens of paleontological resources currently cataloged with archeological collections should be more fully examined.
- The feasibility of cross-referencing paleontological items within FOVA’s archeological collections should be explored.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

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Data Sets

Fort Vancouver National Historic Site Paleontological Archives.

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

Fort Vancouver National Historic Site Museum Collections.

1948–present. (museum specimens; associated specimen notes; collection records; maps; etc.).
Originated by FOVA staff; status: Active.

Lewis and Clark National Historical Park

Lewis and Clark National Historical Park (LEWI) was established to preserve some of the historically significant sites along the western extent of the route travelled by the Corps of Discovery, headed by Meriwether Lewis and William Clark. LEWI also commemorates the ultimate achievement of the transcontinental expedition: the arrival at the Pacific Ocean. The Corps' winter encampment was designated as Fort Clatsop National Memorial, on May 29, 1958. After boundary changes in 1978, 2002, and 2004 the area was re-designated as LEWI October 30, 2004. LEWI has undergone a twenty-fold increase in land area since 2002; additional expansions are being formalized and negotiated at this time (August 2009). LEWI currently consists of a network of cooperatively managed areas that protects more than 4,000 hectares (10,000 acres). Federally administered areas of LEWI include Fort Clatsop, Salt Works, Sunset Beach, Cape Disappointment, Dismal Nitch, and Station Camp units.

Geologic Background

LEWI is located in northwest Oregon and southwest Washington, near the city of Astoria, Oregon. The park occupies areas near the mouth of the Columbia River, through the Oregon Coast Range, and along the Pacific Coast in both Oregon and Washington states. Management units are distributed along a 64 km (40 mile) stretch of Pacific coastline. LEWI consists of a variety of newly acquired management units that are dispersed over a variety of landscapes that includes riverine, estuarine, coastal, plains, dunes, and mountainous settings.

The dominant rocks in southwestern Washington and northwestern Oregon in the area of LEWI include the volcanic rocks of the Eocene Crescent Formation (which comprise many of the hills and upland areas), marine and nonmarine sedimentary rocks consisting primarily of the Oligocene Lincoln Creek Formation and the Miocene Astoria Formation (which occupy mostly lowland areas), volcanic rocks of the Miocene Columbia River Basalt Group, and Pliocene and younger terrace deposits (Armentrout 1987).

During the Eocene (see the appendix for a geologic time scale), the Crescent Formation formed as a chain of seamounts (submarine volcanoes) in the Pacific Ocean basin that eventually collided with the ancient continental margin of western North America (Snively et al. 1980). Sediments shed from the continent and nearby islands were deposited on top of the Crescent Formation and are preserved in the overlying rock units, including the McIntosh Formation, Lincoln Creek Formation, Astoria Formation, and their correlative strata. The depth of the marine depositional basin and the rate of uplift in adjacent areas were both influenced by regional tectonic forces related to the convergence of the North American continent with oceanic crustal plates. Fluctuations in global sea level also affected the depositional environment. Those dynamic fluctuations are recorded in the sedimentological and paleontological evidence contained in the sedimentary strata. In the sedimentary rocks, the presence of tuff (fine particles produced during explosive volcanic eruptions) marks the onset of volcanism from the ancestral-Cascades.

The NPS Geological Resource Inventory program has not yet scoped or produced maps or reports for LEWI. The U.S. Geological Survey has published maps for the southwest corner of the state, near LEWI. The Oregon Department of Geology and Mineral Industries is currently compiling map data for the northwest portion of the state; the dataset is expected to be made available in 2009. Maps created by Niem and Niem (1985) and by Wells (1989) are the basis for information contained in this report.

Virtually all of the rock units that underlie or surround LEWI contain fossils. Two excellent sources of information on fossils in this area include *Fossil Shells from Western Oregon*, by Ellen J. Moore (2000), and *Oregon Fossils*, by Elizabeth L. Orr and William N. Orr (1999). The most well-known fossil producing rock unit in the area is the Astoria Formation. The Astoria Formation has been referred to as “the backbone of the Oregon Coast Range” and also outcrops in sea cliffs along the Pacific Coast, in places in southwestern Washington and Oregon. At first glance, some of the other rock units in this area appear to lack fossils entirely. However, in many cases, closer investigation reveals that some of these

“unfossiliferous” strata contain localized densely fossiliferous deposits that are very small and isolated from one another. These rocks preserve unique chemosynthetic communities that thrive on hydrocarbon seeps along the ocean floor. These “methane seep” (also called “cold seeps”) communities are typified by high abundance and low specific diversity. The Lincoln Creek Formation, the siltstone of Cliff Point, and the siltstone of Shoalwater Bay contain records of this unusual ecological condition. Goedert and Benham (2003) describe how and where methane seeps are formed, and provide descriptions of several methane seep deposits that are just outside of LEWI.

LEWI presents a certain measure of complexity for this inventory, largely due to its recent land acquisitions and significant expansion over the past several years. The recent and rapid expansions mean that park staff are encountering many new natural and cultural resources requiring management following NPS guidelines. The newly acquired management units are dispersed over a variety of diverse landscapes, which means that LEWI has taken on a wide variety of potential paleontological resources with the addition of new rock exposures to park areas. Negotiations for additional expansions are on the horizon, so additional fossil-bearing strata or outcrops may be under the protection of LEWI in the future. In the case of LEWI, this paleontological resource inventory is particularly exciting, relevant, and represents the first time this resource information is compiled for the park.

Sources of Paleontological Resources

Fossils have been documented from the following geologic formations within LEWI. These fossils present opportunities for resource management (including field surveys, inventory, and monitoring), education, interpretation, and continued or future scientific research in the park.

Crescent Formation (early-middle Eocene)

The Crescent Formation consists of basaltic lava flows, pillow lavas, and breccias interbedded with minor mudstone, siltstone, and rare limestone pockets (Squires and Goedert 1994; Garrison 1972). Volcanic rocks of the Crescent Formation may represent an early stage of rifting within a small marine basin or accreted seamounts (e.g. Snavely 1987). Siletz Volcanics and Tillamook Volcanics are correlative to the Crescent Formation. The former name is used in Oregon and the latter is used primarily in Washington State. Within LEWI, the Crescent Formation is best exposed along cliffs at Cape Disappointment; it also comprises a portion of the hills in the area just north of Dismal Nitch and Station Camp. Volcanic breccias near Fort Columbia are probably correlative to the upper Crescent Formation (Wells 1989).

Late Eocene foraminifera were collected from the Crescent Formation in the area of Fort Columbia State Park, but it is not clear whether the locality is within LEWI or just beyond the park boundary (Rau, unpublished data *in* Niem and Niem 1992).

Squires and Goedert (1994) described a diverse macrofaunal assemblage in their studies of several upper Crescent Formation localities approximately 110 km (70 mi) north of LEWI on the southeastern flanks of the Olympic Mountains (at Little River, Grays Harbor County, near Mason County). Nearly 800 good to poorly preserved specimens were collected, but less than 50 specimens were identified to the genus level. In their study, the bivalve *Nayadina (Exputens) batequensis* was identified as the most abundant macrofossil found in the upper Crescent Formation. Locally, mollusk shells are so abundant, they are described as a “coquina” (that is to say, the sedimentary horizons are primarily comprised of shelly material). The paper states that the upper Crescent Formation, as represented in sections at the Little River and Pulali Point (near Quilcene on the western flank of the Olympic Mountains), was deposited in the middle of the early Eocene. Based on the minor amount of abrasion exhibited by the specimens, combined with sedimentological evidence, the authors propose that the fossiliferous sedimentary layers of the upper Crescent Formation represent shallow marine environments, occurring when cumulative eruptions of basaltic lavas became influenced by tidal or even subaerial processes. Taxa reported from the upper Crescent Formation at the Little River localities (outside of LEWI) include radiolaria, coccolithophores, foraminifera, solitary corals, colonial coral, a new species of inarticulate brachiopod (*Craniscus edwilsoni*), articulate brachiopods, polychaete worm tubes (including *Rotularia*), sea urchins,

scaphopods (*Dentalium*), gastropods, bivalves, a barnacle, two sharks (*Isurus?* sp. and *Palaeohypodotus rutoti?*), and fish otoliths. (Please note that tentative taxonomic identifications are, by convention, indicated with a “?”.)

Groves and Squires (1995) reported a new gastropod species (*Proadusta goedertorum*), which appears as a shallow water coquina in the upper Crescent Formation approximately 100 km (60 mi) north of LEWI, at Larch Mountain. In addition, Kiel (2008) identified a wood-fall from a sandstone deposit within the Crescent Formation at a locality approximately 100 km (60 mi) north of LEWI (specimen housed at the Burke Museum).

Squires et al. (1992) observed that sedimentary deposits are rare within the dominantly volcanic rocks of the Crescent Formation, and are therefore unlikely to preserve macrofauna. The authors describe a fossiliferous locality at Pulali Point, which is located more than 160 km (100 mi) northwest of LEWI. Preservation is characterized as “fair,” and diversity tends to be low. Fossils collected from Pulali Point include wood fragments, internal molds of gastropods, disarticulated bivalves, brachiopods, nautiloid fragments, corals, echinoids, and a crab that is recognized as one of the oldest known from the fossil record of Washington State. Microfossils include benthic and planktonic foraminifera, calcareous nannofossils, and radiolaria (Rau 1966; Rau 1981).

Sandstone at Megler (middle Eocene)

The sandstone at Megler is an informal unit consisting of thick-bedded sandstones that are laminated and cross-bedded. The rocks may be correlative to the lower portion of the McIntosh Formation. The sandstone at Megler outcrops on the north shore of the Columbia River near Megler, Washington. These rocks underlie the Dismal Nitch unit of LEWI and portions of the surrounding hills, and a small area on Cape Disappointment. The sandstone at Megler is known to contain foraminifera (Wells 1989).

Smuggler Cove formation and mudstone of Oswald West (late Oligocene-Miocene) (?)

The informal Smuggler Cove formation is equivalent to the informal mudstone of Oswald West (A. Niem, pers. comm., July 2009). The rocks generally consist of fine-grained tuffaceous sediments with graded sandstones. Evidence of burrowing (especially *Helmenthoida* burrows) and bioturbation is pervasive in this unit (Niem and Niem 1985). In the area of LEWI, Smuggler Cove formation is exposed in the Coast Range, particularly in the hills to the west of Fort Clatsop.

Fossils collected from the mudstone of Oswald West at a locality near Oswald West State Park include the trace fossils *Scalarituba*, *Zoophycos*, *Taenidium annulata*, *Planolites*, *Chondrites*, *Teichichnus*, and *?Helminthopsis labyrinthica*. Niem and Van Atta (1973) report that bivalves (*Acila gettysburgensis*, *Lima* cf. *L. twinensis*, and *Lima* n. sp.), gastropods [*Liracassis* (*Echinophoria*) *rex* and *L. apta*], and foraminifera were also collected from this locality. *Zoophycos*, trace fossils that record the feeding behavior of some animals, are so prevalent in some exposures of Smuggler Cove formation that Niem et al. (2003) recommend that the outcrops should be protected as geological heritage sites. The rock unit also contains mollusks and foraminifera (Niem and Van Atta 1973, referring to Warren and Norbistrath 1946 and Warren et al. 1945).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within LEWI. However, future field investigations within the park may yield fossils from one or more (or none) of the following geologic units. Fossils are documented from these units outside of the park.

McIntosh Formation (Middle Eocene)

The McIntosh Formation is a tuffaceous marine sedimentary sequence that includes interbedded basalt flows. It has been correlated to the Cowlitz Formation of southwestern Washington, which is slightly older, and to the Aldwell, Lyre, and parts of the Hoko River and Humptulips formations of the Olympic Peninsula, among other rock units (Snively et al. 1951; Armentrout 1987). The McIntosh Formation is

known to contain foraminifera. Correlative strata are known to be fossiliferous (see formational descriptions in the Olympic National Park section of this report).

Siltstone at Cliff Point (Middle-?Late Eocene)

The siltstone at Cliff Point is an informal unit consisting of reddish – greenish thin-bedded tuffaceous bioturbated sedimentary rocks and volcanolithic sandstones (Wells 1989). The siltstone at Cliff Point underlies the area just east of Dismal Nitch.

Methane seep deposits have been identified from the siltstone at Cliff Point. These deposits preserve bivalves (*Acharax*, *Calypptogena* and *Modiolus*), gastropods [*Margarites* (*Pupillaria*), ?*Homalopoma*, *Provana*, *naticids*, and patelliform limpets], siliceous sponges (*Aphrocallistes polytretos*), in addition to wood fragments, worm tubes, foraminifera, nannofossils, and fish bone (Goedert and Squires 1990; Nesbitt et al. 1994)

Siltstone of Shoalwater Bay (middle-late Eocene)

The siltstone of Shoalwater Bay is an informal unit consisting of dark gray, thin-bedded tuffaceous siltstone. This rock unit is bioturbated, concretionary, and contains foraminifera (Wells 1989). The siltstone of Shoalwater Bay is exposed at Cape Disappointment. An outcrop near Naselle River Bridge exposes a possible methane seep assemblage. At this locality, exposures of the siltstone of Shoalwater Bay and Lincoln Creek Formation yield a diverse assemblage of mollusks (including the gastropods *Ficopsus*, *Exila*, *Polinices*, and *Siphonalia*), and concretions preserving crabs such as *Pulalium vulgare* (previously called *Xanthopsis* or *Zanthopsis vulgare*). (Nesbitt et al. 1994)

Lincoln Creek Formation (Late Oligocene)

The Lincoln Creek Formation is a dark gray, very tuffaceous concretionary marine siltstone; the lower portion is bioturbated. Lincoln Creek Formation is very fossiliferous (especially the portion known as “Porter Shale”); it includes molds and casts of mollusks as well as rare heart urchins. Lincoln Creek Formation outcrops at Cape Disappointment, south of Willapa Bay, and near Knappton, Washington. The exposure at Knappton, Washington, is sometimes mapped as a separate rock unit (Wells 1989).

Tisoa is a trace fossil that was previously unknown from the United States. The burrows are similar to those of arthropods and the Recent amphipod *Corophium* (Frey 1969). The specimens were collected from a locality near Megler, Washington, from rocks that are considered to be part of the Lincoln Creek Formation (Frey and Cowles 1969), though revisions to the stratigraphy may result in these rocks being possibly reassigned to the sandstone at Megler (informal designation) (Niem and Niem 1992). Similar fossils were also described from shales of the Astoria Formation, but the locality is not reported (Boggs, 1968).

Zullo (1982) described a new species of balanoid barnacle, *Arcoscalpellum knapptonensis* (Cirripedia: Thoracica), preserved in concretions collected from an exposure along the Columbia River near Knappton, Washington. The concretion-bearing tuffaceous siltstone is considered correlative to the Lincoln Creek Formation. Further, Zullo proposed that barnacles may be useful in stratigraphic correlations, as they are known to reach worldwide distribution fairly rapidly. This outcrop, less than 1.6 km (1 mile) north of Knappton along the Columbia River, contains other fossils as well and it has been divided into four informal units by Jim and Gail Goedert: 1) the lowermost portion contains barnacles preserved in concretions and the trace fossil burrow, *Tisoa*; 2) an overlying sedimentary package contains vertebrate fossils, decapods, small aturiid nautiloids, sponges, and *Tisoa*; 3) a horizon containing siliceous sponges; and 4) the uppermost unit contains fewer sponges, no *Tisoa*, abundant vertebrate and invertebrate material, and many large *Aturia angustata* (from Zullo 1982). A variety of other fossils have been recovered from nearby localities at Knappton. Squires (1989) defines a new species of gastropod, *Clio goederti*, present in exposures of both the Lincoln Creek and Astoria formations along the Columbia River near Knappton. Goedert et al. (2004) indicate a newly discovered skull of an aetiocetid whale, a significant fossil find collected from the Knappton area, could lead to the establishment of a new subfamily of Aetiocetidae. Goedert and Olson (2004) states that several concretions found weathering out

of the upper part of the Lincoln Creek Formation, near Knappton, contain the earliest record of albatross from the Pacific, and represent a small species of the seabird (Family: Diomedidae). Fierstine (2005) describes a new species of *Aglyptorhynchus billfish* (Perciformes: Scombroidei) from two localities at Knappton. Moore (1984) describes many species from the Knappton locality.

An outcrop near Naselle River Bridge exposes a possible methane seep assemblage preserved in the Lincoln Creek Formation. At this locality, exposures of Lincoln Creek Formation and the siltstone of Shoalwater Bay yield a diverse assemblage of mollusks (including the gastropods *Ficopsus*, *Exila*, *Polinices*, and *Siphonalia*), and concretions preserve crabs such as *Pulalius vulgaris* (previously called *Xanthopsis* or *Zanthopsis vulgaris*). (Nesbitt et al. 1994)

Goedert and Squires (1990) indicate that a methane seep community called the Menlo deposit is contained within the Lincoln Creek Formation on the bank of the Willapa River, near the Chehalis-Raymond Highway in Washington. The presence of *Modiolus* n. sp., *Calyptogena* n. sp., *Chonchocele folgeri*, and a naticid gastropod is noted (Goedert and Squires 1990).

Addicott (1966) described two new mollusk species from the upper Lincoln Creek Formation: *Haminoea articensis* and *Nucula salmonensis* were collected from Grays Harbor County, Washington. Other fossils (including several new species) have been reported from the Lincoln Creek Formation and correlative strata, including corals, mollusks, crabs, sharks, and toothed whales (Nesbitt and Goedert 2003; Goedert and Peckman 2005; Squires and Goedert 1991; Gonzalez-Barba and Goedert 2005; and Barnes and Goedert 2000).

Astoria Formation (Early-Middle Miocene)

The Astoria Formation consists of fossiliferous gray micaceous and carbonaceous fine-grained marine sandstones. In some areas, the upper portion of the Astoria Formation interfingers with the Columbia River Basalt Group because the basaltic lavas were erupting nearby at the same time as late-stage deposition was taking place at the delta fans. In general, rocks of the Astoria Formation represent deltaic deposition along the Pacific coast during the later Tertiary. A river such as the ancestral Columbia River washed sediment from the Coast Range, which was slowly and steadily uplifting during the mid-late Tertiary, and deposited the sediment near the mouth of the river on a westward-aggrading coastal submarine fan complex. Sediments of the Astoria Formation accumulated in several large coastal embayments. Although these embayments represent similar paleoenvironments, they were distinct depositional areas (sometimes called “facies”), which may account for some of the differences in fossils and fossil preservation throughout the Astoria Formation.

What follows is a brief description of how the name “Astoria” has been applied to various rocks in the area of southwestern Washington and northeastern Oregon. A brief description of names used to describe “informal members” of the Astoria Formation is provided here because some faunal studies refer to these informally named members.

Rocks described as “Astoria Formation” have undergone numerous revisions regarding age assignments and stratigraphic relations to other rocks since they were initially described in the latter half of the 1800s. Also, the “Astoria” beds have been lumped together and split apart several times, resulting in a variety of interpretations of the geologic context of the rocks and the significance of some of its contents. Thomas Condon initially used the name “Astoria” to describe the fossiliferous shale beds that were exposed near the town of Astoria, Oregon, though his notes were not published (Cope 1880; Etherington 1931). The “Astoria shales” comprise the lower and middle portions of the formally named Astoria Formation. The Astoria shales were described as bearing Miocene age invertebrate and vertebrate fossils, often preserved within concretions. The original type section of the Astoria Formation (that is, the locality upon which the Astoria beds were originally described, and to which all subsequent exposures of Astoria rocks are compared) was located along the south shore of the Columbia River at the town of Astoria, Oregon. The type section consisted of an outcropping of shales that overlies a sandstone bed that preserves the remains of the extinct nautiloid, *Aturia angustata*. At some point, confusion developed and the *Aturia*

beds were redefined as being Oligocene in age, but are once again considered Miocene. The Astoria Formation is now defined to include the original Astoria shale as well as overlying and underlying sandstone beds (including the aforementioned *Aturia* bed). Today, the type section of the Astoria Formation is completely inaccessible due to urban development, so only museum specimens can be used as reference. Betty Dodds' (1963) report explains the effect Astoria's urban development has had on the accessibility of important geologic sections. Now, a "best reference" section is used in place of the type section; it outcrops along a ridge in the Coast Range of Washington, between Chehalis River and North River. A good early explanation of the discrepancies involving early interpretations of the age and correlation of the Astoria Formation is given in Etherington (1931). Moore (1963) provides a summary of some post-1930s discrepancies, up until a mid-Miocene age for the Astoria Formation was generally agreed upon. Assemblages of foraminifera indicate that the Astoria Formation is lower to middle Miocene in age. Several new species of foraminifera have been described from the Astoria Formation (see, for example, Rau 1948).

Informal member names were established and refer to the different facies within the Astoria Formation. Informal member names include Angora peak, Silver Point, Newport, and Big Creek members (e.g. Cooper 1981). More recently, some of these names have been pre-empted in favor of other informal member names. For example, what was once known as Silver Point is now called the Cannon Beach member, and what was once Big Creek is now Wickiup Mountain member (Niem and Niem 1985).

The Cannon Beach member of the Astoria Formation is exposed throughout the Oregon Coast Range and in the area of Tillamook Head. Niem and Niem (1985) report that diatoms, foraminifera, mollusks, and carbonized leaf imprints are preserved in the Cannon Beach Member.

The Wickiup Mountain member is exposed in the Coast Range, particularly in the hills between Fort Clatsop and Sunset Beach. Niem and Niem (1985) report that the Wickiup Mountain member is fossiliferous and contains mollusks.

Southerly exposures of Astoria Formation, in the area of the Newport Embayment for example, seem to be more fossiliferous than Astoria Formation localities to the north near LEWI. This may be due to differences in the paleoenvironments of the two areas, differential factors affecting fossil preservation, the availability of outcrops in general, or the particular beds of the Astoria Formation that are exposed in the Newport area as compared to the Astoria area.

Ray (1976), presents a detailed history of studies and collections of western Oregon's marine vertebrate fossils, and indicates that Dana's 1849 report is probably the first account of marine vertebrate fossils in Oregon. J. D. Dana, geologist for the Wilkes Expedition, collected extensively in and around the town of Astoria. Dana (1849) indicates that a number of vertebrate remains were collected from localities along the south shore of the Columbia River, about 21 km (13 miles) above the mouth. Dana (1849) also reports finding concretions containing crustaceans and plant remains, as well as foraminifera, within the Astoria Formation.

Dall (1909) states that the Astoria shales and underlying *Aturia*-bearing sandstone bed outcrop along the banks of the lower Columbia River, in a 32 km (20 mile) stretch upstream from the mouth. Dall reports 63 fossil species collected and identified from Astoria. Of the 63 specimens, Dall remarks that 33 are unique to Astoria, 22 are also present in collections made at Coos Bay; 13 are common to correlative strata in Washington, and nine to California. Niem et al. (2003) note that the lower sandstone member of the Astoria Formation contains concretions and is fossiliferous with abundant mollusks, but that it is poorly exposed. It is unclear whether the rarity of exposures is due to the natural distribution of outcrops or due to outcrops destroyed by urban development.

As listed by Moore and Addicott (1987) some mollusks known from the Astoria Formation include Pelecypoda genera: *Acharax*, *Acila*, *Aequipecten*, *Anadara*, *Anomalocardia*, *Clinocardium*, *Chuchocele*, *Cyclocardia*, *Dosinia*, *Katherinella*, *Litorhadia*, *Lucinoma*, *Macoma* *Mytilus*, *Panopea*, *Patinopecten*, *Saccella*, *Securella*, *Solamen*, *Spisula*, *Tellina*, *Vertipectin*, *Yoldia*. Bivalvia genera include: *Acteon*, *Aforia*,

Ancistrolepis, *Antillophos*, *Bruclarkia*, *Cancellaria*, *Chlorostoma*, *Crepidula*, *Epitonium*, *Ficus modesta*, *Liracassis*, *Megasurcula*, *Molopohorus*, *Musachia*, “*Nassarius*,” *Neverita*, *Nucella*, *Mucella*, *Olivella*, *Opalia*, *Priscofusus*, *Semicassis*, *Spirotropis*, *Trophon*, *Trophosycon*, *Turritella*, and *Xenoturris*. Cephalopoda genera include: *Aturia angustata*.

Etherington (1931) lists 102 total marine invertebrate species known from the Astoria Formation, including pelecypods, gastropods, a scaphopod (*Dentailium conradi*), a cephalopod (*Aturia angustata*), a brachiopod (*Terebratulina obsoleta*) and an echinoderm (*Scutella blancoensis*). Etherington’s paper also includes approximately 150 photographs of various mollusk shells known from the Astoria Formation, collected from outcrops within the Chehalis River Valley in Grays Harbor County, Washington.

Studies conducted by Squires (1989) have expanded the geographic range of the Eocene-middle Miocene pteropod gastropod, *Praehyalocylis cretacea*, which was recovered from the Astoria Formation. This fossil had previously only been known from areas as far away as Asia Minor, Germany, Russia, Turkey and Australia. Noting the rarity of such fossils in these formations, Squires (1989) identified two new species of gastropods (*Clio berglundi* and *Clio goederti*) that are preserved as internal molds and concretions in the Astoria and Lincoln Creek formations, thus expanding the temporal and geographic range of the genus *Clio*. Fossil localities are depicted along the Washington side of the Columbia River, between Megler and Altoona, Washington. *Clio goederti* is known exclusively from the lower Astoria Formation (Squires 1989). An outcrop of lower Astoria Formation near Altoona, Washington, produced one specimen preserved in a concretion; that specimen has been designated as the holotype of *Clio berglundi* (Squires 1989).

Addicott (1966) identifies several new gastropod species (*Tegula ellenae*, *Trichotropis goweri*, *Natica vokesi*, and *Scaphander doliaris*) from various localities of the Astoria Formation, including Devils Punch Bowl, Oregon; near Montesano, Washington; Gull Rock, Oregon; and along Artic-Vesta Road, Washington, respectively. Allison and Addicott (1976) identified a new subgenus, *Plicatomytilus*, of the bivalve genus *Mytilus* based upon specimens collected from the upper portion of the Astoria Formation in Tillamook County, Oregon. A new species of the deep water isopod crustacean (Isopoda; *Palaega goedertorum*) was collected and identified from the Astoria Formation (upper portion?). The locality was approximately 13 km (8 miles) east of Dismal Nitch, near the town of Altoona, Washington (Wieder and Feldmann 1989). A new genus and species of decapod crustacean was first identified in the Astoria Formation, at a locality north of Yaquina Lighthouse. *Globihexapus paxillus* is preserved in concretions in the Astoria Formation (Schweitzer and Feldmann 2001). Amano and Hikida (1999) suggest that *Dosinia whitneyi*, as identified in Moore (1963), is better suited to the genus *Kahenaraia*, on the basis of shared morphological affinities with other specimens representing that genera and because Moore’s identification was based on a single shell fragment.

Landslides at Ecola State Park have exposed fossil-bearing portions of the Astoria Formation and Columbia River Basalts. Late early Miocene to early middle Miocene Foraminifera recovered from the site include *Siphogeneria branneri*. Another locality, north of Chapman Point, bears an assemblage of early Miocene foraminifera that is similar to that of the type-locality of the Astoria Formation. Schlicker et al. (1961) mention that “no significant megafossils were found,” which suggests that megafossils are present in the rocks but that those megafossils observed during field investigations were either unidentifiable or, more likely, were not of the type to further refine stratigraphic relations.

Packard (1941) states that marine mammals are present in all exposures of the lower beds of the Astoria Formation, throughout the 161 km (100 mile) stretch between Waldport and Astoria Oregon, and extending into Washington. Fossil material includes the remains of sea lions (including *Desmatophoca oregonensis*), whales (including *Cophocetus oregonensis*), skulls of a small porpoise, shark teeth, large fish vertebrae, as well as skull and carapace fragments representing a type of ancient leatherback turtle from the Dermochelyidae family (Packard 1941). The large estuarine, herbivorous mammal *Desmostylus hesperus* was identified from similar exposures of the upper Astoria Formation (Barnes 1989).

Fossil evidence of eared seals (Otariidae) collected from the Miocene Astoria Formation indicates that the older otariids were less specialized for swimming when compared to otariids from more recent deposits

(Downs 1954). A new genus and species (*Pteronarctos goedertae*) belonging to the extinct subfamily Enaliarctinae of otariids was described from the lower Astoria Formation near Newport, Oregon. In the initial report on *Pteronarctos goedertae*, Barnes (1989) describes this fossil find as an important link in the understanding of pinniped evolution because this single specimen represents the youngest occurrence of the oldest and most primitive member of Otariidae. This specimen is approximately 5 million years younger than any other known specimen of Enaliarctinae (Barnes 1989). See Barnes (1990, 1992) for descriptions of two other new pinnipeds from the upper portion of the Astoria Formation: *Pacificoteria hardomma*, and *Pteronarctos piersoni*.

Three skulls of a chalicothere similar to *Moropus* were collected from the Iron Mountain bed of the upper Astoria Formation, approximately 6.5 km (4 miles) north of Newport, Oregon, from beds which are estimated to be 15-17 million years old. The cranial specimens display an unusual dome-shape just above and behind the animal's eye that Munthe and Coombs (1979) interpret to have facilitated low-impact butting behavior. That paper also mentions that a rhinoceros tooth, identified as *Aphelops* by Mitchell and Repenning (1963), was recovered from the Astoria Formation.

The Astoria Formation has also yielded significant specimens of fossil plants (Miller 1992), crustaceans (Berglund and Goedert 1992; Nyborg 2002), pinnipeds (Demere and Berta 2001, Barnes 1987, Berta 1994; Demere 1999), whales (Packard 1935, 1941, 1947; Orr and Miller 1983; Dooley 1994), and other extinct aquatic mammals (Reinhart 1982) that have contributed to the scientific understanding of evolutionary processes and distribution of these fossil groups.

Columbia River Basalt Group (Miocene)

Basaltic lavas of the Columbia River Basalt Group intertongue with the upper part of the Astoria Formation, because the lavas were erupting from vents while the sediments of the Astoria Formation were being deposited. No fossils have been reported from the Columbia River basalts in the area of LEWI, and it is not common for fossils to be preserved in such environments. However, it is possible that some fossils are preserved, particularly in the sedimentary interbeds of the Columbia River Basalt Group.

Quaternary deposits (Pleistocene-Holocene-Recent)

Willapa Bay has been used as a key study area for numerous investigations of Pleistocene-Recent paleoenvironments and paleobiological processes. These studies benefit from the well-developed stratigraphic framework at Willapa Bay and the fact that the bay provides direct analogs between modern and Pleistocene environments. Examples of research conducted at Willapa Bay are listed here. Analyses of amino acids obtained from *Saxidomus giganteus* collected from Late Pleistocene shell beds along Willapa Bay aid in paleoenvironmental reconstructions (Kvenvolden et al. 1977). Studies conducted at Willapa Bay indicate that diatoms and foraminifera can be used to distinguish between intertidal, marsh, and upland forest paleoenvironments (Hemphill-Haley 1989). Trace fossils are used to distinguish between brackish water subenvironments (Gingras et al. 1997). Examinations of recent faunal distribution have also been conducted in Willapa Bay (i.e. Moreno 1997). Note that the environments and strata examined in these studies also occur in the coastal areas and embayments adjacent to Willapa Bay, including areas within LEWI. Willapa Bay currently lies beyond the administrative boundary of LEWI, though it is in close proximity to the park.

Park Collections

There are no paleontological specimens curated by LEWI. More than 30,000 archeological specimens are curated by LEWI, some of which may be of paleontological significance.

Cultural Resource Contexts

Paleontological resources are often identified within a cultural resource context; Kenworthy and Santucci (2006) present an overview of this topic and cite selected examples from throughout the NPS. Many of the archeological sites within LEWI have not yet been the subject of close examination. This is due, in

part, to the fact that the majority of the park area consists of very recent land acquisitions. The recently acquired Station Camp unit contains the remains of 36 plank houses comprising a Chinook Village. Shells and modified bone material were observed at the site (D. Wood, LEWI Cultural Resources Manager, pers. comm., July 17, 2009). Approximately 15,000 objects were collected during excavations at the site over a period of four years. The objects are currently undergoing analysis at FOVA, and will be cataloged during late summer and early fall of 2009. Another newly acquired unit, not far from the Lewis and Clark River in Oregon, contains evidence of a native hunting site. The site includes both stone tools and the debris from making tools; shells were also found at the site (D. Wood, pers. comm. August, 2009).

Shell middens, which are ubiquitous throughout coastal Pacific Northwest, have been tentatively identified within LEWI, but have not yet been investigated (D. Wood, pers. comm., July 17, 2009). Shell middens of San Juan Island National Historical Park and Olympic National Park (see SAJH and OLYM sections of this report) have been the subject of more detailed studies and may contain paleontological resources that are broadly similar to the shell middens of LEWI. Connolly (1995) examined two shell midden sites near the town of Seaside, Oregon. Bivalves obtained from the middens at Seaside indicate that a quieter water, bay-type environment prevailed there during the last 3,500 years. Bivalves examined in the study include *Macoma* sp., *Protothaca staminea*, *Saxidomus giganteus*, *Tresus capax*, *Mytilus* sp., and *Siliqua patula* (Connolly 1995).

Interestingly, while some evidence of human habitation, such as shell middens, accounts for an increased concentration of paleontological resources in certain areas, other human impact actually destroys paleontological resources. Early settlers are known to have collected carbonate concretions from exposures of the Astoria and Lincoln Creek formations which were then burned to extract lime which is used in building materials. Dall (1909) indicates that this practice contributed to the destruction of some fossiliferous outcrops.

Jengo (2003) observes that of the daily journaling by both Meriwether Lewis and William Clark, 45% of entries from 1803 to 1806 include notations regarding the geological features and processes that the explorers encountered during the expedition. In light of the number of geologic observations made by Lewis and Clark, and considering Thomas Jefferson's zest for paleontology, it seems reasonable that the explorers may have gathered information pertaining to fossils –or even fossil specimens, themselves- to send back to the president.

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service – Geologic Resources Division will sponsor a Geologic Resources Inventory (GRI) scoping meeting for LEWI during October, 2009.
- The park should consider future field inventories for paleontological resources to more fully document *in situ* occurrences of fossils. The park may consider a formal site documentation and condition assessment for significant fossil localities. Monitoring of significant sites should be undertaken at least once a year in the future. A forthcoming (2009) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring (Santucci et al. in press).
- Given the fossiliferous nature of many of the geologic units, park staff should be encouraged to observe the surface deposits and rock outcrops for fossil material while conducting their usual duties. Staff should photodocument any observations. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist.

- LEWI's archeological collections should be reviewed for items of paleontological value, including bone, shells, and wood fragments that may have been collected from shell middens, homesites, Corps of Discovery camps, or other sites with evidence of human occupation.
- Review field notes and journal entries by Captains Meriwether Lewis and William Clark for observations of in situ fossils, fossiliferous strata, or references to fossils that may have been collected and possibly delivered to Thomas Jefferson, American paleontologist (and third President of the United States).
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

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

Lewis and Clark National Historical Park Museum Collections.

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Originated by LEWI staff; status: Active.

Mount Rainier National Park

Mount Rainier National Park (MORA) encompasses the bold and distinctive peak of Mount Rainier (or “Tahoma”) and its surrounding area, which has been described as “superbly majestic,” and “an arctic island in a temperate zone” (Hubbard et al. 1894). The establishment of this national park also provided increased protection of the volcano’s forested flanks, which now play a critical role in the mitigation of debris flow hazards. MORA was established as the nation’s sixth national park on March 2, 1899, and most of the park was designated as a wilderness area on November 16, 1988. The administrative boundary was modified in 1926, 1931, 1960, 1988, and 2004. Today, MORA encompasses 95,328 ha (235,562 acres), 92,462 ha (228,480 acres) of which are designated as wilderness.

Geologic Background

Geographically, MORA is within the central portion of the Cascade Range of southwestern Washington. The Columbia Plateau lies to the east and the Puget Lowland is to the west. MORA is situated just south of the Olympic-Wallowa Lineament (a long, northwest-southeast trending structural feature of unknown origin and uncertain geologic context), which appears to divide the Cascade Range in two geologically distinct sections, with Paleozoic-Mesozoic crystalline rocks to the north and Cenozoic volcanic and sedimentary rocks to the south of the lineament (see the appendix for a geologic time scale). Mount Rainier is also an episodically active volcano that is situated 80 km (50 miles) southeast of Seattle, Washington; it is south of Glacier Peak and north of Mount Saint Helens and Mount Baker. At 4,392 m (14,411 ft) above sea level, Mount Rainier is the highest point in the Cascade Range.

Mount Rainier has formed in a manner similar to other volcanoes of the Cascade Range. Approximately 50-100 km (about 30-60 miles) beneath Mount Rainier, high temperatures and pressures inside the Earth drive water out of the oceanic rocks of the Juan de Fuca Plate which has been subducting beneath the northwestern continental margin since the early Cenozoic. The water lowers the melting point of the overlying rock, thus supplying magma for Cascade volcanoes, from British Columbia’s Meager Mountain to California’s Lassen Peak. Volcanic and tectonic forces have been shaping the Cascades area for more than 50 million years by repeatedly intruding magmas, erupting lavas, and uplifting, downwarping, faulting, and eroding older rocks.

Mount Rainier is a stratovolcano, about 500,000 years old, perched on the lava flows and crystalline cores of its predecessors. The edifice of Mount Rainier comprises late Pleistocene and Holocene lava flows and interbeds of volcanoclastic rocks. Lava flows predominate and alternate with subordinate pyroclastic-flow deposits and tephra (airborne material ejected during eruptions), resulting in the steep composite cone, or stratovolcano, seen today. Its steep flanks produce enormous debris avalanches capable of overwhelming river valleys and flooding low-lying areas as far away as the large urban centers of the Puget Sound lowland, home to 1.5 million people. Pringle (2008) provides a detailed geologic history of the area, and summarizes the latest understanding of Mount Rainier’s features and processes. The National Park Service Geologic Resources Division published a map and report (Graham 2005) focusing on the geologic features and processes of MORA via the Geologic Resources Inventory (GRI). The GRI products were based primarily on the U. S. Geological Survey (USGS) publications by Fiske et al. (1963, 1964) and Crandell (1969).

Geologic mapping during the 1950s and 1960s provided the basic stratigraphic framework of Mount Rainier National Park and vicinity. Schasse (1987) produced a more detailed map as part of a state-sponsored geologic mapping project. The work of Fiske et al. (1963, 1964) standardized stratigraphic nomenclature for the area, but only in a broad sense. More modern techniques, such as geochemical fingerprinting and radiometric dating (including the work of Swanson et al. 1989, 1997; and Tabor et al. 1984), have allowed for better correlations of strata with sources and dramatically improved the age control of eruptive events. Geochemical investigations are ongoing (e.g. the work of Tom Sisson and Jim

Vallance, USGS) and the coming years will likely bring a more refined stratigraphy, and with it, a better sense of the chronology and processes that influence the area.

Recent investigations by Sisson and Vallance (2008) have revealed that Mount Rainier produced many more Holocene eruptions than previously thought. The study is based on geochemical fingerprinting and paleomagnetic information obtained from volcanic and pyroclastic deposits. Whereas previous work (Mullineaux 1974) documented only ten eruptions in the past 10,000 years and only one in the past 2,600 years, the new stratigraphic and geochemical study has allowed geologists to discern more than ten separate eruptions during the last 2,600 years. Sisson and Vallance's (2008) study indicates that nearly all of Mount Rainier's large lahars occur during magmatic eruptions. It also shows that small and moderate eruptions are as likely as large ones to cause large lahars. Small to modest sized debris flows which are an almost yearly occurrence at Mount Rainier are caused by hydrologic and meteorologic events rather than eruptions (Vallance et al. 2002). Debris avalanches, mudflows and lahars are a significant factor in landscape evolution on Mount Rainier that are capable of filling valleys, smothering lowlands, blanketing forests, and also carving new valleys. See "Sources of Paleontological Resources: Mass wasting deposits" for more information.

Volcanoes are not typically regarded for their fossils or their potential for fossil preservation; nonetheless, important fossils can be preserved in volcanic terrain like that of Mount Rainier. Lahars and ashfall have preserved forests on the flanks of Mount Hood, revealing information about that volcano's tumultuous history. Explosive volcanic eruptions are capable of encapsulating nearby areas with thick "pyroclastic" (volcanic ejecta produced by explosive eruptions) deposits, as in the case of the AD 79 eruption of Italy's Mount Vesuvius which entombed the nearby towns of Pompeii and Herculaneum. Basaltic lavas ooze through forests, preserving molds of tree trunks in Hawaii, Idaho, and New Mexico. Cascadian volcanogenic sedimentary rocks (derived from slightly older volcanic rocks) can be deposited great distances away from the eruptive vent ("distal deposits"), such as the well-studied rocks at John Day Fossil Beds National Monument, Oregon, which preserve a detailed record of life throughout the Eocene, Oligocene, and Miocene. Fossil trees and woody material preserved in lahar, tephra (ash fall) and wood in mudflow deposits are the most common fossils preserved in Mount Rainier National Park. Fossils are also preserved in deposits of Quaternary age, older lahars, and volcanoclastic deposits.

Sources of Paleontological Resources

Fossils have been documented from the following geologic formations as well as the museum collections within MORA. These fossils present opportunities for resource management (including field surveys, inventory, and monitoring), education, interpretation, and continued or future scientific research in the park.

Ohanapecosh Formation (late Eocene-Oligocene)

The Ohanapecosh Formation is interpreted to represent the onset of Cascadian Arc volcanism. The lower portion interfingers with sedimentary rocks which may correlate to the Puget Group; the contact is considered conformable. In outcrop within MORA, the Ohanapecosh has been measured as much as 3,000 m (10,000 ft) thick. Because the top and bottom of the strata have not been identified in the field within MORA, it is inferred that the original deposit was even thicker than it appears today. Due to an interval of folding, faulting, and erosion that occurred after the deposition of the Ohanapecosh Formation, the unit's upper contact with the overlying Stevens Ridge Formation does not always represent a continuous time sequence. Confusingly, the Ohanapecosh Formation (or portions of it) is also referred to as the "Park Boundary series" or the "Keechelus series", especially by early mappers. Waters (1961) attempted to resolve the "Keechelus problem" once and for all. As described by Fiske et al. (1963), the Ohanapecosh Formation consists of a very thick accumulation primarily of andesitic lava flows and mudflows, with minor constituents of volcanoclastic sediments and rhyolitic ashfall deposits. Lava flows, normally 3 m to 30 m (10 to 100 ft) thick, are brecciated at the top. Thick packages of unsorted and unstratified mudflows are interbedded between the lavaflows. Stratified volcanoclastic sediments are also interbedded within the Ohanapecosh, alternating with tuff-breccias (particularly in the vicinity of Stevens

Canyon and Ohanapecosh River). Some volcanoclastic strata exhibit sedimentary structures such as crossbedding, laminations, load casts, and minor ripple marks, in addition to somewhat rounded and sorted grains. Wood is preserved in volcanoclastic beds throughout the succession as are plant fossils immediately adjacent to park boundaries.

Fiske et al. (1963) explicitly state that reconnaissance field studies of the Ohanapecosh Formation within MORA yielded “no identifiable fossils.” However, plant fossils were collected from volcanoclastic rocks of the Ohanapecosh Formation at a locality just 600 m (2,000 ft) west of the park boundary on the north side of the North Puyallup River. Plant remains identified by Roland Brown include: the palm *Sabal* sp., *Carya* sp., the chestnut *Castanea* sp., *Chaetoptelea* sp., *Cercidiphyllum* sp., the hydrangea *Hydrangea* sp., the sycamore *Platanus* sp., *Cinnamomum* sp., the laurel *Laurus* sp., *Sassafras* sp., the sweetgum *Liquidambar* sp.; the assemblage is late Eocene in age. According to the mappers the fossil-bearing rocks may outcrop within MORA near Round Pass and in the saddle just north of Tumtum Peak, on the basis of field relationships of the strata. Further investigations in this area may yield fossil material within the park.

In a subsequent publication, Fiske (1963) concludes that many of the Ohanapecosh beds either erupted or were deposited in a subaqueous setting. “Thin beds” of the Ohanapecosh Formation, especially in the eastern portion of MORA, are interpreted by Fiske (1963) to represent water-laid pyroclastic deposits; they are well bedded and dominantly tuffaceous. Fiske reports that “shreds of plant matter and larger pieces of wood” are common in the upper beds; specifically in a turbidity deposit along a roadcut near Cayuse Pass and in the basal portion of a pyroclastic-flow deposit on Backbone Ridge (both within MORA). Additionally, Fiske observes that thin sections of rocks from the east side of Backbone Ridge may possibly contain very poorly preserved remains of aquatic organisms including ostracods, gastropods, and foraminifera. Meanwhile, other geologists (e.g. Vance et al. 1987) are skeptical of Fiske’s interpretation of aqueous components within the Ohanapecosh Formation, citing the lack of pillow lavas and the discovery of nonmarine vertebrate fossils as evidence for terrestrial deposition of the unit. The variable topography of the area when these beds were deposited is not in dispute. It seems reasonable that some portions of the Ohanapecosh Formation could have been deposited in aqueous settings while others may have been deposited in terrestrial settings. Hence, it is conceivable that the Ohanapecosh Formation could locally preserve the remains of both terrestrial and aquatic organisms.

According to Fiske et al. (1963), Ellingson refers to a fossil collection taken by J. A. Wolfe from a tongue of coal-bearing arkose in the Ohanapecosh Formation on Summit Creek. Wolfe considered the assemblage to be early Eocene in age, but Roland Brown considered the assemblage to be middle Eocene or younger; the manuscript does not provide a floral list. Later in the manuscript, Fiske et al. describe the overlying 900 m (3,000 ft) of Ohanapecosh—the most prevalent on this portion of the park—as unfossiliferous.

Fisher (1957) describes additional fossil localities from volcanoclastic rocks to the south and southwest of MORA. Fisher refers to the volcanoclastic deposits as “lower”, “middle” and “upper” and occasionally refers to them as Keechel series. Today they would probably be considered part of the Ohanapecosh Formation. “Lower” and “middle” parts of the volcanic series are of heterogeneous lithologies and contain more sedimentary interbeds than the “upper part.”

Fisher (1957) reports that the “lower part” of the volcanic series commonly contains carbonized wood fragments and leaf imprints along bedding planes. Roland Brown collected plant fossils from USGS localities on Osborne Mountain and at Catt Creek (3 km, or 2 mi, southwest of MORA). According to Fisher (1957), Brown indicates that the assemblage is late Eocene in age. Brown collected the fern *Lastrea fischeri* Heer, *Metasequoia occidentalis* (Newberry) Chaney, *Carya* sp., the willow *Salix* sp., the fern *Comptonia* sp., the birch *Betula* sp., the alder *Alnus* sp., the mountainbay *Calyptrotheca* sp., and the laurel *Persea* sp.

Plant fossils collected by both Fisher and Brown from a locality along Skate Creek indicate an Eocene age for the “middle part” (Fisher 1957). Fossils include the fern *Adiantum anastomosum* Brown, the beech *Castanea castaneaefolia* (Unger) Knowlton, *Cercidiphyllum elongatum* Brown, *Dillinites* sp., *Glyptostrobus dakotensis* Brown, *Laurus* sp., *Metasequoia occidentalis* (Newberry) Chaney, the sycamore *Platanus* sp.,

and *Sequoia affinis* Lesquereux. Fisher notes that these are similar to a late Eocene assemblage at Steel's Crossing, near Renton, Washington (about 70 km, or 45 mi, northwest of MORA). A well preserved pinecone (*Picea*) was recovered from a "Keechelus series" lahar deposit (Ohanapecosh Formation) near the confluence of Skate and Johnson creeks (1.6 km, or 1 mi, south of MORA).

An unconformable layer of tuff at the base of the "upper part" of the "Keechelus series" at Catt Creek (6.5 km or 4 mi west of MORA) yields fossil leaves suggestive of an Oligocene age (Fisher 1957). Plant fossils collected by Roland Brown from a tuffaceous breccia at the USGS Creaking Tree locality includes *Metasequoia occidentalis* (Newberry) Chaney, *Cercidiphyllum* sp., *Betula* sp., *Persea* sp., *Ulmus* sp., and a fragment of a maple seed *Acer glabroides* Brown.

Ted Fremd (NPS Guest Scientist) examined a site near the town of Mineral, Washington (approximately 24 km, or 15 mi, west of MORA) that was being reviewed for possible inclusion in the National Natural Landmark (NNL) program. Fremd drafted an internal report, submitted to Steve Gibbons (NNL Coordinator), in which he described the site as being of local interest but not of global significance. The site is described as a fossil forest entombed by a Tertiary lahar, preserving gymnosperm and sycamore fossils whose condition of preservation is fair. Fremd speculated that the plant fossils are of middle Eocene age, and that a proximal portion (a portion nearer to the source) of this lahar deposit is likely to occur within MORA's administrative boundary. Fremd notes that a nearby site, located on private land approximately 16 km (10 mi) from MORA, bears a spectacularly preserved sycamore stump. (T. Fremd, NPS Guest Scientist, pers. comm., April 29, 2009.)

The first vertebrate fossil discovered from the Ohanapecosh Formation, the lower jaw of a juvenile oreodont identified as *Eporeodon*, was found along a tributary of Wildcat Creek. It was identified by R. A. Stirton of the University of California, and first published by Grant (1941). *Eporeodon* is a large, cow-sized browsing animal thought to be related to camels. Other oreodont remains are known from similarly aged strata of Badlands National Park, South Dakota, Agate Fossil Beds National Monument, Nebraska, and John Day Fossil Beds National Monument, Oregon.

Near Rimrock Lake, approximately 24 km (15 mi) southwest of MORA, volcanoclastic sediments correlative to the Ohanapecosh Formation preserve an abundance of vertebrate fossil remains (Swanson 1978). The fossiliferous strata represent a distal portion of the Ohanapecosh Formation, dominated by well-bedded tuffaceous volcanoclastic layers; interbedded lava flows are absent (Swanson 1978; Vance et al. 1987). As listed by Lander and Swanson (1989), a lower tuffaceous stratum ("tuff of Milk Creek"), fission-track dated between 33.7 and 32.2 million years ago (Ma), yields a primitive rhinocerotid of the older Kloodman Rock Local Fauna, and is considered to be of an early Oligocene age. Upper tuffaceous beds of the section at Wildcat Creek have been fission-track dated between 32.2 and 24.6 Ma and may be correlative to the John Day Formation (Turtle Cove or Kimberly members). Wildcat Creek Local Fauna include the rodents, *Leidymys nematodon* (Cope), the bear dog *Daphoenus ruber* Stock, the canid *Tomarctus*, n. sp., the three-toed horse *Miohippus annectens* Marsh, the "crescent horn" rhinocerotid *Menoceras annectens* Marsh, the peccary *Cynorca?* sp. undet., the oreodonts *Eporeodon?* *major* Leidy, *Merycochoerus superbis* Leidy, *Merycoides parigonus* Cope, and the mouse deer *Allomeryx planiceps* Sinclair (recombined as *Nanotragulus princeps* by Webb, 1998 in Paleobiology database 2009) (Lander and Swanson 1989; Lander 2002). (Please note that tentative taxonomic identifications are, by convention, indicated with a "?".)

More recently, these rocks have been investigated during the course of C. Strganac's graduate research (Southern Methodist University; advised by Louis Jacobs). Strganac describes Washington's earliest record of nonmarine vertebrates including: A fragment of a perissodactyl tooth that was recovered from the tuff of Milk Creek, and fragments of *Daphoenus*, a cricetid rodent, *Miohippus equinanus*, *Eporeodon major*, a mouse deer *Hypertragulus*, a predaceous canid *Cormocyon copei*, a rhinocerotid *Diceratherium annectens*, an oreodont *Promerycochoerus superbis*, and a peccary comparable to *Thinohyus*, preserved in the overlying Wildcat Creek beds (Strganac 2007). A manuscript of Strganac's work is in preparation. Although the localities examined in this study lay more than 32 km (20 miles) beyond the boundary of

MORA, correlative strata of the Ohanapecosh Formation within MORA might preserve similarly significant fossils, especially teeth which are more easily preserved (C. Strganac, pers. comm., July 30, 2009). Fossils are more likely to be preserved in the sedimentary interbeds of the Ohanapecosh Formation.

Stevens Ridge Formation (Oligocene - Miocene)

The Stevens Ridge Formation unconformably overlies, and is lighter in color than, the Ohanapecosh Formation. The angular unconformity between the two units varies throughout MORA, from almost 0° to nearly 90°. The Stevens Ridge Formation is comprised dominantly of altered and devitrified (glassy material converted into crystalline material) quartz-bearing ash flows that range from 5 to 110 m (15 to 350 ft) in thickness. Highly altered volcanoclastic beds occur throughout, but are mostly concentrated at the top of the unit. The beds can be ribbon-thin or up to 9 m (30 ft) thick. An abundance of crystals and pumice within the volcanoclastic constituents indicate an explosive volcanic origin for the sediments. Beds showing sedimentary structures such as cross-stratification and cut-and-fill indicate that they were reworked by flowing water; other parallel beds where such structures are absent may represent ashfall deposits (Fiske et al. 1963).

A contact between the Ohanapecosh and Stevens Ridge Formations can be seen within MORA along Backbone Ridge, forever preserving a violent moment in the geologic history of Mount Rainier. Here, the exposed Ohanapecosh rocks produced a varied topography, including canyons, hills, and a flat plain upon which a forest grew. A massive ashflow (of the basal Stevens Ridge Formation) ripped through the former canyon and spilled out over the broad plain, completely engulfing the forest with more than 90 m (300 ft) of ash. The violent torrent of hot ash obliterated the smaller vegetation, and left the trees' larger limbs and trunks completely charred.

Fiske et al. (1963) reports that conifer needles were collected from several localities of the Stevens Ridge Formation throughout MORA. However, because the fossil needles were decidedly not age-diagnostic, neither the fossils nor the localities are described in further detail. Fiske et al. (1963) tentatively correlate the Stevens Ridge Formation with fossiliferous strata outside of MORA.

A freshwater gastropod (*Viviparus*) was collected from another locality outside of MORA (a quarry north of Packwood, Washington; about 13 km, or 8 mi, south of MORA) and was assigned a probable late Oligocene or Miocene age; Fiske et al. (1963) tentatively correlate the strata to the Stevens Ridge Formation.

Modern pollen and lacustrine deposits (Holocene)

Pollen studies provide information about regional climates and do not appear to be representative enough for detailed forest reconstructions, according to Heusser (1973) on the basis of extensive analyses of MORA's modern pollen profiles. This is an important consideration when establishing pollen-based paleoenvironmental reconstructions. Furthermore, pollen does not always allow for species-level identification. Plant macrofossil investigations can add significantly to data obtained from studies of fossil pollen. The macrofossils reveal a history of forest composition for a specific area. The work of Dunwiddie (1983, 1985, 1986, 1987) reveals that aspects of ancient forests can be reconstructed with the analysis of even partial plant leaves. Dunwiddie's work details a 6,000 year record of forest succession established upon deposits of the Paradise Lahar, and is based on macrofossils sieved from sediment cores taken from three lakes: Jay Bath, Log Wallow, and Reflection Pond 1, on the south side of Mount Rainier, just off the park road, within MORA. Temporally, the reconstruction is well resolved because the sediment records contain many pyroclastic deposits which preserve organic matter suitable for radiocarbon dating, originally performed by Mullineaux (1974). A similar forest composition study focused on several lakes near MORA (Sunrise, Tipsoo, Shadow, and Clover lakes, in addition to the Jay Bath locality examined by Dunwiddie, 1985), which covers a wider geographic range (Marotta et al. 1982). Dunwiddie (1987) also examined recent plant macrofossil assemblages collected from 30 lake bottoms throughout MORA, ultimately providing evidence suggesting that plant macrofossil studies may be more useful than pollen studies in reconstructing montane paleoenvironments.

Mass wasting deposits (Holocene)

Holocene-recent mass wasting deposits dominate MORA's surficial geology (e.g. Crandell 1963a, 1963b, 1963c, 1969). Mass wasting deposits include rockfall avalanches, debris avalanches, debris flows and lahars. Origins of such deposits include landslides, the eruption of hot rock on ice and snow, and meteorological and hydrological events. Mass wasting events can be triggered by any number of environmental factors and forces, including volcanic eruptions, earthquakes, movement of magma within the magma chamber, and steam explosions (when hot rock or magma comes into contact with water, typically pore water). Ash and unconsolidated material can be remobilized by outburst flooding of glacial lakes or heavy rainfall. All mass wasting processes are capable of burying organisms; therefore, all mass wasting features and deposits are capable of preserving or containing paleontological resources. The catastrophic nature of mass wasting events means that each deposit is a time capsule, with each deposit recording a "geologic instant." Many of the mass wasting deposits within the park contain Holocene (last few thousand years) fossils. Though they may not fit into the layperson's conventional definition of a "fossil", trees and other organic material encapsulated in these deposits are of paleontological value. For example, age dates obtained from charcoal and wood fragments collected from volcanic and glacial deposits have helped to constrain the timing of glacial and eruptive events at other Cascade volcanoes. In light of their scientific value, these remains are considered paleontological resources, as described by Santucci (2002), and are referred to as "fossils" in this report.

Individual mass wasting deposits exhibit a wide variety of lithologies and textures. The heterogeneous nature of mass wasting deposits complicates detailed mapping efforts, so only a few deposits have been the subject of detailed studies. Geochemical and paleontological investigations help to refine the mapping of Mount Rainier's mass wasting deposits and help to establish a chronology of its event-filled past. Most importantly, fossils analyzed during these studies serve to advance our understanding of Mount Rainier's hazardous potential.

According to Vallance and Scott (1997), about 5,600 years ago, volcanism near the summit of Mount Rainier destabilized the upper northeast slopes and summit of Mount Rainier. The volcanic edifice contained large volumes of weakened, clay-rich hydrothermally-altered rocks that harbored a large proportion of pore water. Once this unstable assortment of debris, pore water, and glacier ice became unstable and moved downslope, it quickly developed into a voluminous clay-rich mudflow called a lahar. This lahar, formally named the "Osceola Mudflow," originated on the northeastern flank of the volcano, inundated the White River valleys to depths of 80-150m (260-490 ft), spread across more than 200 km² (77 mi²) of Puget lowland and emptied into Puget Sound. The Osceola Mudflow deposited almost 4 km³ (1 mi³) of unconsolidated volcanogenic debris as much as 20 m (65 ft) thick along a path 120 km (75 miles) long, blanketing bedrock, glacial drift, and older, lahar deposits. Osceola Mudflow is the most voluminous lahar produced by Mount Rainier since the Pleistocene ice ages. It is one of the largest lahars in the world (McKee 1968). Russell Cliff, Liberty Cap, Point Success, and Disappointment Cleaver define the huge depression formed after the massive collapse (Vallance and Scott 1997).

Osceola Mudflow deposits consist of three distinct facies: axial facies (graded), valley-side facies (ungraded), and hummocky facies (generally ungraded, contains huge, house-size blocks)—the latter facies was originally defined as a separate lahar (Greenwater Lahar) by Crandell (1971). Axial facies deposits, laid down in valleys and on terraces, are 2 to 20 m (7 to 65 ft) thick and graded. Wood is common in basal parts of axial deposits greater than 3 m (10 ft) thick. The pink-hued bases of the deposit contain wood fragments and the yellow-hued tops contain wood casts. Vallance (1999) speculates that dissolution of wood in the upper portion of mudflows may be related to bacterial action (also mentioned in Vallance and Scott, 1997). Radiocarbon dates are known from wood, bark, charcoal, and peat from 12 localities (outside MORA) associated with Osceola Mudflow. More complete locality descriptions are given in Scott et al. (1995), Crandell (1963a), Mullineaux (1974), Dragovich et al. (1994), Luzier (1969), and (Vallance and Scott 1997).

While the Osceola Mudflow is the one of the largest and most widespread lahar deposits in the park, many other similar deposits have originated at Mount Rainier in the past 10,000 years. The 500-year-old

Electron and 2600-year-old Round Pass lahars, for example, both produced widespread wood-bearing deposits that descended the western flank of the volcano. Another lahar on the south flank of the volcano, Paradise lahar, is similar in age to the Osceola Mudflow and also contains wood fragments.

Pat Pringle, a researcher formerly associated with both Washington State Department of Natural Resources and USGS, now a professor of geology at Centralia College, has been examining buried and submerged forests of Mount Rainier and other Cascadian volcanoes since the mid-1980s. Pringle has authored and coauthored numerous manuscripts, abstracts, and presentations on buried and submerged forests in the region (e.g.: Cameron and Pringle 1986, Cameron and Pringle 1991, Pringle 2000, Pringle 2001, Pringle 2003, Pringle 2005, Pringle et al. 1997, Pringle et al. 1998, Scott et al. 1995). To date, his most detailed manuscripts pertain to the fossil forests of Mount Hood, in Oregon. For more than 20 years, Pringle has collected data obtained from remains of buried forests within MORA and nearby, which he is assembling into a manuscript. Some of this work appears in his roadside guide (see Pringle 2008).

Many of Pringle's papers pertain to forests buried by Holocene lahars and describe localities along White River near Buck Creek, Puyallup River, West Fork White River, Carbon River, Mowich River (near Rushingwater Creek), Kautz Creek, Nisqually River, Stevens Creek, and Muddy Fork Cowlitz River (Pringle 2005). More than 60 post-glacial lahars originating from Mount Rainier have been identified. In addition to the lahars described above, this includes Round Pass Mudflow (2,600 ybp) as well as the 1947 debris flow along Kautz Creek which was caused by torrential rain and the melting of Kautz Glacier (Pringle and Scott 2001). Vallance and Pringle obtained a radiocarbon date of about AD 1500 from five samples obtained from a tree in Orting that had been buried by the Election Mudflow. That tree is shown in Fig. J-5 of Pringle (2008). Further, Pringle has provisionally estimated an age using dendrochronology that brackets the emplacement of the mudflow to between the end of the growing season in AD 1502 and the end of the growing season in AD 1503 (P. Pringle, pers. comm., 2009).

Additionally, Pringle et al. (1998) radiocarbon dated fossil wood associated with ancient landslide deposits throughout the Cascade Range. The trees were either buried by debris, or drowned due to lake formation resulting from landslide dams. Reported ages for the eight landslide deposits range from about 80 ybp to 1,090 ybp, and each slide is thought to have been caused by seismic events. While MORA was not the focus of this particular investigation, MORA does contain similar ancient landslide deposits.

The landscape around Mount Rainier is dynamic and is continually shaped by mass wasting. This means that new "time capsules" are being revealed, covered, or destroyed annually, if not seasonally. For example, trees buried by debris from one mass wasting event may be exhumed by another, only to be swept away completely by a subsequent event, as in the case of the tree depicted on page 156 of Pringle (2008) (the tree was situated within MORA, along Westside Road). Similar cases are known from the confluence of North Puyallup and South Puyallup rivers, and South Puyallup River near Wonderland Trail (within MORA).

Investigations of Mount Rainier's past mudflows and lahars shed light on potential hazards of this and other volcanoes. Lahar deposits located within MORA are directly linked to sites outside of MORA, and are of equal significance for the purposes of reconstructing Mount Rainier's volatile history. It is important to understand that resolving the chronology of Mount Rainier is a work in progress, and that not all of its history is known. Because of this, each exposed tree may reveal a previously unknown catastrophic event (P. Pringle, Centralia College, pers. comm., May 12, 2009).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within MORA. However, future field investigations within the park may yield fossils from one or more (or none) of the following geologic units. Fossils are documented from these units outside of the park, in some cases in very close proximity to the park.

Rocks apparently correlating to the Puget Group (Eocene)

Prior to the initial phases of Cascadian volcanism, sediments were transported by vast, westward flowing rivers that emptied into marine basins along the ancestral coast of western North America. The area around MORA was a coastal plain, dominated by swamps and marshland. These sediments, preserved as rocks of the Puget Group or Puget Series, are exposed throughout the Puget Lowland. Farther east, towards MORA, rocks that appear to correlate to the uppermost Puget Group intertongue with volcanic rocks of the lower Ohanapecosh Formation, signal the onset of Cascadian arc volcanism near the ancient coast. Locally, these rocks bear a variety of names because the correlation with the Puget Group is somewhat tenuous. Most correlations are based on references to fossil leaf assemblages originally identified by USGS paleobotanists Jack A. Wolfe and Roland W. Brown, discovered within the rocks of Alaska, Puget Lowland, and other localities throughout the Western U.S. (e.g. Brown 1935, 1937, 1956; Wolfe 1960, 1961, 1968, 1972; Wolfe et al. 1961; Wolfe and Wehr 1991). Two well-described plant fossil-bearing localities located near MORA are Copper Creek and Summit Creek. Copper Creek is located approximately 3 km (2 mi) west of MORA, just north of the town of Ashford, Washington. Summit Creek is located approximately 1.6 km (1 mi) southeast of MORA. Both localities exhibit sedimentary strata, similar to the upper Puget Group, and overlain by an unbroken succession of volcanogenic rocks of the Ohanapecosh Formation.

Uppermost Puget Group, west of MORA (Eocene)

Fisher (1961) mapped the geology just outside the southwest corner of MORA, near the town of Ashford, Washington. The geology of the area consists of thick packages of sedimentary rocks intertonguing with even thicker successions of volcanic and volcanoclastic rocks. Fisher identified fossils in both the sedimentary and the volcanoclastic strata; all localities appear to be within 8 km (5 mi) of MORA's southwest boundary. Although Fisher refrains from naming the rock units, they most likely correlate to rocks of the Puget Group and the overlying Ohanapecosh Formation.

Fisher's (1961) oldest map unit, "unit 1," is an interbedded sandstone and shale, which has thin coal seams. The shale fractions contain fossil leaves and a poorly preserved pelecypod. Fisher does not give specific locality information in the report, but unit 1 is mapped in the area north of the town of Ashford. Leaf fossils were also discovered at localities in the Copper Creek drainage (University of Washington Locality WA 231). The area is mapped as Unit 5, which Fisher describes as being lithologically similar to units 1 and 3 (units 1, 3, and 5 correspond to eastward thinning tongues of the upper Puget Group). The fossil assemblage was identified by Roland W. Brown of the USGS as "Eocene, perhaps late," and may represent a moist, lowland environment. Plant fossils from unit 5 include the hickory *Carya magnifica* (Knowlton) La Motte, the Magnoliopsid *Cercidiphyllum arcticum* (Heer) Brown, the cypress *Glyptostrobus dakotensis* Brown, the elm *Ulmus* sp.; the extinct redwood *Metasequoia occidentalis* (Newberry) Chaney, and *Cercidiphyllum* sp.. The latter two were collected by Brown from the same locality. In modern times, the genera *Cercidiphyllum* and *Glyptostrobus* are not recognized outside of Asia; only one extant species of *Metasequoia* is known.

From a USGS locality at the town of Mineral, Washington (approximately 24 km, or 15 mi, west of MORA), Brown collected the chain fern *Woodwardia* sp., the horsetail *Equisetum* sp., the pine *Pinus* sp., *Cercidiphyllum elongatum* Brown, the laurel *Cinnamomum dilleri* Brown, the alder *Alnus* sp., the mountainbay *Calyptrotheca* sp., *Laurophyllum* sp. and *Platanophyllum* sp., indicating a middle or late Eocene age on the basis of shared affinities with Oregon's Comstock flora and Washington's Renton and McIntosh floras. Fisher (1957) collected *Sparaganium antiquum* (Newberry) Berry, *Platanophyllum whitneyi* from the same locality, and *Equisetum* sp. and *Laurus* sp. from a nearby locality, indicating a moist depositional environment similar to the Copper Creek locality.

Summit Creek sandstone, southeast of MORA (Eocene)

Ellingson (1959) produced some of the first detailed maps in the area of Mount Rainier. While the naming and stratigraphy has been revised by numerous authors (and many of the strata have yet to be formally named even today), his reports of plant fossils within sandstones in the Summit Creek area produced some of the first relative age estimates for the area. The section at Summit Creek is described as basal

andesites, overlain by massive arkosic sandstone and more finely grained carbonaceous rocks with coal seams (now informally known as the Summit Creek sandstone), conformably overlain by water laid volcanics and volcanoclastics (now known as the Ohanapecosh Formation). According to Ellingson's stratigraphic columns, the lower portion of the Summit Creek section contains "good fossil leaves" occurring in 1-1.2 m (3-4 ft) thick argillaceous coal beds or carbon-rich fine grained strata, which appear to be concentrated within the more finely-textured horizons. Ellingson collected Tertiary leaves from the sandstone of Summit Creek (approximately 1.6 km, or 1 mi, southeast of MORA's boundary), which Standish Mallory (University of Washington) identified as ?*Alnus* sp., *Equisetum* sp., *Laurus* sp., and the legume ?*Sophora* sp. Ellingson also reports that Mallory compared these to Eocene-Oligocene leaves collected from the area of Renton, Washington. Though it is unclear which rock outcrops Ellingson is specifically referring to, he reports that Jack Wolfe collected leaves from the "basal part of the sandstone" (presumably from a Summit Creek locality, but not explicitly stated, therefore he may be referencing sections near Renton, Washington. This is reported by way of oral communication and was apparently not published by Wolfe). Wolfe identified the assemblage, consisting of conifer fossils *Metasequoia occidentalis* (Newberry) Chaney, and the dicots *Arctocarya clenensis* Wolfe, *Carya clarnensis* (Knowlton) Wolfe, the elm *Chaetoptelea pseudofulva* (Lesquereux) MacGinitie, *Cercidiphyllum elongatum* Brown, the laurel *Persea pseudocarolinensis* Lesquereux, the legume *Dalbergia* sp., n.sp., *Mallotus riparius* MacGinitie, as "very clearly middle or early Eocene" and compares the findings to assemblages found in the nearby Roslyn Formation and the Clarno Flora (preserved within John Day Fossil Beds National Monument [JODA]). On the basis of plant assemblages, Ellingson's Summit Creek sandstone is correlated to the Puget Group.

Fifes Peak Formation (Oligocene - Miocene)

The Fifes Peak Formation consists of mostly andesitic and basaltic lava flows derived from multiple eruptive centers, with relatively minor components of volcanoclastic rocks and mudflows. On the whole, volcanic rocks of the Fifes Peak Formation are not nearly so altered by volcanic processes as the Ohanapecosh or Stevens Peak formations. The Fifes Peak Formation appears to conformably overlie the Stevens Ridge Formation, but the uppermost portion of the unit is eroded within MORA. While no paleontological resources are reported from the Fifes Peak Formation, its mudflow and volcanoclastic deposits are likely to contain wood or wood fragments, similar to both older and younger rock units.

Strata correlative to Fifes Peak Formation or Stevens Ridge Formation? (Miocene)

A single layer, which outcrops between Mount Adams and Mount St. Helens (approximately 60 km or 40 mi south of MORA), preserves a diverse assemblage of trace fossils. The lithology seems to consist of thinly bedded (less than 30 cm, or 1 ft-thick) pumiceous volcanoclastic sedimentary layers. Raindrop impressions are preserved in the same horizon as the trace fossils. The trace fossils are described by Kaler (1998) as containing approximately ten late Arikarean mammal "age" vertebrate trackways, reported to be 23 million years old (early Miocene). On the basis of the morphology of the molds and gait analysis, Kaler concludes that the tracks represent a wading bird, rodent-like animals, large quadrupeds with carnivore affinities, and a small reptile or amphibian. Leaf fossils are also reported at the site but are not described in the manuscript. The precise location, field relations, referable map unit, and lithology of the trace fossil-bearing stratum are not reported. However, because MORA contains rocks of similar age and broadly similar lithology, it is conceivable that analogous paleontological resources may occur within MORA.

Park Collections

MORA park collections contain six known paleontological specimens. All six specimens appear to represent seed-bearing paleoflora (needles and broadleaves are preserved) and are presumably of a Cenozoic age. One specimen (MORA 13164; informally referred to as the "Ohana specimen") is the only paleo-specimen with any provenance information. A park volunteer found the specimen in the Ohanapecosh River, upstream from the Stevens Canyon landslide, sometime shortly after the flood of 2006. The specimen probably derived from volcanoclastic rocks of the Ohanapecosh Formation, which is the pervasive rock unit in the area of the Ohanapecosh River drainage. Locality, collection, and ancillary

information pertaining to the other five specimens are not known. Those specimens were found in a box marked “archeology” but were otherwise unlabeled (B. Childrey, MORA Curator, pers. comm., April 21, 2009).

Regan Dunn (formerly a paleobotanist with JODA, now pursuing graduate research at University of Washington), examined photographs of MORA’s paleobotanical specimens. Dunn ascribes a middle Eocene age to the specimens, indicating that they are similar to flora preserved in the Herren Formation of Heppner, Oregon, or to Alaskan or Puget Group (King County, Washington) flora described by Jack Wolfe. A photograph of a specimen containing a broadleaf with serrated edges is interpreted to belong to the Fagaceae (beech) family, and may represent a relative of a chestnut. A photograph of a specimen containing a conifer may represent *Glyptostrobus* sp. A photograph of a specimen of fossilized wood resembles the growth patterns of a pine. (R. Dunn, pers. comm., May 6, 2009.)

A number of specimens within MORA’s geology collection are described as “carbonized wood,” but ancillary information is limited for these specimens. Almost any rock unit in MORA could have produced such material.

External Collections

Paleobotanical specimens collected by USGS personnel (including R. W. Brown), are maintained by the Smithsonian Institution’s National Museum of Natural History in Washington, DC.

R. V. Fisher’s 1957 thesis reports that the specimens described therein (e.g. UW 13700-13705, among others), are maintained by the University of Washington’s Burke Museum. At present, those specimens are not at the Burke Museum; they might have been relocated to University of California at Santa Barbara (E. Nesbitt, Burke Museum, pers. comm., 2009).

Paleontological Resource Management, Preliminary Recommendations

- The NPS Geologic Resources Division produced a Geologic Resource Evaluation report for MORA (Graham 2005). Paleontological resources were not specifically mentioned in the report.
- In consideration of the potential research value of fossil wood contained in recent mudflow and landslide deposits, collaborate with USGS, Washington Department of Natural Resources and other researchers when new material is exposed as a result of natural processes or infrastructure projects.
- Using the USGS paleoflora locality register, identify locations of USGS localities that may be in or near MORA (including but not limited to USGS localities visited by R. W. Brown, L. M. Gard, and Fischer; USGS locality numbers 11523, 11524, 9295, 9296, 9312-9317, 9374, 9376, 9397).
- Conduct field surveys through the Ohanapecosh River Valley and in the area between Round Pass and Tumtum Peak, to identify probable fossiliferous strata. Areas correlating to the sections at Summit Creek and Wildcat Creek may also bear significant paleontological resources.
- The park may consider a formal site documentation and condition assessment for significant fossil localities. Monitoring of significant sites should be undertaken at least once a year in the future. A forthcoming (2009) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring (Santucci et al. in press).
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should photodocument and potentially monitor any occurrences of paleontological resources.
- Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or

direct human impacts. Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist.

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

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Data Sets

Mount Rainier National Park Paleontological Archives

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

Mount Rainier National Park Monument Museum Collections

1899–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by MORA staff; status: Active.

U.S. Geological Survey collections at the National Museum of Natural History

1897–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by NMNH and USGS staff; status: Active

University of Washington Burke Museum of Natural History and Culture

1996–present. (museum specimens; associated specimen and collections records; field notes; etc.) Originated by Burke Museum staff; status: Active.

Mount Rainier National Park Digital Geologic Map

2006–present. (geologic map data; electronic files; GIS metadata). Originated by NPS-Geologic Resource Inventory staff; status: Active. Online. <http://science.nature.nps.gov/nrdata/datastore.cfm?ID=38958>.

North Cascades National Park Service Complex

North Cascades National Park Service Complex (NOCA) provides Americans with opportunities to use, enjoy, and be inspired by the heart of the rugged and majestic North Cascade Mountains, its glaciers, watercourses, and diverse ecosystems. NOCA was established October 2, 1968. In 1988, more than 90% of NOCA was designated as Stephen Mather Wilderness, protecting numerous threatened or endangered animals, swaths of old-growth forests, and a very diverse plant assemblage representing eight different life zones. The NOCA service complex totals 276,927 ha (684,302 acres), including the Ross Lake and Lake Chelan national recreation areas.

Geologic Background

NOCA occupies a large portion of the Northern Cascade Mountains physiographic region. The 49th Parallel marks the U.S.-Canada border and the park's northern boundary. NOCA is bordered by Mount Baker-Snoqualmie National Forest to the west, Wenatchee National Forest and Glacier Peak Wilderness to the south, and by Okanogan National Forest and Pasayten Wilderness to the east. NOCA resides in Whatcom, Skagit, and Chelan counties. The region is often referred to as a "mountain mosaic", where geologically distinct slivers of the Earth's crust have been thrust over and under each other, and welded together by igneous rocks.

Though the geologic history of the North Cascades is notoriously complex, rocks in the area of NOCA can be divided into three general groups on the basis of lithology and degree of metamorphism: Rocks of the northwestern Cascades, rocks of the crystalline core, and rocks of the Methow Ocean Basin. These rocks are overlain by younger Tertiary volcanic rocks and by Quaternary sediments deposited by glaciers, streams, and mass wasting processes. Refer to the appendix for a geologic time scale.

Rocks of the northwestern Cascades occupy the area west of the Straight Creek Fault Zone, and consist of several terranes, including the Yellow Aster Complex, Nooksack, Chilliwack, Bell Pass mélange, and Easton terranes. These terranes represent a variety of marine depositional environments including slope, submarine fan, and deep ocean. Many of these terranes also include submarine volcanic rocks, indicating that they may have formed near or in a volcanic arc or oceanic spreading ridge prior to being thrust over one another and sutured to western North America. Marine rocks such as these are known to preserve microfossils and invertebrate fossils. Subsequent to deposition, these rocks were subjected to low-grade metamorphism which occurred as a result of tectonic forces such as compression, shear, and burial. During metamorphism, fossils contained in the marine deposits may have been destroyed. Chilliwack, Bell Pass mélange, and Easton terranes are exposed within NOCA.

Rocks of the crystalline core constitute the majority of rocks within NOCA; they are situated between the Straight Creek Fault Zone and the Ross Lake Fault Zone. The Chelan Mountain Terrane, and Skagit Gneiss Complex are represented within NOCA. Although much of the crystalline core is composed of intrusive crystalline rocks ("igneous plutons") or other metamorphosed igneous rocks, some core rocks are interpreted to have originated as marine sedimentary-volcanic rocks (volcanic island arcs), which may have contained marine microfossils and marine invertebrates. However, some time after their deposition, these rocks were subject to such high pressures and temperatures that fossil remains were likely to have been completely destroyed. No fossils have been reported from rocks within the crystalline core of NOCA. However, some rock units could potentially (with the aid of a keen eye or microscope and geologic thin section) yield the rare, poorly preserved specimen. Several geologists have attempted to correlate so-called "parent-rocks" of the crystalline core with less-metamorphosed rocks just outside of the crystalline core. Such correlations are somewhat speculative because the area is riddled with faults and folds, and the precise cause of the metamorphism is a matter of much debate.

Rocks of the Methow Basin lie to the east of the Ross Lake Fault zone. These rocks record the "filling up" of the Jurassic-Cretaceous Methow Ocean Basin, as sediments were shed from the surrounding highlands—mostly from the east. Basin-filling deposits such as these commonly represent a range of deep-

to- shallow marine and even terrestrial environments, and consequently contain a variety of plant and animal remains. These rocks have been faulted and folded but have not been metamorphosed, so they contain better preserved fossils. Additional rock units within or near the Ross Lake Fault zone include the Skymo Complex, the Hozameen Terrane, and the Little Jack Mountain Terrane.

The original geologic mapping of a portion of this vast area was underwritten by border commissions of the Canadian and U.S. governments during the late 1800s and early 1900s. George Otis Smith and Frank Cathcart Calkins worked on behalf of the U.S. Geological Survey, as Reginald Aldworth Daly worked for the Canadian International Boundary Commission. Peter Misch (1909-1987), a former professor at University of Washington, spent 40 years working in the North Cascades. During this time, he added significantly to the body of knowledge relating to the “mountain mosaic.” His legacy includes a framework for the geology of the North Cascades as well as a succession of talented students who also devoted much of their careers to studying the exceptionally rugged area. One of Misch’s protégés, Rowland W. Tabor, recently coauthored a popular book describing the general geology of North Cascades (see Tabor and Haugerud 1999). Peter Misch published numerous manuscripts and maps (e.g. Misch 1979) covering the geology North Cascades region. More recent maps were used as the foundation for information gathered during the writing of this report, including Tabor et al. (2002, 2003), Dragovich and Norman (1995), Stoffel and McGroder (1990), and McGroder et al. (1990).

Pleistocene glaciations by continental ice sheets and long alpine glacier systems created the present shape of the North Cascades. Valleys cut deeply into crystalline bedrock have glacial and nonglacial sediments that are up to several hundred feet thick on valley floors. Most of these deposits date to the last ice age, and have been shown to contain abundant macrofossils and pollen (Riedel 2007). Archeological sites in late Pleistocene and Holocene deposits also are known to contain evidence of the past flora and fauna of the park complex.

Sources of Paleontological Resources

Fossils have been documented from the following geologic formations as well as the museum collections within NOCA. These fossils present opportunities for resource management (including field surveys, inventory, and monitoring), education, interpretation, and continued or future scientific research in the park.

Ross Lake Fault Zone: Hozameen (or Hozomeen) Group (Pennsylvanian - Triassic)

The Hozameen Group consists of ribbon chert, limestone pods, greenstones, and volcanic breccias, tuffs, and pillow lavas, and is interpreted to have formed in a region adjacent to a subduction zone volcanic arc. The terrane may be equivalent to the Bridge Creek Terrane of British Columbia. The Hozameen Group was studied extensively by Haugerud (1985) and several other geologists, including Smith and Calkins (1904), Cairnes (1924, 1944), Shideler (1965), Misch (1966, 1977), Staatz et al. (1971), and Cordey (1998).

Haugerud (1985) reports that McTaggart and Thompson (1967) identify “dubious brachiopods” from the Hozameen Group, and states that non-diagnostic bryozoans were found near Crater Lake less than 3 km (2 mi) east of NOCA boundary. Reliable age determinations for the Hozameen Group come from radiolaria. Haugerud (1985) indicates that much of chert within the Hozameen Group is “heavily veined and too strongly recrystallized for microfossil preservation;” he then goes on to state that many radiolarites in his study area contain undeformed radiolarians. Haugerud states that lower and middle Jurassic radiolaria and middle and upper Triassic radiolaria are present in the Hozameen Group of Canada, within just a few kilometers of the NOCA boundary.

Upper Triassic radiolaria are present within NOCA, near where Little Beaver Creek empties into Ross Lake (see Park Collections section, below). Haugerud reports that Tennyson et al. (1982) identifies Permian microfossils from a locality just east of NOCA (approximately 3 km [2 mi] east of NOCA boundary, at Jerry Lakes near Jack Mountain). The age distribution of radiolaria identified from these rocks indicates a general trend of Northwest-younging for the formation of the Hozameen Group.

Microscopic analysis of thin sections taken from limestone pods of the Hozameen Group reveal that the limestones are recrystallized, and shell fragments may be observed in rare samples. Early–Middle Pennsylvanian conodonts were reported from a limestone-bearing outcrop of the Hozameen Group located just outside NOCA, slightly east of the ridgecrest, less than 1 km (0.5 mile) north of Hozomeen Mountain.

Northwest Cascades: Chuckanut Formation (Late Cretaceous – Eocene) and “other Tertiary sandstones” (?Tertiary)

The Chuckanut Formation was deposited along a broad, low lying coastal plain, and it is well exposed throughout northwestern Washington and southwestern British Columbia. It correlates to the Huntingdon Formation of British Columbia. It may have been deposited contemporaneously with the Swauk Formation (e.g. Weaver 1911), which now lies to the south, offset 275 km (170 mi) along the Straight Creek Fault. The Chuckanut Formation is well studied and is known for its abundant plant fossils. Extensive investigations of the Chuckanut Formation and its paleobiology have been conducted by Butala and Cridland (1973), Carlisle (2004, 2007), Chaney (1951), Dillhoff et al. (2007), Donohoo-Hurley (2004), Evans and Ristow (1991), Fisk and Elmandorf (1978), Frizell et al. (1979), Gilley and Mustard (2003), Griggs (1965, 1970), Johnson (1982, 1984, 1985), Knowlton (1902), La Motte (1938), Lesquereux (1859, 1878), Mathewes and Mustard (2007), Mustoe (1993, 2002), Mustoe et al. (2007), Mustoe and Gannaway (1995), Mustoe and Pevear (1983), Newberry (1863, 1898), Pabst (1968), Reiswig and Jensen (1983), Riston and Evans (1991), Robertson (1981), Thorne (1998), and Vance (2002).

Some plant fossils identified from outcrops of the Chuckanut Formation west of NOCA include many fossil palm fragments (*Sabalites campbelli* is the most prevalent, occurring throughout the formation), the tree fern, *Cyathea pinnati* (MacGinitie) La Motte, climbing plants and vines (such as *Lygosdium kaulfusi* Heer, *Tetracera*, and *Goweria*), and trees such as sycamore (*Platanus*), alder (*Alnus*), hazel (*Corylus*), a laurel (*Sassafras*), yews (*Taxodium* and *Glyptostrubus*), and a cypress (*Mesocyparis*), according to information compiled by Mustoe and Gannaway (1995). Trace fossils (reported in Mustoe [2002] to include a variety of bird trackways, turtle trackways, perissodactyl tracks, and plantigrade tracks), invertebrate and vertebrate fossils (including a turtle carapace) are also reported from the strata west of NOCA (Mustoe et al. 2007).

There is some disagreement as to whether the Chuckanut Formation outcrops within NOCA. Tabor et al. (2003) make a distinction between the Chuckanut Formation and another informal sedimentary unit, Tertiary sandstones and conglomerates of uncertain age. Chuckanut Formation is mapped entirely to the west of NOCA, separate from the informal unit which is mapped entirely within NOCA. Tabor et al. (2003) indicates that the informal sedimentary strata may have been deposited in association with extensional and strike-slip faults, such as the Fraser-Straight Creek Fault. The paper also notes that these strata contain poorly preserved non age diagnostic plant fragments. Another publication (Tabor and Haugerud 1999), written by the same principal authors, includes a depiction of a fossil log (their figure 8B) from the north side of Bacon Peak (within NOCA) and a caption which states that the strata is in fact Chuckanut Formation, rather than the informal sedimentary unit which, according to the later map, underlies the same area. This fossil log is the only documented *in situ* paleontological resource within NOCA. Most assuredly, other plant fossils are preserved throughout these deposits, however, the quality of preservation and the value of these fossils as tools for stratigraphic correlation are uncertain.

Staatz et al. (1972) assign NOCA’s Tertiary sedimentary strata to the Chuckanut Formation, noting that poorly preserved plant fragments are found along bedding planes. Evans and Ristow (1991) correlate the fault-related strata to the Chuckanut Formation, and report that the eastern outcrops preserve in situ tree stumps and roots, though they do not list localities. Brown et al. (1987) reports an abundance of plant fossils, including Palmetto, from fine grained portions of the Chuckanut Formation, but it does not include fossil locality information.

Glacial and lacustrine deposits (Pleistocene - Recent)

High resolution climate studies of lake sediment cores throughout the North Cascades are used to reconstruct climatic conditions during the past 2,000 years, and are also used to calibrate other core studies (Nelson et al. 2001). For that study, paleotemperatures are resolved using analyses of fossil diatoms, a type of phytoplanktonic algae. See Weckström et al. (2006) for other diatom studies.

Plant macrofossils, pollen, and charcoal preserved in lake sediments have been used to reconstruct the late Pleistocene - Holocene paleoenvironmental history of portions of the North Cascades. Two sediment cores, obtained from Ridley Lake and Thunder Lake (within NOCA, near Ross Lake), capture a climate record dating back 14,000 calendar years before present (ybp). Flora identified from these cores include, fir (*Abies amabilis/gradis*, *Abies lasiocarpa*, *Abies procera*, *Alnus sinuata*, *Pseudotsuga menziesii*), alder (*Alnus rubra*), Asteraceae-family (daisies), birch (*Betula*), cypress (*Chaemacyparis nootkatensis*, *Thuja plicata*), heath (*Ericaceae*), ash (*Fraxinus*), spruce (*Picea engelmannii*), pine (*Pinus albicaulis*, *P. contorta*, *P. monticola*), willow (*Salix*), and hemlock (*Tsuga herterophylla* and *T. mertensiana*) as reported in Prichard (2003) and Spooner et al. (2007, 2008). Spooner et al. (2008) suggests that the floral assemblages obtained from each sediment core reflect a similar climatic trend with minor temporal variations that are partially attributed to differences in elevation: Beginning with a cool, dry post-glacial climate, followed by Younger Dryas cooling, and later, a cool, moist climate prevailed. Evidence from six lakes, including Big Twin, Little Twin, and Davis lakes, indicates drought conditions during the middle Holocene (Nelson et al. 2001, 2003).

Charcoal from meadow bogs, buried soils, and peat-rich layers near moraines has been radiocarbon dated in order to constrain the timing of glacial advances in the area of Mount Baker (Kovanen and Easterbrook 2001) and at several sites within NOCA (Riedel 2007). These studies indicate that glaciers have fluctuated in response to rapid global cooling events at the end of the last ice age about 12,000 years ago. However, the extensive alpine glacier systems reported by Easterbrook and Kovanen (1999) more likely represent stagnant masses of the Cordilleran Ice Sheet. Recent work on Mount Baker supports the conclusion of numerous regional pollen studies that indicate that the region was warm and dry during the early Holocene, and that glaciers were not as extensive as previously reported (Davis et al. 2005, 2006, 2007; Riedel et al. 2006; Osborn et al. 2007; Ryane et al. 2007). Glaciers have fluctuated in response to millennial scale climate fluctuations in the Holocene, with the most recent advance during the Little Ice Age (from about the 1500s to the early 1800s) being the most extensive since the end of the last ice age (Riedel et al. 1987).

A pond sediment core collected from outside NOCA (approximately 3 km, or 2 mi, west of Mount Shuksan) reveals that vegetation, on the basis of plant macrofossils, was established at 1,360 m (4,460 ft) elevations approximately 9,350 ybp (Burrows et al. 2007; see also Burrows 2000).

Macrofossils in Skagit valley, Washington, provide information on climate and environmental change in the North Cascades during the Evans Creek stage of the Fraser Glaciation (Riedel 2007). Between 24,000 and at least 18,020 radiocarbon ybp the floor of upper Skagit valley was dominated by subalpine species, including whitebark pine (*Pinus albicaulis*), Engelmann spruce (*Picea engelmannii*), and subalpine fir (*Abies lasiocarpa*). Other taxa indicative of a subalpine forest include bark beetles (Scotylidae) and bog birch (*Betula nana*). Treeline during the Evans Creek stage was about 500 m (1,640 ft) above sea level, or 1200 ± 150 m ($3,900 \pm 490$ ft) below its present elevation, which corresponds to an approximately $7 \pm 1^\circ$ C decrease in mean July temperature. Northern spikemoss (*Selaginella selaginoides*) and willow (*Salix*) macrofossils are particularly abundant in fossil plant assemblages in lake sediments deposited in lower Skagit valley between 19,980 and 17,570 radiocarbon ybp. Coleopteran macrofossils include ground beetles (Staphylinidae) and leaf beetles (Chrysomelidae); no bark beetles indicative of substantial forest cover were found. The floral and faunal assemblages also reveal second-order climate changes within the Evans Creek stage. Increases in Sitka spruce (*Picea sitchensis*), mountain hemlock (*Tsuga mertensiana*), and Pacific silver fir (*Abies amabilis*) macrofossils in glacial Lake Skymo sediments after 20,770 radiocarbon ybp indicate an increase in precipitation of about 200 mm (8 in) from amounts of the previous cold dry period. An increase in the abundance and diversity of conifer macrofossils, and the

absence of northern spikemoss fossils by 17,170 radiocarbon ybp mark a shift to more mesic conditions near the end of the Evans Creek stage in Skagit valley.

Mass wasting deposits

Easterbrook and Kovanen (1996) reports that large logs are preserved in a lahar deposit, originating from Mount Baker and extending 35 km (22 mi) west into the Nooksack River Valley. Radiocarbon ages were not reported. Given that both Glacier Peak and Mount Baker volcanoes drain into streams to the west of NOCA, it is unlikely that lahar deposits occur in the park. However, several volcanic ash layers from these volcanoes have been identified.

Cary et al. (1992) reports a buried forest near the town of Glacier, Washington (approximately 15 km [10 mi] west of NOCA). Cedar and fir trunks measure up to 1.5 m (5 ft) in diameter; the old growth forest was buried by an enormous landslide. Carpenter (1993) describes the slide in detail and cites an age of 2,700 radiocarbon ybp obtained from buried logs.

A landslide along Damnation Creek (within NOCA) dammed the upper Skagit River and formed a lake. The lake deposits contain buried trees preserved in growth position in addition to woody fragments. Radiocarbon ages obtained from woody material indicate that the lake formed at least 7,040 ybp and endured for several centuries (Riedel et al. 2001).

Most of the large landslides at NOCA have been inventoried (Riedel and Probala 2005), and lake deposits upstream of landslide dams likely contain records of floral and faunal change at NOCA in the Holocene. However, many of these features have not been studied in detail. Darrington Phyllite is known to underlie many large landslides in the region (Jakob et al. 2003); it outcrops along the western NOCA boundary, north of Baker Lake.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within NOCA. However, future field investigations within the park may yield fossils from one or more (or none) of the following geologic units. Fossils are documented from these units outside of the park, in some cases in very close proximity to the park.

Northwest Cascades: Chilliwack Group (Devonian – Permian)

The Chilliwack Group primarily consists of sandstones, argillites, minor limestones, and volcanic rocks, and is known to be fossiliferous outside of NOCA. Fossils of the Chilliwack Terrane are known from older (Devonian-Permian), thicker limestone deposits, that are mapped outside of the park boundary. The portion of Chilliwack Terrane which outcrops in NOCA, near Mount Herman, is Permian in age and consists of pillow lavas, volcano-lithic sandstone, and has a minor limestone component. Some mid-late Paleozoic Chilliwack rocks lie less than 1.5 km (1 mi) beyond the park boundary (in the area of Lake Ann and Price Lake), however, it is unlikely that fossil-bearing units of Chilliwack Terrane outcrop within NOCA, based on interpretations of structural relations of the strata.

Chilliwack exposures west of NOCA have yielded Permian fusulinids, Paleozoic gastropods, Mississippian crinoids, Devonian corals, and Siluro-Devonian brachiopods, Paleozoic plant fragments, stromatoporoids, and radiolarians (compiled from citations in Tabor et al. 2003, their Table 2).

Triassic conodonts of the *Neogondolella polygnathiformis* Assemblage Zone were collected from “Hilltop Limestone” in a former unit that was previously mapped as Devonian rocks Chilliwack Group, indicating a need for major stratigraphic revisions (Evans and Savage 1979). Locality and follow-up information was not identified.

Northwest Cascades: Bell Pass mélange (Late Jurassic - Cretaceous)

Bell Pass mélange of the northwest Cascades consists of sandstones, argillites, ribbon cherts, mafic rocks, and sheared blocks of other more intensely metamorphosed rock units (including Yellow Aster Complex

and Vedder Complex). Numerous samples of chert from the Bell Pass mélange (“Elbow Lake Formation”) have produced radiolaria ranging in age from late Pennsylvanian to late Jurassic; all known localities are outside of NOCA. Tabor et al. (2003) plot a fossil locality, 49f (described as highly deformed chert, Mesozoic in age), at an exposure of Bell Pass mélange less than 1 km (.5 mi) west of NOCA, just north of Lake Ann, but no other information is given.

Northwest Cascades: Easton Terrane (Early Cretaceous)

Easton Terrane of the northwest Cascades consists of metamorphosed deep ocean sediments and basaltic seafloor and includes the Darrington Phyllite and the Shuksan Greenschist. Darrington Phyllite is rich in graphite, a mineral that is formed when deposits of organic material are metamorphosed beyond the level of coal formation. It is possible that some fine-grained metamorphosed sedimentary rocks of the Easton Terrane could yield identifiable, age-diagnostic siliceous microfossils. Darrington Phyllite and Shuksan Greenschist are two potentially fossil-bearing rock units of the Easton Terrane that outcrop within NOCA—particularly in the Cascade River valley.

Crystalline core: Chelan Terrane, Cascade River Schist and Napeequa Schist (Late Cretaceous metamorphic age)

The Cascade River Schist and Napeequa Schist of the crystalline core are medium-grade metamorphic rocks that comprise a large portion of the bedrock geology near the southern portion of NOCA in the vicinity of Lake Chelan, in the Sauk River and Twisp quadrangles (see Tabor et al. 2002; Dragovich and Norman 1995). According to Dragovich et al. (1989), the Cascade River Schist probably formed as an oceanic arc and basin during the Triassic Period (or younger) and was subsequently metamorphosed. These rocks could potentially preserve marine fossils, though none are reported in the literature. Both the Cascade River Schist and the Napeequa Schist, particularly in the area of Marble Creek, contain some coarse-grained marble, which is recrystallized limestone. The process of metamorphism obliterates fossils, in most cases, but it is possible for fossils to be preserved in marble. The stratigraphic value of such fossils in North Cascades rocks is questionable, however.

Methow Basin: Newby Group, Twisp Formation and Buck Mountain Formation (Early Jurassic – Early Cretaceous)

Due to extremely limited geologic mapping conducted in the area between Ross Lake and NOCA’s eastern boundary, it is unclear which rock units of the Methow basin actually outcrop within NOCA. However, fossil bearing rocks from the Methow Basin have been deposited on terraces, floodplains, and alluvial fans along the east side of Ross Lake. Note that some deposits of the Methow Basin may correlate to deposits of the Tyaughten Basin in Canada. The Newby Group is described here because similar strata may outcrop within NOCA. R. W. Tabor and R. A. Haugerud are preparing geologic maps for this area, including Robinson Mountain and Twisp quadrangles, which will help to resolve this matter.

The Newby Group is subdivided into the older Twisp Formation and the younger Buck Mountain Formation. The two formations represent two separate intervals of deposition that are separated by an erosional unconformity of uncertain duration. The Newby Group consist of volcanic and volcanoclastic rocks including andesitic lava flows, breccias, tuffs, black shales, lithic sandstones, and conglomerates, all of which were shed from eastern highlands. According to Barksdale (1975) these rocks outcrop in the vicinity of NOCA, outside of the park boundary. The map created by Barksdale (1975) shows rocks of the Newby Group nearest to NOCA in the area north of Lake Chelan, between McAlester Mountain and Reynolds Peak. Here, the NOCA boundary appears to follow the ridgecrest, and rocks of the Newby Group are mapped on the north and east side of the divide. The rock units are included here because geologic mapping in this area is not thoroughly resolved. Kriens (1988) maps Newby Group within NOCA throughout the Ross Lake area, though his conclusions are contested (R. W. Tabor, pers. comm., July 2009). All of the fossils detailed here are known from outcrops of the Newby Group located between 5 and 25 km (3 and 15 mi) from the park boundary, as reported by Barksdale (1975).

Fossils of the Twisp Formation include fragments of cycads, belemnite molds, and a fish scale, but the specimens are not suitable for resolving the age of the strata (Barksdale 1975; McGroder et al. 1990;

Girouard 2001). The Twisp Formation is considered Early-Middle Jurassic, and it may correlate to a portion of the Ladner Group of British Columbia, which is recognized as Middle-Upper Jurassic in age (Barksdale 1975).

The Buck Mountain Formation is the more fossiliferous of the two subdivisions. Fossils found therein are reported to be Hauterivian-Barremian (Early Cretaceous) in age (Barksdale 1975). The lower volcanic unit of the Buck Mountain Formation yielded a belemnite (*Acroteuthis* cf. *A. impressa*), described by V. Standish Mallory (Barksdale 1975). The middle unit of the Buck Mountain Formation is comprised of packages of sedimentary rocks ranging from black shales to heterolithic conglomeratic beds, and contains ammonites (*Shastrioceras hesperum* and *S. poniente*), pelecypods (*Inoceramus colonicus*, *Periplomya trinitatis*, and *Pleuromya papyracea*), and belemnites (*Acroteuthis aboriginalis* and *A. shastensis*), collected by Robert Dabritz and V. Standish Mallory (Barksdale 1975). The upper unit of the Buck Mountain Formation is lithologically similar to the middle unit described above, except that the upper unit lacks the coarse conglomeratic component. Fossils recovered from the uppermost beds include ammonites (*Hoplocrioceras remondi*, and ?*Ancycloceras ajax*). Coral was also found in the Buck Mountain Formation (Barksdale 1975). Girouard (2001) indicates that fragments of cycads (*Pterophyllum*) were also collected from the Buck Mountain Formation. See McGroder et al. (1990) for a more complete faunal list. (Please note that tentative taxonomic identifications are, by convention, indicated with a “?”.)

Methow Basin: Goat Creek Formation (Early Cretaceous)

The Goat Creek Formation of the Methow Basin is described here because geologic mapping is not well resolved in the area between Ross Lake and the eastern border of NOCA. At present, it is unclear if this rock unit outcrops within NOCA or in the immediate vicinity. The Goat Creek Formation is described here because similar strata may outcrop within NOCA. R. W. Tabor and R. A. Haugerud are preparing geologic maps for this area, including Robinson Mountain and Twisp quadrangles, which will help to resolve this matter.

The Goat Creek Formation consists of arkosic sandstones and dark shales shed from western highlands. The contact of the Goat Creek Formation with the underlying Newby Group is unconformable. The contact with the overlying Panther Creek Formation is conformable. No fossils have been found from the Goat Creek Formation in the United States (Stoffel and McGroder 1990), but Barremian to early Albian (Early Cretaceous) fossils were recovered from correlative strata in British Columbia (Barksdale 1975). See Coates (1970a, 1970b, 1974), Jeletzky (1972), Barksdale (1975), Stoffel and McGroder (1990), and McGroder et al. (1990) for possible correlations.

Methow Basin: Panther Creek Formation (Early Cretaceous)

The Panther Creek Formation of the Methow Basin is described here because geologic mapping in this area is not thoroughly resolved. At present, it is unclear if this rock unit outcrops within NOCA or in the immediate vicinity. The Panther Creek Formation is described here because similar strata may outcrop within NOCA. R. W. Tabor and R. A. Haugerud are preparing geologic maps for this area, including Robinson Mountain and Twisp quadrangles, which will help to resolve this matter.

The Panther Creek Formation is dominantly comprised of extremely thick packages of black shale (in excess of 300 m (1,000 ft) thick] with relatively minor clastic interbeds, all shed from western highlands. The Panther Creek Formation conformably overlies the Goat Creek Formation, and conformably underlies the Harts Pass Formation. Clastic beds are reported to contain molds of marine fossils, and several pelecypods have also been identified (*Megatrigonia* cf. *M. condoni*, *Pterotrigonia oregona*, *Anchura biangulata*, and *Ampullina avellana*) by V. Standish Mallory (Barksdale 1975), collected from a locality that is inferred to be approximately 30 km (20 mi) east of NOCA, near McLeod Mountain. Girouard (2001) indicates that invertebrate fossils of the Panther Creek Formation have been found in association with fossil plant fragments. See McGroder et al. (1990) for a more complete faunal list.

Methow Basin: Harts Pass Formation (Early Cretaceous)

The Harts Pass Formation is described here because geologic mapping is not well resolved in the area between Ross Lake and the eastern border of NOCA. At present, it is unclear if this rock unit outcrops within NOCA or in the immediate vicinity. The Harts Pass Formation is described here because similar strata may outcrop within NOCA. R. W. Tabor and R. A. Haugerud are preparing geologic maps for this area, including Robinson Mountain and Twisp quadrangles, which will help to resolve this matter.

The Harts Pass Formation consists of arkosic sandstone and shale shed from western highlands. It conformably overlies the Panther Creek Formation, and unconformably underlies the Virginian Ridge Formation. Locally abundant invertebrate fossils from the Harts Pass Formation are recognized as Albian-Aptian (late Early Cretaceous) in age, and have been identified by Simon William Muller (Stanford University), David L. Jones (USGS), and V. Standish Mallory. Fossils reported in Barksdale (1975) include ammonites (*Hamites*, *Hamites* cf. *H. attenuatus*, *Puzosia* cf. *P. mayoriana* or *Puzosia* cf. *P. sharpei*, *Melchiorites* sp., *Melchiorites* cf. *M. shastensis*, *Chelonoceras* sp., *Hypophylloceras* cf. *H. onoensis*), echinoids (*Dumblea* sp.), pelecypods (*Pinna equivellara*), and gastropods (*Anchura biangulata*). The original fossiliferous locality of the Harts Pass Formation is approximately 15 km (10 mi) east of NOCA, at a road cut just southeast of Harts Pass. See McGroder et al. (1990) for a more complete faunal list.

Methow Basin: Pasayten Group, Virginian Ridge Formation (Early – Late Cretaceous)

The Virginian Ridge Formation is described here because geologic mapping is not well resolved in the area between Ross Lake and the eastern border of NOCA. At present, it is unclear if this rock unit outcrops within NOCA or in the immediate vicinity. The Virginian Ridge Formation is described here because similar strata may outcrop within NOCA. R. W. Tabor and R. A. Haugerud are preparing geologic maps for this area, including Robinson Mountain and Twisp quadrangles, which will help to resolve this matter.

The Virginian Ridge Formation, part of the Pasayten Group, consists of clastic rocks that are relatively chert-rich, including sandstones, siltstone, and minor shales. Sediments of the Virginian Ridge Formation were shed from eastern highlands. The Virginian Ridge Formation has been correlated to the Jackass Mountain Group in British Columbia (Barksdale 1948, 1975; Stoffel and McGroder 1990), which is a revision of the Dewdney Creek Group. The Virginian Ridge Formation unconformably overlies the Harts Pass Formation, and grades upward into the overlying Winthrop Sandstone. Fossiliferous outcrops of the Virginian Ridge Formation (e.g. Slate Peak) are located approximately 15 km (10 mi) east of the park boundary. Fossils from the Virginian Ridge Formation represent Aptian-Cenomanian or Turonian (Early Cretaceous - Late Cretaceous) ages. Bivalves [*Trigonia* sp. cf. *T. evansana*, *Trigonia* sp. cf. *T. leana*, *Trigonia* sp. cf. *T. maudensis*, *Trigonia* sp. cf. *T. diversicostata*, ?*Etea angulata* (as *Meretrix*), ?*Trigonarca* sp., *Venerid* sp., *Cucullaea* sp. cf. *C. ponderosa*, *Megatrigonia* cf. *M. condoni*, *Pteritrigonia oregona*], gastropods (*Turritella* sp. *Turritella* cf. *T. hearni*, *Actaeonella packardi* -molds), ammonites (*Beudanticeras haydeni*), and brachiopods (?*Cyclothyris* sp.) are reported from the Virginian Ridge Formation (Barksdale 1948, 1975). Additionally, McGroder et al. (1990) reports the articulate brachiopod *Rhynchonella whitneyi*, the bivalve *Glycimeris* sp., the tusk shell ?*Dentalium* sp., the polychaete worm *Ditrupa cornu*, belemnite fragments, and a possible cycad.

Kriens (1988) suggests that the Virginian Ridge Formation contains terrestrial plant fossils. It is not clear whether Kriens may have confused Virginian Ridge with the conformably overlying Winthrop Sandstone, which represents shallower water environments and is more widely recognized for its preservation of plant remains and coal-bearing strata. Girouard (2001, reported via personal communication with Ralph Haugerud) also reports plant fossils from interbeds of the Virginian Ridge Formation that were derived from terrestrial sources. Royce (1995) postulates that the area where the Virginian Ridge Formation interfingers with the Winthrop Sandstone supported a thriving marine community which included gastropods and brachiopods. Winthrop Sandstone does not appear to outcrop within or near NOCA. For additional discussion of strata belonging to the Pasayten Group, Methow Group, or Ladner Group, see Tennyson (1974), Staatz et al. (1971), Coates (1970a, 1970b, 1974), and Haugerud et al. (2002).

Ross Lake Fault Zone: Little Jack Mountain Terrane (Late Cretaceous – Middle Eocene)

The Little Jack Mountain Terrane primarily consists of phyllite and schist with some ultramafic rocks; ribbon chert and rare marble are also present in these rocks. Little Jack Mountain Terrane is interpreted to represent sediments that were deposited at the toe of submarine fan along the margin of the Methow Basin and subsequently metamorphosed. Some geologists speculate that rocks of the Little Jack Mountain Terrane may have been deposited in the Methow Basin (e.g. Misch 1977). No fossils have been reported from the Little Jack Mountain Terrane; however, obscured fossils, especially microfossils, may be present among the fine grained phyllites, ribbon cherts, and marbles (for example, see Misch and Mallory 1956).

Volcanic deposits (Tertiary)

Volcanoes are not typically regarded for their fossils nor for their potential for fossil preservation, but that is not to say that they do not or cannot contain or preserve important fossils. Lahars and ashfall have preserved forests on the flanks of Mount Hood, revealing information about that volcano's tumultuous history. Explosive volcanic eruptions are capable of encapsulating nearby areas with thick "pyroclastic" (volcanic ejecta produced by explosive eruptions) deposits, as in the case of the 79 AD eruption of Italy's Mount Vesuvius which entombed the nearby towns of Pompeii and Herculaneum. Basaltic lavas ooze through forests, preserving molds of tree trunks in Hawaii, Idaho, and New Mexico. Cascadian volcanogenic sedimentary rocks (derived from slightly older volcanic rocks) which can be deposited great distances away from the eruptive vent ("distal deposits"), including the well-studied rocks at John Day Fossil Beds National Monument which preserve a detailed record of life throughout the Eocene, Oligocene, and Miocene. At Mount Rainier National Park (see MORA section in this report), paleontological resources consist of fossil trees and woody material preserved in lahar and mudflow deposits. Though most evident in deposits of Quaternary age, older lahar and volcaniclastic deposits are also likely to contain similar paleontological resources. Similar paleontological resources may be present within NOCA, especially in the distal lava flows, tuffs, lahar deposits, and volcaniclastic sediments originating from Mount Baker and Glacier Peak. Other volcanic rocks within NOCA that may preserve undocumented paleontological resources include the Pliocene-age Hannegan Volcanics, the Oligocene-age volcanic rocks of Mount Rahm, Pioneer Ridge, and Big Bosom Buttes, and the Mesozoic-age North Creek Volcanics.

Park Collections

NOCA park collections contain 13 known paleontological specimens (K. Cahill, NOCA Collections Manager, pers. comm., 2009). One of these specimens was collected within the park, NOCA 17244. NOCA 17244 was collected April 17, 1998, by Marshall Plumer (NOCA Park Ranger) from an alluvial fan, where Lightning Creek empties into Ross Lake. Ranger Plumer, who was investigating an archeological site when he discovered the fossil, notes that he "has seen no other fossils in his 3 years working on Ross Lake." The specimen was identified by Elizabeth Nesbitt (Burke Museum, Curator of Invertebrate Paleontology) as *Buchia* sp. and a possible gastropod. Interestingly, Jon Riedel reports that *Buchia* and other fossils are common on the Lightning Creek alluvial fan. One plausible scenario for the presence of *Buchia* within NOCA is that the specimen eroded out of a *Buchia*-bearing rock unit and, after some unknown period of time, was transported down the Lightning Creek Drainage, and was then deposited at the mouth of the drainage, before being collected by Ranger Plumer. Another possibility is that, sometime during the Pleistocene, the specimen was moved downslope by alpine glacial advance, or it could have been plucked from Canadian rocks and transported south by continental glaciation. All the marine rocks deposited in the Methow Basin could potentially yield *Buchia*. McGroder et al. (1990) reports that several *Buchia* specimens were collected from the Buck Mountain and Harts Pass formations from localities to the east of NOCA; none are reported from the Twisp, Goat Creek, Panther Creek, or Virginian Ridge formations.

The other 12 paleontological specimens were collected from localities outside of NOCA, and comprise part of the Rowland W. Tabor geology collection. The R. W. Tabor geology collection at NOCA consists of more than 3,000 geological specimens collected during the course of USGS geologic field mapping and Tabor's other research in the North Cascade region, throughout the 1970s, 1980s and 1990s. Specimens

considered to be of paleontological value were reserved by the USGS prior to the remainder of the collection being released to NOCA. Less than one-third of the Tabor collection at NOCA has been cataloged, thus far. It is possible that other specimens within the Tabor collection will also be of paleontological interest. Thin sections of the Tabor collection are held by coauthor Ralph Haugerud at Western Washington University.

The R. W. Tabor geology collection includes paleontological specimens collected from outside NOCA. Precise locality information is included in NOCA's ANCS+ database. The following information was obtained from NOCA's ANCS+ database and personal communication with Kelly Cahill, NOCA Collections Manager.

- Two specimens were collected from rocks of the Chilliwack Group (Devonian-Permian): NOCA 20279, “marble with fossils”, was collected from a locality about 28 km (18 mi) west of NOCA (near Canyon Creek and the Canadian Border), and NOCA 20280, unspecified “fossil debris”, was collected from a locality about 32 km (20 mi) west of NOCA (near the southern tip of Lake Shannon).
- One specimen was collected from the Cultus Formation (Late Triassic-Early Jurassic): NOCA 20286, fossiliferous limestone, collected from a locality approximately 20 km (12 mi) west of NOCA (near Loomis Mountain).
- Three specimens were collected from the Nooksack Formation (Late Jurassic-Early Cretaceous): NOCA 20316, shell, possibly *Buchia pacifica*, collected from a locality about 15 km (10 mi) west of NOCA (near Hadley Peak), NOCA 20319, fossil belemnite, collected from a locality approximately 15 km (10 mi) west of NOCA (near Boulder Creek), and NOCA 20332, *Buchia*, collected from a locality approximately 25 km (15 mi) west of NOCA (near Fossil Creek).
- One specimen was collected from the Chuckanut Formation (Late Cretaceous-Eocene): NOCA 20865, unspecified leaf fossils, collected from a locality about 28 km (18 mi) west of NOCA (near Clearwater Creek).
- Five specimens were collected from the Swauk Formation (Eocene): NOCA 21074, NOCA 21506, NOCA 21507, NOCA 21508, and NOCA 21509, all of which are described as “unspecified fossils”, though the latter four specimens appear to represent broadleaf plants. All five specimens were collected from localities more than 80 km (50 mi) south of NOCA.

Field samples collected by Peter Misch between 1948 and 1984 are accessioned at NOCA, but not cataloged. The collection consists of hand specimens and thin sections. It is not clear which, if any, of the specimens are paleontological. Like the Tabor collection, the Misch collection also comes from the North Cascades region and is not necessarily from within park boundaries. The field notes that accompany that collection reside at the University of Washington Library Special Collections, Seattle, Washington. These field notes were scanned into black and white PDF's in 2007 by Kelly Cahill, NOCA Museum Curator.

External Collections

In the course of field mapping the North Cascades region, Rowland W. Tabor collected a number of paleontological specimens. The U.S. Geological Survey reserved some of the more stratigraphically significant specimens before releasing the remainder of the field samples to NOCA (described above). Specimens that appear to have been collected from inside or very near NOCA consist of Radiolaria (except where noted), and include the following original field numbers, grouped by locality:

- KD-94-87, *Archaeodictyomitra* or *Mitra* sp., near Skymo Lake, ribbon chert of Hozameen Group
- RH 91-336, ?*Pseudostylosphaera* sp., near Skymo Creek, ribbon chert of Hozameen Group
- RH 91-337, unidentified, near Skymo Creek, ribbon chert of Hozameen Group

- RH 91-338, unidentified, near Skymo Creek, ribbon chert of Hozameen Group
- RH 91-339, possibly Capnodocinae family, near Skymo Creek, ribbon chert of Hozameen Group
- RH 91-342, *Praeconocaryomma* sp., ?*Canutus* sp., near Skymo Creek, ribbon chert of Hozameen Group
- RH 91-343, *Pseudostylosphaera helicum*, *P.* sp. aff. *P. japonica*, ?*Recoarella* sp., ?*Staurocontium* sp. *Triassocampe* sp., near Skymo Creek, ribbon chert of Hozameen Group
- RH 91-347, *Canesium lentum*, *Canoptum* sp. aff. *C. farawayense*, *C. antiqua*, *Capnodoce beulieui*, *C. media*, *Latium paucum*, *Triassocampe* sp., near Skymo Creek, ribbon chert of Hozameen Group
- RH 91-348, *Betraccium* sp., *Capnodoce* sp. aff. *C. venusta*, ?*Capnuchosphaera* sp., *Pantanellium* sp., near Skymo Creek, ribbon chert of Hozameen Group
- RH 91-349, ?*Capnuchosphaera* or *Sarla* sp., ?*Pseudoheliodiscus* sp., near Skymo Creek, ribbon chert of Hozameen Group
- RH 91-216, possibly *Gorgansium*, near Excelsior Pass, argillite with concretions within Nooksack Group
- RH 91-225, *Canoptum* sp., head of Rocky Creek, chert in argillite of Elbow Lake Formation
- RH 91-260, ?*Cantalum* sp., near Little Beaver Creek, Hozameen Group
- RH 91-261, *Hexastylus* or *Kahlerosphaera*, near Little Beaver Creek. Hozameen Group
- RWT 293-91, ?*Pseudostylosphaera* sp. aff. *P. hellenica*, Little Beaver Creek, ribbon chert of Hozameen Group
- RWT 276-91, possibly *Eptingium*, Lightning Creek, concretions within argillite of ?Ladner Unit
- RWT 310-91, Conodonta: *Idiognathus* sp., *Mesogondolella* sp., Mt. Hozomeen, greenstone of Hozameen Group

Cultural Resource Contexts

Archeological sites in NOCA have revealed well-preserved faunal and floral remains. Such items are just one example of fossils found in cultural resource contexts; Kenworthy and Santucci (2006) present an overview and cite selected examples from throughout the NPS. In the upper Skagit River valley between Damnation Creek and Ross Lake, charred animal bone fragments are preserved in food processing features and under a rockshelter overhang dated 2,000-250 ybp, and include mountain goat (*Oreamnos americanus*), deer (*Odocoileus* spp.), bear (*Ursus* spp.), beaver (*Castor canadensis*), elk (*Cervus elaphus*), Canid, and unidentified fish and bird (Mierendorf 1986; Mierendorf et al. 1998). Two *Dentalium* shells, of marine origin, were also found in archeological context at Newhalem Rockshelter (Mierendorf 1997). From site 45WH239 in the upper Skagit River valley, beetle fragments (*Dyslobus decorates*) were recovered from intact deposits dated 2,700-1,400 ybp (Bush et al. 2008).

Abundant carbonized plant remains are preserved in most intact food processing features. Red elderberry (*Sambucus racemosa*) seeds were identified from a cookstone feature dated 475 ybp from the Skagit River near Damnation Creek (Mierendorf 1986). Bush et al. (2008) identified seeds of Brassicaceae, Lamiaceae, *Carex*, and *Prunus* from archeological contexts dated 2,700-1,400 ybp in the Ross Lake area. Most recently, abundant carbonized wood has been dated 9,000-2,100 calendar ybp from Cascade Pass, an alpine archeological site located on the crest of the Cascade Range in NOCA (Mierendorf and Foit 2008). The preserved wood fragments are currently being identified, but juvenile wood or branch material from conifer species are clearly present.

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division sponsored a Geologic Resources Inventory (GRI) scoping meeting for NOCA and other NCCN parks which took place in Seattle, Washington, on September 10, 2002. GRI map data was discussed at the meeting; other geologic needs were not identified at that time. Marsha Davis (Pacific West Regional Office) wrote a GRI scoping report covering the North Cascades National Park Service Complex (National Park Service, n. d.). GRI has not yet produced a final report for NOCA.
- NOCA should work with the GRD to identify fossil plant specimens in the park collections. Collections managers should be aware that the accessioning and cataloging of other “geological” specimens, particularly from the Tabor geology collection, may reveal additional paleontological specimens. Locality, collection, and ancillary information for any specimen-of-interest should be checked against Tabor’s own field notes, which are temporarily housed at USGS in Menlo Park, California until they are relocated to USGS archives in Denver, Colorado.
- The park should consider future field inventories for paleontological resources to more fully document in situ occurrences of fossils. The park may consider a formal site documentation and condition assessment for significant fossil localities. Monitoring of significant sites should be undertaken at least once a year in the future. A forthcoming (2009) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring (Santucci et al. in press).
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should photodocument and potentially monitor any occurrences of paleontological resources. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts. Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

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Olympic National Park

Olympic National Park (OLYM) protects a variety of superlative landscapes and diverse ecosystems including subalpine, montane, and lowland forests, temperate rainforests, alpine meadows, and coastal environments, and associated endemic flora and fauna (e.g. Roosevelt elk, Olympic marmot, and Piper's bellflower). Conservation began in 1909 with the establishment of Mount Olympus National Monument, which was administered by the U. S. Forest Service. Administrative responsibilities were transferred to the National Park Service in 1933, and the area was re-designated as Olympic National Park in 1938. The administrative boundary was modified many times, in 1940, 1943, 1953, 1976, 1986, and 1988. OLYM was designated a UNESCO International Biosphere Reserve in 1976, and a World Heritage Site in 1981. Olympic Wilderness, accounting for 95% of OLYM, was designated on November 16, 1988. OLYM encompasses a total of 373,384 ha (922,651 acres), comprised of essentially two discrete areas; one narrow corridor along the Pacific Coast, and one large area of the Olympic Mountains and western foothills.

Geologic Background

OLYM is situated in the Olympic Mountains section of the Pacific Border Physiographic Province. The park is located approximately 50 km (30 mi) by air west of Seattle, Washington, on the Olympic Peninsula, in Jefferson, Clallam, Grays Harbor and Mason counties. The majority of OLYM is bordered by private land along the Strait of Juan de Fuca to the north, by Olympic National Forest and several wilderness areas to the east and south. The coastal corridor is bordered on the west by Olympic Coast National Marine Sanctuary and Quillayute Needles National Wildlife Refuge and Wilderness. The intervening land consists of private, U.S. Forest Service, and tribal lands.

The bedrock geology of the Olympic Peninsula consists of volcanic and sedimentary rocks that were structurally deformed and subjected to low degrees of metamorphism. The complexly folded and faulted strata, which often outcrop as small juxtaposed blocks, are difficult to correlate and interpret. Rugged topography, dense vegetative cover (particularly within the temperate rainforests and western lowlands), and scant fossil occurrence have further hindered geologists' understanding of the area. Throughout the last century, a number of geologists working in the region have set about "solving" the geologic puzzle, each using a different approach. These sometimes discordant efforts led some geologists to develop a unique nomenclature for rocks in their area of interest, while other geologists adopted, adapted, or modified the nomenclature used by their predecessors. Ultimately, a variety of formal and informal, and sometimes overlapping, rock unit names had developed. While the geologic story continues to unfold, this report presents a summary of the current understanding of Olympic geology. This introduction to OLYM geology begins with a brief summary of prevalent depositional paleoenvironments and the major rock suites of the Olympic Peninsula. It explains the large-scale tectonic processes that formed the peninsula, and concludes with an overview of the significance of fossil occurrences in the area. Refer to the appendix for a geologic time scale.

The majority of rocks within OLYM were deposited in a marine environment and include marine sedimentary rocks and submarine volcanic rocks. Most of OLYM's rocks were subsequently covered by glacial deposits. Marine sedimentary rocks within OLYM are predominantly siltstones and sandstones, which are observed here as thin, rhythmically alternating beds. The fine-grained sedimentary beds are interpreted to represent the slow accumulation of sediments on submarine fans and slopes. Finer sediments, particularly when bedded, are likely to preserve trace fossils such as worm burrows (e.g. Armentrout 1980), and *in situ* epifaunal and infaunal marine invertebrates. The normally-quiet deep, open marine waters were episodically disrupted by large scale submarine landslides and debris flows (turbidites), which are represented by massive or chaotic bedding, and characterized by coarse-grained sandstones and conglomerates. Coarser sediments (deposited during landslides) are likely to preserve a mixture of *in situ* taxa and taxa transported from the shelf environment (e.g.: Nesbitt and Goedert 2003). Volcanic rocks within OLYM are predominantly tholeiitic basalts, and are therefore compositionally similar to lavas produced at fissures along the sea floor. Where exposed, the majority of these basalts

display pillow lava-textures, which occur when hot lava is erupted into water. These submarine basalt layers include interbeds or lenses of silt, sand, pebbles or larger clasts, and even limestone. Microfossils within the sedimentary interbeds help determine the ages and correlations of these volcanic rocks.

Most rock units within OLYM are described as either marine sediments with volcanic constituents or volcanic rocks with marine sedimentary interbeds. The intercalated nature of lavas with sediments indicates that the eruptive center (or centers) were proximal to the depositional fans and slopes, and in some cases reflect times when the lavas erupted in shallower water, depending upon the nature of the interbedded sediments and their associated taxa.

The rock units depicted on most geologic maps of the Olympic Peninsula can be categorized as one of three basic suites or groups: peripheral rocks, core rocks, and coastal blocks; each of which are described below. The boundary of OLYM includes virtually all of the core rocks; several coastal blocks, and the majority of the peripheral rocks lie outside the park.

Peripheral rocks resemble a horseshoe in their pattern of outcrop distribution. In the North, the horseshoe extends from the farthest northwestern portion of the Olympic Peninsula, near Archawit Peak, and along the Strait of Juan de Fuca. The peripheral rocks wrap the eastern edge of the peninsula near Hood Canal and extend as far south as the northern portion of Grays Harbor County and west as far as Quinault Ridge. The peripheral rocks, or Crescent Terrane, consist of the following rock units: Blue Mountain unit (informal), Crescent Formation, Aldwell Formation, Lyre Formation and the Twin River Group.

Core rocks, which are situated within the peripheral horseshoe, are intensely folded, sheared, and variously metamorphosed. The core rocks are minimally correlated and, therefore, the mapping of these units remains contentious. A large portion of the rugged and remote Olympic Mountains is comprised of core rocks. In the literature, the core rocks have historically received little attention, possibly due to the inaccessibility of the terrain. The term “core rock” is inconsistently applied to rocks on the western portion of the peninsula. Tabor and Cady (1978) apply names to groups of rocks (or “lithic assemblages”) in the core area, based generally on the degree of deformation or gross lithology. Tabor and Cady’s lithic assemblages include (all are informal designations): Elwha, Grand Valley, Needles-Gray Wolf, Western Olympic, Mount Constance, and Hoh. Some subsequent workers have abandoned Tabor and Cady’s nomenclature without proposing formal names; opting instead for strictly lithologic classifications (e.g. the “Marine clastic rocks, dominantly thick-bedded lithic sandstone (Miocene-Eocene),” of Gerstel and Lingley Jr. 2000). Stewart and Brandon, 2004, designates a more recent formalized nomenclature for the rock units. Geologists agree that the rocks situated in the core of the Olympic Peninsula represent predominantly deep marine sediments that were folded and faulted during large-scale crustal movement.

Coastal formations and blocks, some of which are referred to as “western core rocks,” include formally named units, informally named units, units with formal names which are typically disregarded, and “blocks” which are fault-bounded groups of rocks that are not otherwise formally named or stratigraphically correlated. Coastal blocks are considered to have been emplaced by accretion, underthrusting, or piercement (diapiric rise) and include the Portage Head-Point of Arches Coastal Block (Sooes Terrane), the Ozette Lake-Calawah Ridge Block (Ozette Terrane), the Cape Alava Coastal Block (Ozette Terrane), and the piercement structures of the Hoh Formation (formal, but rarely used) or Hoh assemblage (informal, but more widely accepted). Coastal formations, including the Humptulips, Montesano, Quillayute, and Quinault formations, represent emergent shelf deposits.

Accretion, the major geologic process responsible for forming the Olympic Peninsula, is driven by subduction of oceanic crust of the Juan de Fuca Plate beneath the coastal margin of continental crust of the North American Plate. Similar to a grocery store checkout line where groceries pile up at the end of a conveyor belt, the “conveyor belt” of the Juan de Fuca Plate transports terranes and other off-shore marine deposits and features to the subduction zone where the features pile up and are compressed together (or “accreted”).

The Crescent Terrane is one of the oldest rock units of the Olympic Peninsula. The precise origin of the Crescent Terrane is still a subject of debate in the literature. The terrane may represent a ridge where the seafloor had rifted, an island arc, a hotspot track, a series of seamounts, or an area where the edge of the continental shelf rifted apart before it rejoined the North American continent (e.g. Duncan 1982; Haussler et al. 2003). Whatever its origin, one widely accepted explanation for the horseshoe shape of the peripheral rocks is that the Crescent Terrane was transported by a subducting slab of oceanic crust and then squeezed into a preexisting embayment along the ancient continental margin.

During subduction, deep marine sediments were scraped off the top of the seafloor and were piled up at the subduction zone. Subduction caused the scraped-off rocks to be thrust over or under the adjacent rocks. The core rocks and coastal blocks are part of this pile, which geologists call a subduction complex or accretionary wedge. Heat and forces at the accretionary wedge were great enough to fold, break, and jumble the rocks, as well as cause some of the minerals to chemically restabilize at the higher temperatures and pressures. Unfortunately for paleontologists and field geologists, these processes typically destroy the fossils in the subducting rocks and sediments. The thick pile of oceanic sediments is less dense than the surrounding rock and has a tendency to “buoy up” from the softer material in the underlying mantle. This buoyancy caused the uplift of the Olympic Mountains. Subduction of the Juan de Fuca Plate continues today. It is the process responsible for the uplift of the Olympic Mountains, the formation of the Cascade Range volcanoes, and the primary cause of earthquakes of the Pacific Northwest.

Fossils are not commonly preserved within subduction complexes; the rarity of OLYM’s fossil resources adds to their significance. Rocks and fossils of the Crescent Terrane (exposed primarily along OLYM’s northern, eastern, and to some extent, southern boundaries) are fairly well studied, as are the hydrocarbon bearing rock units along the coast. Extremely limited information is available in the literature pertaining to the rocks and fossils of the so-called “core rocks” which underlie the majority of OLYM.

Sedimentary beds and interbeds of all rock units of the Olympic Peninsula likely contain rare to abundant microfossils and nannofossils. Microfossils and nannofossils consist of the skeletal or shelly remains of very small organisms, generally smaller than 1 mm; careful study requires the aid of a microscope. Some of these organisms lived in the water column (planktonic organisms) and others lived on the seabed (benthic organisms). Rocks of the Olympic Peninsula preserve the microscopic remains of protista, including Foraminifera (planktonic and benthic), radiolaria (planktonic), and coccolithophores (planktonic). Because protists evolved and diversified very rapidly, analysis of these microfossils helps to constrain the relative ages of sedimentary deposits. Microfossils are extremely important in the stratigraphic correlation and age determination of Olympic rock units, and contribute to the scientific understanding of accretionary processes.

Marine sedimentary rocks of the peripheral units are locally fossiliferous and may contain a variety of macrofossils, though macrofossils are rarely found within OLYM. Macrofossils are usually greater than 1 mm in size and can be studied with the naked eye. The macrofossils identified from this region are often examples of entirely new species or genera, they often reflect the earliest known examples of a particular taxon in the Pacific Ocean, or they may represent the northernmost occurrence of a particular species. Macrofossils of the Olympic Peninsula are important for climatic and oceanographic reconstructions.

Numerous scientific studies have examined locally variable communities preserved within Olympic rocks. All known sites from middle Eocene to Miocene-Pliocene strata are situated outside of OLYM. However, because rocks of similar ages and lithologies also exist within the park, the potential exists for new and exciting paleontological discoveries to take place within OLYM. The known faunal sites are typified by taxa that are locally highly abundant and low in species diversity, and are interpreted to represent some of the earliest chemosynthetic communities thriving along hydrocarbon seeps (also called “methane seeps” or “cold seeps”) and “falls” (where whale or fish carcasses or large woody debris have settled on the deep ocean floor). Isolated and very small occurrences of limestones are preserved within the dominantly clastic sediments; these limestones formed in conjunction with the methane seep communities. These

sites are sometimes identified from deposits that are otherwise unfossiliferous; fall-associated taxa occur near one another, representing a highly localized ecological community. The oldest known examples of whale-fall communities come from Eocene age strata of western Washington. Goedert and Benham (2003) describe how and where methane seeps are formed.

Using microfossils, Weldon Rau made great strides in resolving ages and relations of rock units throughout the region. A description of his vast collection, acquired throughout the duration of his career with U. S. Geological Survey and with the State of Washington, was recently compiled (Rau 2004). The publication includes a detailed Excel spreadsheet listing all foraminiferal sample localities and related information. The most extensive investigations of Olympic macrofossils, especially mollusks, have been conducted by Richard Squires (California State University), John Armentrout (Mobil Oil Corporation and Cascade Stratigraphics) and Elizabeth Nesbitt (University of Washington, Burke Museum), which build upon and refine the earlier studies conducted by Warren O. Addicott (USGS) and Charles Weaver (University of Washington). Recent studies by Elizabeth Nesbitt (University of Washington, Burke Museum), Kathleen Campbell (University of Auckland, New Zealand), James Goedert (affiliate of the Burke Museum), and Steffen Kiel (Christian-Albrechts-Universität, Germany), address the paleoecology and implications of faunal sites throughout the Olympic Peninsula.

Sources of Paleontological Resources

Fossils have been documented from the following geologic formations and museum collections within OLYM. These fossils present opportunities for resource management (including field surveys, inventory, and monitoring), education, interpretation, and continued or future scientific research in the park.

Crescent Terrane:

The peripheral Crescent Terrane may represent a marginal rift-basin sequence. The Crescent Formation may have formed in a marine basin along the continental margin, above an active subduction zone. The basaltic rocks may have erupted as a result of extensional or “pull-apart” forces within the basin. Older rocks of the Crescent Terrane (Blue Mountain unit and Crescent Formation) may represent the early sedimentary and rifting phases of the developing basin, and the younger strata (Aldwell Formation, Lyre Formation, and Twin River Group) represent later phases, as the basin filled with sediment.

Crescent Terrane: Crescent Formation (early-middle Eocene)

The lower Crescent Formation is dominated by pillow lava structures (evidence of submarine volcanism), that are interbedded with fine grained marine sediments, including sandstone, chert, and limestone. The upper Crescent Formation contains flow structures and columnar jointing (evidence of subaerial volcanism), that are interbedded with volcanogenic conglomerates, sandstones, and red argillites. The upper and lower volcanic portions may have originated from different eruptive vents. The Crescent Formation is exposed along the northern and eastern park boundaries from Mount Constance to Mount Bretherton. The lower Crescent Formation outcrops more frequently within OLYM than the upper Crescent. Exposures of both upper and lower Crescent Formation within OLYM contain Foraminifera (Rau 1964, 1966, 1981). Detailed studies of macropaleontology were conducted by Squires et al (1992) and by Squires and Goedert (1994), based on upper Crescent Formation exposures outside of OLYM.

Exposures of the lower Crescent Formation yield planktonic foraminifera, which are concentrated in the reddish calcareous argillite (or argillaceous limestone) that is interbedded with basaltic lavas of the Crescent Formation. The remains of planktonic foraminifera were probably transported by ocean currents and deposited at quiescent times (Rau 1964). Globigerinids and globorotalids dominate the assemblage. The Crescent Formation is designated an early Tertiary age because Cretaceous-age globotruncanids are absent from the planktonic assemblages. Rau’s map (1964, Plate 1) shows several planktonic foraminiferal localities of the lower Crescent Formation that appear to be situated within OLYM. Localities f11712 and f11713 are just north of Fairholme, f11714 and f11715 are road cuts along Hurricane Ridge road near Round Mountain.

Rau (1964) collected an assemblage of benthic Foraminifera from the upper Crescent Formation at localities outside of OLYM (Observatory Point). Rau (1964, Table 1) identifies the following few to rare occurrences of benthic Foraminifera from locality f11716, at Devils Point along Lake Crescent (within OLYM): ?*Robulus*, *Bulimina corrugata*, ?*Eponides*, *Amphistegina californica*, and questionably *Cibicides mcmastersi*. The benthic foraminifer *Amphistegina californica*, the most prevalent upper Crescent taxon, suggests warm, shallow, clear water. (Please note that tentative taxonomic identifications are, by convention, indicated with a “?”.)

Squires et al. (1992) observe that sedimentary deposits are rare within the dominantly volcanic rocks of the Crescent Formation, and therefore they are not likely to preserve macrofauna. The authors describe a fossiliferous early Eocene locality of the Crescent Formation outside the park (at Pulali Point), where the alternating succession of basalt and shallow water pebble conglomerate yield roughly 40 taxa of macro and microfossils. The age of this locality is based on microfossils and macrofossils. Pulali Point specimens tend to be found among the conglomeratic constituents. Preservation is characterized as “fair,” and diversity tends to be low. Collections are dominated by *Turritella* gastropods (internal molds are most common), but also include wood fragments, disarticulated bivalves, brachiopods (both valves), nautiloid fragments, corals, echinoids, and a crab that is recognized as one of the oldest known from the fossil record of Washington State. The earliest record of the anomiid bivalve genus *Pododesmus* is based on fossils from Pulali Point (Squires 1993). Microfossils include benthic and planktonic Foraminifera, calcareous nannofossils, and Radiolaria. Preservation of some delicate features indicates that transport was at a minimum. Faunal assemblages suggest a warm, generally shallow subtidal environment; Squires et al. found local evidence for fluctuating water depth, noting that Rau (1964) reported a comparable paleoenvironment from a section near Crescent Lake. Specimens identified from the Pulali Point locality have extended the northernmost geographic range of several species of gastropods, bivalves, and one crab (Squires et al. 1992). The authors note that the Crescent Formation type-section (at Crescent Bay, along the Strait of Juan de Fuca) is the only other locality where macrofossils have been studied.

Squires and Goedert (1994) describe a diverse macrofauna in their studies of several upper Crescent Formation localities south of OLYM (at Little River, Grays Harbor County, near Mason County). Nearly 800 good to poorly preserved specimens were collected, but less than 50 specimens were identified to the genus level. The bivalve *Nayadina (Exputens) batequensis* is identified as the most abundant macrofossil found in the upper Crescent Formation by this study. Locally, mollusk shells are so abundant, they are described as a “coquina” (i.e. the sedimentary horizons are primarily comprised of shelly material). The paper states that the upper Crescent Formation, as represented at the Little River and Pulali Point sections, was deposited in the middle of the early Eocene, during the overlap of the foraminiferal Ulatisian Stage (Rau 1981; Almgren et al. 1988) and the molluscan “Capay Stage” (Clark and Vokes 1936; Givens 1974). Based on the minor amount of abrasion exhibited by the specimens, combined with sedimentological evidence, the authors propose that the fossiliferous sedimentary layers of the upper Crescent Formation represent shallow marine environments, occurring when cumulative eruptions of basaltic lavas became influenced by tidal or even subaerial processes. Taxa reported from the upper Crescent Formation at the Little River localities (outside of OLYM) include radiolaria, coccolithophores, Foraminifera, solitary corals, colonial coral, a new species of inarticulate brachiopod (*Craniscus edwilsoni*), articulate brachiopods, polychaete worms (including Rotularia), sea urchins, scaphopods (*Dentalium*), gastropods, bivalves, a barnacle, two sharks (*Isurus?* sp, and *Palaeohypodotus rutoti?*), and fish otoliths.

Groves and Squires (1995) report a new gastropod species (*Proadusta goedertorum*), which appears as a shallow water coquina in the upper Crescent Formation 65 km (40 mi) south of OLYM, at Capitol Peak. Kiel (2008) identifies a wood-fall from a sandstone deposit within the Crescent Formation at a locality south of OLYM (specimen housed at the Burke Museum). Schweitzer (2000) described fossil crabs from the Blue Mountain unit in the Tyler Peak quadrangle, east of OLYM. Similar discoveries could be made within OLYM.

Crescent Terrane: Aldwell Formation (middle-late Eocene)

The Aldwell Formation of the peripheral Crescent Terrane consists of deep marine siltstones with lenses of unsorted conglomerate and basalt breccia that overlies and sometimes intertongues with the upper portion of the Crescent Formation. The type section is located just north of OLYM at Aldwell Lake. According to Tabor and Cady (1978), earlier studies referred to portions of the Aldwell Formation as the “Boundary Shale” (Weaver considered the Boundary Shale to be the uppermost part of the Crescent Formation in his 1937 report). The Aldwell Formation yields a foraminiferal assemblage representative of cooler, deeper water than those contained in the underlying Crescent Formation, indicating a deepening trend (Rau 1964, 2000), at least within the local marine basin.

Within OLYM, the Aldwell Formation outcrops on the northern tip of Lake Crescent and at a small outcrop near Round Mountain. Rau assigns a middle-late Eocene age to the Aldwell Formation, based on its foraminiferal assemblage (2000). Two Foraminifera localities discussed in Rau’s 1964 report appear to fall within OLYM: USGS localities f11723 and f11724 (see Rau 1964 for specific locality information). Aldwell Formation locality f11723 is located within OLYM along the Lyre River. Rau’s Table 2 (1964) tentatively identifies the following Foraminifera from f11723: *Robulus holcombensis*, few to rare *Nodosarua longistagata*, *Pseudoglandulina* cf. *P. inflata*, few to rare *Bulimina* cf. *B. bradburyi*, abundant *Bulimina corrugata*, *Bulimina* cf. *B. ovata*, *Alabamina kernensis* sp., few to rare *Globigerina* cf. *G. yeguaensis*, and *Anomalina* cf. *A. regina*. Aldwell Formation locality f11724 is located along the north shore of Lake Crescent, near Piedmont, Washington. Rau (1964) tentatively identifies the following Foraminifera from f11724: questionably *Nodosarua longistagata*, *Bulimina lirata*, few to rare *Cassidulina globosa*, *Allomorphina macrostoma*, *Chilostomella* cf. *C. oolina*, and *Cibicides celebrus*.

Squires et al. (1992) tentatively identified a fossiliferous Aldwell Formation locality outside of OLYM (near Pulali Point) where the rocks are interpreted to represent the deep water channel scours and fills of a submarine fan. The submarine fan deposit contains Foraminifera which are ascribed to the middle Eocene, and reworked Eocene-age concretions. Most specimens were recovered from the basal boulder conglomerate or the allochthonous sandstone blocks. Brachiopods, nautiloids and crabs were identified from reworked concretions of the basal conglomerate. Algae, wood fragments, brachiopods, bivalves, crabs (both shallow and deep marine varieties, within reworked concretions; Schwietzer et al. 2000), lobster (within reworked concretions), and a shark tooth were identified within allochthonous sandstone blocks. *In situ* finds include gastropods, bivalves, an echinoid, and fish scales. Delicate “mud pectens” are preserved in the upper sequence, suggesting stable conditions at bathyal depths (depths of 200-3,500 m or 650-11,500 ft).

The Aldwell Formation contains concretions which are known to preserve a diversity of taxa including fossil crabs. Other concretion-bearing strata may also be fossil-rich. Some concretions may occur in situ while others may be allochthonous (having been transported from shallower water environments, possibly during storm events or while entrained in debris flows). Nesbitt and Goedert (2003) warn that faunal diversity data and geochronology data obtained from these sections may not reflect the actual diversity at the time of formation.

The Aldwell Formation correlates to the Humptulips Formation (Rau 1984), which also correlates to lower portions of the notably fossiliferous Twin River Group. Outside of OLYM, many unique faunal sites are described from the Humptulips Formation including methane seep communities (Goedert and Squires 1990; Kiel 2006) and wood-fall communities (Kiel 2008). Younger strata, such as the Lincoln Creek and upper members of the Twin River Group, preserve whale-fall and fish-fall communities (Kiel 2008), but whale-fall communities have not been described from strata occurring within OLYM. Kiel (2008) describes taxa found among the various “fall” communities, compared to taxa found among hydrocarbon seep and hydrothermal vent communities. Goedert and Squires (1990) discussed methane seep communities found in the Humptulips and other formations.

Crescent Terrane: Lyre Formation (middle Eocene)

Lyre Formation of the peripheral Crescent Terrane is a marine conglomerate and sandstone with unsorted or very coarse-grained channel deposits. As described by Tabor and Cady (1978), the Lyre Formation does not contain abundant fossils, except at an outcrop outside of OLYM (near Maynard, Washington). Tabor and Cady (1978) note that significant facies changes occur across the mapped unit. Tabor and Cady (1978) and Schasse (2003a) mapped a sand-siltstone facies of the Lyre Formation on the slopes above the north shore of Lake Crescent. Tabor and Cady (1978) mapped a breccia and conglomerate facies of the Lyre Formation within the coastal corridor of OLYM at Point of Arches and Portage Head. Later, this same outcrop was mapped as part of the Portage Head-Point of Arches Block of the Sooes Terrane (further described in the “Potential Sources” section) by Schasse (2003b). The outcrop yields middle Eocene Foraminifera identified by Rau (reported as written communication in Snively et al. 1993). Rau (1964) notes that scant foraminiferal occurrence in the Lyre Formation may indicate rapid deposition and a turbulent environment at that time.

Rocks of the Olympic Subduction Complex (Eocene-Oligocene):

The majority of OLYM’s bedrock geology is comprised of these rocks. Referred to as “(eastern) Core Rocks” by Tabor and Cady (1978), “Olympic Subduction Complex” by Brandon and Calderwood (1990), and “Terrane South of the Crescent Fault and North of the Calawah Fault” by Schasse (2003a, 2003b), these rocks represent the accretionary prism of the Cascadia Subduction Zone. Deep marine sediments and rocks were sheared off the top of the subducting oceanic crust and subjected to elevated pressures and temperatures, causing the formation of certain metamorphic minerals (low grade metamorphism: zeolite facies to prehnite-pumpellyite facies).

These rocks were divided into the following groups, named after the prominent geographic features they underlie: Needles-Gray Wolf, Mount Constance, Elwha, Grand Valley, and Western Olympic lithic assemblages (Tabor and Cady 1978). The majority of fossil occurrences within core rocks are reported from exposures of the Needles-Gray Wolf lithic assemblage, within OLYM.

Recent map makers have abandoned these names and have instead opted to describe the “core rocks” in strictly lithologic terms. In the general parlance of these geologists (Gerstel and Lingley Jr. 2000; Gerstel and Lingley Jr. 2003; Schasse 2003a, 2003b), these units are dominated by “Marine sedimentary rocks,” “Marine rhythmites” (or turbidites), and minor “Basalt.”

Olympic Subduction Complex: Marine sedimentary rocks

Thickly bedded sandstones, conglomerates, and minor siltstones; sometimes crossbedded, commonly micaceous, and locally calcareous. Most of these rocks have been metamorphosed to semischist, phyllite, and slate. Fossils are not reported from these strata.

Olympic Subduction Complex: Marine “rhythmites” of Schasse (2003a) or “turbidites” of Squires and Goedert (1997)

Thinly bedded metamorphosed micaceous sandstones and siltstones, containing slaty intraclasts, limestone interbeds, and concretions. Schasse (2003a) mentions that a portion of this unit is referable to the Tabor and Cady’s (1978) Needles-Gray Wolf lithic assemblage and contains Tejon Stage (34-44 million years old) megafossils, described by Squires and Goedert (1997) and summarized below.

Cady and MacLeod (1963) report fragments of megafossils including a gastropod (*Gremmula?*), bivalves (*Acila* and *Crassatella?*)—from specimens which Squires and Goedert assert cannot be identified to the familial level), in addition to microfossils from the Needles-Gray Wolf lithic assemblage. Tabor (1975) indicates that the bivalve *Venericardia* and gastropod *Turritella* were found here. Squires and Goedert (1997) indicate that an agglutinated tube fossil *Terebellina* found in Needles-Gray Wolf rocks near Obstruction Peak by Danner in 1955 was later determined to be the remains of the deep water foram, *Bathysiphon*, by Miller (1995), and that *Bathysiphon* remains are also found in peripheral rocks (Squires and Goedert 1997).

Squires and Goedert (1997) present a faunal list of specimens collected from a locality just north of The Needles, which is dominated by external molds of juvenile whorls of the gastropod *Turritella uvasana*, and recrystallized shells and internal molds of the bivalve *Callista andersoni*. The list includes gastropods (*Turritella uvasana*, *Crepidula*?, and a naticid), and bivalves (*Glycymeris*, *Venericardia*, ?*Callista andersoni*, and ?*Callista conradiana*). Specimens collected from sparsely fossiliferous localities near Mount Baldy are tentatively identified as belonging to the middle Eocene to late Eocene. These specimens include: Foraminifera (*Bathysiphon*), unidentified echinoderm fragments, gastropods (*Turritella uvasana*, *Whitneyella*?, *Gemmula*), and bivalves (*Crepidula*?, *Acila* (*Truncacila*) *decisa*, *Glycymeris*, *Venericardia*, ?*Callista andersoni*, ?*Callista conradiana*).

Tabor et al. (1972) depicts several coccolithophore, radiolarian, and foraminiferal localities; taxa are not discussed in detail beyond age-approximations. Microfossil localities are plotted along South Branch Little River, along a north-trending slope above Morse Creek (opposite Klahhane Ridge), above a minor tributary of Morse Creek in the Maiden Peak area, at the confluence of two larger Morse Creek tributaries north of Elk Mountain, at Etta Lake, along a trail above Grand Lake (connecting to Obstruction Point Road), around and above Lillian Glacier, several localities in the vicinity of Mount Cameron and Cameron Pass, by Cedar Lake, by Gray Wolf Pass, and at Thousand Acre Meadow. The map description alludes to macrofossil localities that were not otherwise discernible on the map; these may be the same macrofossils discussed in Squires and Goedert's 1997 report. The map description also refers to concretions within Mount Constance Lithic Assemblage, which may have been subsequently mapped as Lyre or Twin River formations. Concretions in other units have been reported to contain fossils.

Similarly, Cady et al (1972) mention microfossils and macrofossils, citing written communication with W. O. Addicott and W. W. Rau. The paper reports that the Needles-Gray Wolf—referred to as Soleduck/Solduc Formation by Weaver (1937)—contains worm tracks and flattened casts of worm burrows.

One fossil locality within the Oligocene-Eocene Western Olympic lithic assemblage of Tabor and Cady (1978) is located near Mt. Appleton. It is shown as locality M14975 on Tabor and Cady's map but this appears to be an invalid number because no such locality or fossil collection could be found at USGS Menlo Park archives in the 1980s (J. L. Goedert, pers. communication). Fieldwork by J. L. Goedert in 1994 revealed that the locality is actually about one mile farther west than shown on the geologic map. This locality is a poorly exposed and weathered limestone mass. A few poorly preserved bivalves were collected, but they cannot be identified. A sample of the limestone was analyzed by Dr. J. Peckmann (Forschungszentrum Ozeanränder, University of Bremen) and he confirmed that it formed due to the oxidation of methane at a cold-seep (Kiel, in preparation). A collection of fossils made in 1940 was identified by R. Stewart as including the bivalve genera *Solemya*, *Thyasira*, *Vesicomya*, *Panope*, *Macrocallista*, *Spisula*, and *Thracia*, as well as the scaphopod *Dentalium* (Harvey 1959). The whereabouts of this collection is unknown. Several of the bivalves are taxa that are common in methane seep communities.

Coastal Formations and Piercement Structures (upper Eocene-Pliocene):

A majority of the coastal area is covered by thick Quaternary glacial deposits and alluvium. Rock outcrops are generally confined to the sea coast, river valleys, road cuts, and some ridge tops. These isolated localities expose rocks of the Hoh Assemblage and Quillayute Formation.

Coastal Formations: Quillayute Formation (late Miocene-Pliocene)

Medium to coarse grained sandstones with fossiliferous conglomeratic lenses identified as the Quillayute Formation are confined to narrow outcrops along the Bogachiel and Quillayute rivers, generally outside of the OLYM boundary. In the literature, the same rocks have been referred to as "Empire sandstone" (Arnold and Hannibal 1913). The Quillayute Formation unconformably overlies rocks belonging to the Hoh assemblage. Approximately 60 taxa (including gastropods, bivalves, and an echinoid [*Kewia* sp., sand dollar]) were identified by Addicott (in Rau 1979) from four exposures along the Bogachiel and Soleduck

rivers (outside OLYM), and an assemblage of mollusks were collected from an outcrop along Maxfield Creek (outside OLYM) by Reagan (1909). Additionally, the Burke Museum maintains numerous marine invertebrate fossils collected by both C. E. Weaver and R. J. Rector from localities near the Bogacheil River and Maxfield Creek. Although the collection localities are situated outside of OLYM, fossils could be washed downstream and collected within OLYM as “float” (E. Nesbitt, Burke Museum, pers. comm., 2009). Bivalves from the Weaver and Rector collections at the Burke museum include *Yoldia* sp., *Ostrea* sp., *Pandora* sp., *Cerastodesma meekianum*, *Protothaca staleyi*, *Macoma inquinata*, *Tellina* sp., *Spisula* (*Mactomeris*) *albaria*, *Pseudocarium olympica*, *Schizothaerus nutalli*, and *Mya arenaria*; gastropods include *Polinices* (*Tectonatica*) *nuttali*, *Calyptrea inornata*, *Strombiformis washingtoni*, *Neptunea lirata*, *Liomesus sulculatus*, *Gyrineum mediocre*, *Thais lamillosa*, *Thais lima*, *Purpura foliata*, *Antiplanes perversa*, *Lora tabulata*, and *Olivella pedroana*. The crabs *Cancer majister* and *C. coosensis* were described from these outcrops (Goedert and Berglund 1992) and non-diagnostic Foraminifera were collected from these outcrops by Rau (1979). Cetacean bones are common in some exposures (J.L. Goedert, pers. comm., 2009). The faunal assemblages indicate a shallow water littoral environment. Some macro and microfauna known from the Quillayute Formation are also common to the Quinault and Montesano Formations of Southwest Washington and the Empire Formation of Oregon (Rau 1979.)

Piercement Structures: Hoh assemblage (late Eocene-Oligocene-Miocene)

The Hoh rocks are “piercement structures” that were extruded up through younger overlying rocks. North-south trending mélange units typically coincide with thrust-faults, which were subsequently offset by strike-slip faulting. Field relationships of units bearing age-diagnostic microfossils indicate that some younger strata have been thrust underneath older strata, particularly in the lithologic suites exposed north of Goodman Creek (Rau 1979).

Sheared and folded rocks of the Hoh assemblage include a range of lithologies and ages, and have been variously influenced by physical and metamorphic processes (e.g. some rocks appear to have been folded once, while others appear to have been folded several times). Generally, the shales, siltstones, massive brown sandstones, conglomerates, brecciated mélange, and volcanic rocks of the Hoh assemblage are interpreted as turbidites that were deposited in a marginal basin setting. The rocky headlands at Kalaloch and between the Hoh and Quillayute rivers are formed out of resistant Hoh turbidites, and the intervening coves are formed by more easily eroded Hoh mélange (Rau 1980).

A rare and unusual fossil starfish was recently (July 2009) recovered from rocks of the Hoh Formation. This is the first known fossil of its kind to be found in these rocks and it is the first from this area. A park visitor found the fossil at a popular OLYM beach (near Kalaloch) and reported the discovery to an OLYM interpretive ranger. The starfish was found in an outcrop of friable sandstone—part of a Hoh turbidite deposit, which preserved many delicate details (see cover illustration). Gay Hunter (OLYM Museum Curator) described the exciting find to Kirk Johnson, Ted Fremd, and Liz Nesbitt, who all advised that the specimen should be removed from the friable rock formation at the popular beach locality. Steve Fradkin (OLYM Coastal Ecologist) used a diamond blade saw to remove the specimen and its associated rock matrix. The specimen is being prepared and examined at the University of Washington Burke Museum under the direction of Liz Nesbitt. The specimen has not yet been identified, but it may be a new taxon given its rarity.

Microfossils have been collected from Hoh rocks at numerous sites along the coast at OLYM. Foraminifera from Hoh Head to First Beach, collected by Rau (1979), indicate bathyal depths in cold, open waters. The presence of some shallower water Foraminifera indicate fluctuations in water depth or post-mortem transport. Turbidic sandstones and siltstones outcrop continuously for 600 m (2,000 ft) at Browns Point and Starfish Point. Rare Foraminifera collected from Browns Point are early Miocene in age. At Starfish Point, siltstones yield Foraminifera and sandstones yield megafossils (Rau 1979). The Hoh turbidite at Destruction Island is similar to the siltstones and sandstones at Browns and Starfish Points. Rau also collected Foraminifera “immediately below the Destruction Island viewpoint sign” and near “Beach Trail 5” (Rau 1979).

Many megafossils are reported from a locality 2.5 km (1.5 mi) upstream from the mouth of the Hoh River. All taxa inhabited shallow marine waters during the early-middle Miocene, according to Addicott (pers. comm. in Rau 1973). Specimens identified by Addicott include: Gastropods (*Buclarkia oregonensis*, *Cancellaria* cf. *C. alaskensis*, *Crepidula* aff. *C. rostralis*, and *Trochita*?), and bivalves (*Acila* cf. *A. conradi*, *Diplodonta parilis*, *Glycymeris*, cf. *G. vancouverensis*, *Solen* cf. *S. curtus*, *Tellina emacerata*, *Thracia schencki*, *Spisula albaria*, and *Vertipecten fucanus*) (Rau 1973).

A locality known as Fletcher's Ranch, by Fossil Creek (outside OLYM?) yields a quantity of gastropods, scaphopods, and bivalves representing a subtidal environment (identified by Addicott in Rau 1979), and relatively deeper water (inner shelf) fauna have been collected from a locality along Mosquito Creek (between Hoh Head and Goodman Creek). Many of these taxa are common to the Clallam Formation (a fossiliferous unit that outcrops outside OLYM, along the Strait of Juan de Fuca between Pillar Point and Slip Point), including the species *Vertipecten fucanus*.

Weaver's 1916 manuscript lists three macrofossil localities which appear to lie within OLYM: Locality 201 (ocean cliffs 2.4 km, or 1.5 mi, north of Point Grenville), which contains the bivalve *Pecten coosensis* Shumard; locality 202 (approximately 3 km, or 1.75 mi, north of Point Grenville in cliffs along the ocean), which contains the bivalve *Yoldia submontereyensis* Arnold; and locality 177 (Ocean Cliff south from Hoh River, Jefferson County) which probably contains gastropods and bivalves. However, due to an apparent typographical error in the manuscript's faunal list, it is unclear exactly which genera are preserved at locality 177. Liz Nesbitt (pers. comm. 2009) reports that these localities actually represent the Quinault Formation.

Weaver (1912) describes fossiliferous sandstones and shales of the "Montesano Formation" as occupying most of the area south of Ozette Lake and north of the Hoh River. This is the same area where the Hoh assemblage and other undifferentiated rocks are mapped by later geologists. Based on similar fauna, Weaver correlates this "Montesano Formation" with other Montesano outcrops to the south (near the town of Montesano). He does not present locality information, but lists the presence of plant remains, gastropods, bivalves (including the first described species *Chione chehalisensis* and *C. montesanoensis*), scaphopods, echinoderms, and shark's teeth from the Montesano Formation. In a later manuscript, Weaver refrains from applying formal names to the strata, and recommends that others refrain from correlating strata until additional information is acquired (Weaver and Van Winkle Palmer 1922). The difficulty of correlating the Hoh strata within the park challenges geologists and paleontologists today.

"Hoh Formation" is the formally recognized name for these rocks. "Hoh Rock Assemblage" is preferred by Rau because it accounts for the full variety of rocks present, and Tabor and Cady (1978) refer to the suite as the "Hoh lithic assemblage." Recent mapping by Gerstel and Lingley Jr. (2000) abandon proper names in favor of, "Marine clastic rocks, dominantly thick-bedded lithic sandstone," "Marine sedimentary rocks, rhythmic thin- to medium-bedded sandstone and shale," "Marine clastic rocks, dominantly thick-bedded lithic sandstone conglomerate, pebble," and "Tectonic breccia." Rau (1973) mentions that Glover (1940) originally referred to part of the Hoh assemblage as "Brown's Point Formation;" though not a formal designation, the name occasionally appears in the literature.

Quaternary deposits (Pleistocene - Holocene)

The majority of the unconsolidated sediments covering OLYM were deposited by alpine glaciers. Numerous investigations have determined that the glacial history of the Olympic Mountains (and of other coastal mountain ranges) does not fully correlate with continental glacial history. Heusser (1972) reports an organic and pollen rich sea cliff locality 3 km (1.8 mi) North of Kalaloch, WA (within OLYM) that was used to correlate this climate sequence with the major sequences preserved throughout the Puget Lowland. However, Heusser ultimately concludes that the western Washington sequence is more complex. Heusser's other studies have focused on sites from the lower Bogachiel River (Heusser 1978) and the Hoh River valley (Heusser 1964, 1974). Similar studies were also conducted by Florer (1972, 1973).

The glacial record of the western valleys may also be asynchronous with respect to that of the eastern valleys. Thackray (2001) determined that six alpine glacial advances are recorded from the west side of Olympic Mountains during the Wisconsinan, from 54,000 to 18,300 radiocarbon years before present (ybp). The last glacial maximum seems to correspond to warmer and wetter climates. This is consistent with Holocene glacial history observed in other areas, indicating that recent alpine glacial systems forming in West Coast Mountains are known to be sustained by the precipitation delivered by Pacific climate cells. However, Heusser et al. (1999) observe drier conditions during the majority of Wisconsinan time, based on pollen assemblages obtained near the town of Humptulips, WA, indicating that the Laurentide (Cordilleran) ice sheet was a more significant influence on the regional, pre-Holocene climate.

Only the northernmost portion of OLYM was affected by the Cordilleran continental ice sheet. The famous Manis Mastodon paleontological and archeological site (18 km, or 10 mi, northeast of OLYM) is preserved in late Fraser age (Vashon Stade) recessional glacial deposits. Bones of mastodon, caribou, and bison were recovered from the site along with plant fossils and pollen. Pollen and plant assemblages containing the remains of Cactaceae (cactus) indicate that the eastern rain shadow of the Olympic Mountains was warm and dry from 12,000-11,000 ybp (Petersen et al. 1983). However, the presence of *Ceratophyllum*, a drought-intolerant flowering plant may indicate a more complex microclimate.

Throughout the Olympic Mountains, the glacial history included episodes of ice-damming and the subsequent formation of glacial lakes (Riedel et al. 2006). These lake deposits yield pollen and woody material. Outside of OLYM, the remains of Pleistocene spawning sockeye salmon were identified from lacustrine deposits along South Fork Skokomish River (Smith et al. 2007).

Rau (1973) briefly discusses Quaternary paleontological resources along the coastal corridor, including: Organic rich lacustrine sediments between the Hoh River and Point Grenville, emergent fluvial and beach deposits exhibiting holes bored by piddock clams (*Pholodidea penita*) at Browns Point and Starfish Point, and carbonized plants and woody material found between Scott's Bluff and Taylor Point.

Prolific and diverse, beetles (order Coleoptera) are an excellent paleoclimate indicator, though specimens collected from Quaternary deposits are generally interpreted to represent a time of taxonomic stasis rather than speciation (Ashworth 2001). Coleoptera thrive over a vast geographic range in a variety of terrestrial and freshwater environments, from arid deserts to tropical rainforests. Fossil beetles are commonly preserved in unconsolidated sediments deposited in shallow lake, marsh, and fluvial environments. Shaoguang Cong conducted doctoral research on fossil beetle assemblages collected from Quaternary deposits. Fossil beetle assemblages collected from seacliffs near Kalaloch (within OLYM) indicate that the 44,000-48,000 ybp (Middle Wisconsinan) climate was similar to that of today. Some species which are not present in the area today (*Micropeplus laticollis*, *Olophrum consimile*, *Olophrum boreale*, *Arpedium cribratum*, and *Tachinus thruppi*) indicate that the temperature was approximately 1°C cooler than today. Late Pleistocene (Later Wisconsinan) deposits yield primarily non-arboreal coleopteran assemblages, indicate that a tundra environment persisted in a climate that was approximately 3°C cooler than today. (Cong 1996)

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within OLYM. However, future field investigations within the park may yield fossils from one or more (or none) of the following geologic units. Fossils may be documented from these units outside of the park.

Coastal Blocks: (Jurassic-Oligocene)

Mapped by Snavely et al. (1993), the coastal blocks contain Foraminifera, Radiolaria, and Cocolithophore microfossils. Snavely et al. do not identify taxa within the text, and all mentions of microfossils are reported by way of personal communication. These coastal blocks represent terranes of rocks formed elsewhere and subsequently accreted onto the ancient coastline of North America during the Cenozoic.

Coastal Block: Sooes Terrane, Portage Head-Point of Arches Coastal Block (Jurassic-Oligocene)

Mapped by Schasse (2003b) the Portage Head-Point of Arches block contains a variety of juxtaposed lithologies (some of which were mapped as Lyre Formation by Tabor and Cady 1978). These rocks are comprised mostly of conglomerates and sandstones, and also include a thick interbed of concretionary siltstone that contains upper Narizian (late middle Eocene) Foraminifera (mapped as “Tpac” by Snavely et al. 1993). A bioturbated sand and siltstone yields Refugian and Narizian (middle-upper Eocene) Foraminifera (mapped as “Tpas” by Snavely et al. 1993). A micaceous feldspathic lithic sandstone with pillow basalts and chert-rich interbeds contains early Cretaceous radiolaria. (Mapped as “Kpas” by Snavely et al. 1993). A pillow basalt with interbedded calcareous argillite contains early Eocene coccolithophores (mapped as “Tpab” by Snavely et al. 1993). Snavely et al. (1993) do not report fossils from the ?Cretaceous-age conglomerate and breccia (mapped as “Tpacb”).

Coastal Blocks: Ozette Terrane, Ozette Lake-Calawah Ridge Block (Eocene-Oligocene)

Snavely et al. (1993) describe the rocks of the Ozette Lake-Calawah Ridge Block as including a sandstone containing lower Narizian (lower middle Eocene) Foraminifera, and a mud-siltstone containing Narizian-Ulatisian (lower middle – middle Eocene) Foraminifera, that includes concretions (no fossil associations with the concretions are indicated within the text). These rocks are exposed in a quarry north of Ozette Lake, by Swan Bay (located just outside of OLYM?).

Coastal Blocks: Ozette Terrane, Cape Alava Coastal Block (Oligocene)

Siltstones, sandstones, and conglomerates of the Cape Alava Coastal Block outcrop at headlands and islands between Sand Point, and just north of Ozette Indian Reservation. The rocks contain Zemorrian? (Oligocene) Foraminifera (Snavely et al. 1993), although no localities or taxa are specifically identified in the text. Snavely also mentions the occurrence of concretions within these units, but does not state whether the concretions are associated with fossils of any kind. Concretions found in other Tertiary marine strata of Western Washington (such as the Aldwell, Humptulips, Cowlitz, Twin River Group, Lincoln Creek, Clallam, Astoria, and Montesano formations) are known to preserve macrofossils.

Crescent Terrane: “Blue Mountain unit” (Paleocene? - Eocene)

The peripheral marine sedimentary rocks of the “Blue Mountain unit” are characterized as dark lithic sandstones and siltstones with Foraminifera (Rau 2000). The unit contains a locally thick conglomerate with rip-up clasts, chert cobbles, and rare concretions. Rocks of the Blue Mountain unit are interpreted as submarine fan deposits, beneath and between eruptive centers. Outcrops occur in one large swath, from near the northern boundary of OLYM, south of Lake Crescent (including Sourdough Mountain, Aurora Peak, Happy Lake Ridge, and Lizard Peak), continuing in and out of the eastern boundary, from Buckhorn Wilderness to Wonder Mountain. The Blue Mountain unit was mapped by Tabor and Cady (1978). At some localities, the upper portion of the Blue Mountain unit is interbedded with the lower portion of the Crescent Formation. Similarly, the Soleduck Formation (or Sol Duc Formation), mapped by Reagan (1909), is also reported to underlie and interfinger with the lower Crescent Formation.

Tabor and Cady (1978) and Arnold (1906) report abundant megafossils from sections of the Blue Mountain unit outside of OLYM (at Crescent Bay, and along the west branch of the Wynoochee River). Fossil crabs from the Tyler Peak quadrangle were described by Schweitzer (2000). Fossils have not yet been described from this unit within the park.

Park Collections

A total of 66 paleontological specimens are curated in the park collection at OLYM, including 42 fossil specimens residing at OLYM, 22 specimens maintained as part of an external collection at the Geosciences Department of North Dakota State University, and two missing specimens (G. Hunter, OLYM Curator, pers. comm., March 13, 2009). Many more are curated in an archeological context. See the “Cultural Resources Context” section for more information.

OLYM's collections include two unidentified specimens, six trace fossils resembling worm burrows, six plant fossils ("wormwood," and other unidentified specimens), 25 mollusks which include ten bivalves (*Acila gettysbergensis*, *Chione securis*, *Macoma* sp., *Pitar arnoldi* var. *etheningtoni*, *Pitar dalli*, *Spisula albaria scappoosensis*, *Spisula hannibali*, *Thyasira bisecta*), and five gastropods (*Fusinus (Priscofusus) chehalisensis*, *Natica dalli*, *Natica teglandae*, *Polinices galianoi*, *Turritella* sp., *T. mauropsis blakeleyensis*). Four mammoth molars and one mammoth tusk comprise the vertebrate fossil collection. Provenance information including age, locality, rock unit, collector and date of collection is largely incomplete.

Twenty-two specimens housed at North Dakota State University consist entirely of Coleoptera collected and published by Shaoguang Cong while conducting graduate research and subsequent work (e.g.: Cong and Ashworth 1996). Specimens include *Agabus* sp., *Amphizoa insolens*, *Bembidion erasum*, *Bembidion grapii*, *Bembidion* spp., *Bidessus affinis*, *Cicindela oregona oregona*, *Diplous aterrimus*, *Donacia hirticollis*, *Nebria crassicornis crassicornis*, *Nebria kincaidi kincaidi*, *Plateumaris neomexicanus*, *Pterostichus algidus*, *Pterostichus castaneus*, *Pterostichus neobrunneus*, *Pterostichus nigrocaeruleus*, *Scaphinotus angusticollis*, *Steremnius tuberosus*, *Trechus chalyheus*, *Zacotus matthewsi*.

As mentioned in the following section, the majority of OLYM's paleontological resources occur as archeological specimens. Descriptions of selected archeological collections follow.

Approximately 100 artifacts of worked and unworked bone material (mammal bone and unidentified bone) were recovered from an archeological site near Toleak Point during a 1958 excavation. In general, individual bones from the Toleak Point collection are not described in detail; OLYM 37095 ("whale bone") and OLYM 16280 ("antler") are exceptions. Several unidentified shell samples were also collected from the site. (See Newman 1959, 1960.)

More than 400 samples of worked and unworked bone material were collected from an archeological site near White Rock Village during a 1961 excavation. Bone material is identified as belonging to osteichthyes, avian, and mammal groups. In general, individual bones are not described in this collection, although there are some exceptions (e.g.: OLYM 14769, teeth; OLYM 15720, mandible; OLYM 15708, skull). Approximately 300 samples of unidentified shell material were also collected from the site near White Rock Village (e.g. Guinn 1962, 1963; Giovas 2007).

More than 1,000 faunal specimens were recovered from the Cedar Creek site. Fauna represented in the collection include an unidentified tetrapod specimen (may be Reptilian or Amphibian), approximately 850 fish specimens, nearly 50 bird specimens, and more than 200 mammal specimens (both terrestrial and marine are represented). The majority of the specimens in this collection are identified to the generic or specific level. Fish specimens are dominated by *Embiotica lateralis*, *Hemilepidotus hemilepidotus*, *Hexagrammos* sp., and *Scorpaenichtys marmoratus*, bird specimens are dominated by orders of seabirds (Charadriiformes, Pelecaniformes, and Procellariiformes), and marine mammal specimens are dominated by the eared seal, *Callorhinus ursinus*. (G. Hunter and D. Conca, pers comm., April 21, 2009).

Approximately 200 faunal specimens were recovered from the Chilean Memorial. Fauna represented in the collection include an unidentified crab specimen, more than 150 fish specimens, approximately 10 bird specimens, and nearly 20 mammal specimens. Fish specimens are dominated by *Hemilepidotus hemilepidotus*, *Hexagrammos* sp., *Ophiodon elongatus*, and *Scorpaenichtys marmoratus*; few of the bird specimens are identified (Anatidae, *Larus*, and *Phalacrocorax*), and mammal specimens are dominated by the mustelid, *Enhydra lutris* (D. Conca, pers. comm. April 21, 2009).

External Collections

According to his 1912 report, Weaver's samples reside at the University of Washington. Weaver and Van Winkle Palmer's collections were studied "in the paleontological laboratory at University of California" then split: Half went with Weaver to the University of Washington, and the other half went with Van Winkle Palmer to Cornell University. However, localities mentioned in the manuscript that seem to be located within OLYM are not described in the faunal list.

Cady's samples (1972 mapping) are with the USGS, Menlo Park; other specimens are housed at USNM – Smithsonian Institution National Museum of Natural History, Washington D.C. (according to Squires and Goedert 1997).

Rau (2004) reports that his entire collection is maintained by the Burke Museum in Seattle, Washington.

Many of OLYM's archeology specimens previously housed at the Burke Museum have been returned to NOCA. Artifacts recovered from the Ozette Village Site are maintained by the Makah Museum in Neah Bay.

Cultural Resources Contexts

The vast majority of OLYM's paleontological resources occur in cultural contexts. Approximately 750 known archeological sites within OLYM contribute to a record of roughly 10,000 years of human occupation in the area. Many of these sites are undocumented. Less than 1% of OLYM's total land area has been surveyed for archeological resources. The majority of archeological studies in the area discuss findings of the Ozette Village site. Encapsulated during a single catastrophic event, the Ozette Village site has been compared to Pompeii in regard to its cultural significance. The village was buried in a landslide that is estimated to have occurred in AD 1700. The majority of the site is located on the Ozette Reservation of the Makah Tribe, but a minor portion of the site, consisting of a midden, is located within OLYM's administrative boundary.

Middens are some of the most conspicuous and common archeological sites within OLYM; they tend to be concentrated along the coast, and are often exposed at wave-cut terraces. Many of these sites preserve a record of occupation dating back 400 years, though some sites are much older. Midden sites include the village at Toileak Point, Strawberry Point, Sandpoint, White Rock Village, Cedar Creek, and Chilean Memorial. Many of the kitchen refuse sites occur as somewhat linear features situated parallel to the shoreline. Middens are most likely to occur near strategic lookouts or prime harvesting locations, but their proximity to shorelines make them particularly susceptible to beach erosion. Some sites were the subject of archeological field studies as early as the 1910s, however the majority of the early work was conducted around the 1950s. Some sites are the subject of ongoing monitoring efforts.

Middens contain both unworked and worked faunal remains, primarily consisting of bones and shells representing the discarded skeletons of organisms harvested for food, as well as tools (such as needles, points, hooks, or wedges) or other objects (e.g.: pendants) fashioned from the skeletons. Excavations reveal that the individual deposits are stratified, recording the temporal changes of the inhabitants' consumptive habits or tool usage. Differing faunal constituents among the strata may reflect seasonal versus year-long occupation or persistent versus recurring use, especially at long-established sites.

Invertebrate faunal remains recovered from middens commonly include chitons such as Steller's chitons (*Cryptochiton sterlleri*), black katy chitons (*Katharina tunicata*), and mossy chitons (*Mopalia muscosa*), gastropods such as spired limpets (*Acmaea pelta*), bivalves such as California mussels (*Mytilus californicus*), steamer clams (*Protothaca stamina*), butter clams (*Saxidomus gigantus*), barnacles (*Balanus cariosus*), and urchin remains. Vertebrate faunal remains may include fish (e.g. *Embiotica lateralis* and *Hemilepidotus hemilepidotus*), aves (e.g. white-winged scoter, *Melanitta fusca*; brown pelican, *Pelecanus occidentalis*, and murre, *Uria* sp.), terrestrial mammals (e.g. deer, *Odocoileus hemionus*), and marine mammals, including eared seals (most commonly *Callorhinus ursinus*, and sometimes *Eumatopias jubata*) and true seals (e.g. *Phoca vitulina*), among other pinnipeds, however, many mammal specimens remain unidentified. (D. Conca, pers. comm., April 21, 2009).

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service – Geologic Resources Division sponsored a Geologic Resources Inventory (GRI) scoping meeting for OLYM and other NCCN parks which took place in Seattle,

Washington, on September 10, 2002. GRI map data was discussed at the meeting; other geologic needs were not identified at that time. A scoping report has not been completed for OLYM. GRI has not yet produced a final report for OLYM.

- The July 2009 discovery and subsequent excavation of the fossil starfish from the Hoh Formation near Kalaloch is an excellent example of paleontological resource management and could serve as a model for future discoveries. The actions of a responsible park visitor reporting the discovery, the collaboration between park staff, working with technical experts, and utilizing proper excavation techniques helped preserve an extremely significant fossil specimen—currently the only fossil starfish known from the Hoh Formation, and one of very few fossil starfish from the Pacific Northwest.
- All known paleontology specimens should be cross referenced into the NPS Museum Catalog (ANCS+) if they were collected from an NPS area.
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should photodocument and potentially monitor any occurrences of paleontological resources.
- Park staff should be aware that even small, fragmental, or otherwise “insignificant-looking” fossils, especially among rocks of the Olympic Subduction Complex (core rocks) are extremely rare and can, therefore, contribute significantly to the understanding of the geology of the Olympic Peninsula.
- Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts. Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist.
- The park should consider future field inventories for paleontological resources to more fully document in situ occurrences of fossils. The park may consider a formal site documentation and condition assessment for significant fossil localities. Monitoring of significant sites should be undertaken at least once a year in the future. A forthcoming (2009) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring (Santucci et al. in press).
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

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Data Sets

Olympic National Park Paleontological Archives.

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

Olympic National Park Collections.

1978–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by OLYM staff; status: Active.

University of California Museum of Paleontology at Berkeley.

Unknown – present. (museum specimens; associated specimen and collections records; field notes; etc.) Originated by UCMP staff; status: Active.

U.S. Geological Survey Collections

1950–present. (research specimens; associated specimen and collections records; field notes; etc.) Originated by Weldon W. Rau.

Burke Museum of Natural History and Culture, University of Washington.

Unknown–present. (museum specimens; research specimens; associated specimen and collections records; field notes; etc.) Possibly originated by Charles Weaver.

North Dakota State University

1994-present. (research specimens; associated specimen and collections records; field notes; etc.)

Originated by Shaoguang Cong.

Cornell University

1922?-present. (research specimens; associated specimen and collections records; field notes; etc.)

Originated by Katherine Van Winkle Palmer and Charles Weaver.

Smithsonian Institution National Museum of Natural History

1961-present. (research specimens; associated specimen and collections records; field notes; etc.)

Originated by W. M. Cady.

San Juan Island National Historical Park

San Juan Island National Historical Park (SAJH) was established to commemorate the peaceable resolution of a boundary dispute between Great Britain and the United States that simmered from 1853 to 1872 when the matter was arbitrated by Kaiser Wilhelm I of Germany. SAJH was established as a National Historical Park, September 9, 1966. SAJH encompasses 709 hectares (1,752 acres), of which 698 hectares (1,725 acres) are federally administered. A park boundary expansion is proposed to include additional land near Cattle Point (C. Davis, NPS-SAJH, pers. comm., January 30, 2009).

Geologic Background

SAJH is located on San Juan Island of the San Juan Archipelago, off the northwestern coast of Washington State. San Juan Island is adjacent to Vancouver Island across Haro Strait, and adjacent to Orcas, Shaw, and Lopez islands across the San Juan Channel. San Juan Island is approximately 25 km (roughly 15 mi) northwest of Ebey's Landing National Historical Reserve, on Whidbey Island. SAJH consists of two discrete management units: English (British) Camp and American Camp. English Camp is situated on the west coast of the northern portion of San Juan Island, along the Garrison and Westcott Bays of Haro Strait and the United States – Canada International Border (Roche Harbor 7.5 quadrangle). Its highest point is Young Hill, which stands 197 m (646 ft) above sea level. American Camp occupies most of San Juan Island's southeastern promontory, surrounded by Griffin Bay, to the north, and by the Strait of Juan de Fuca, to the south. (Friday Harbor; Shaw Harbor 7.5 quadrangles). Mt. Finlayson 90 m, or 295 ft above sea level) is the highest point within American Camp.

SAJH is situated in the Puget Lowland (or Puget Trough) physiographic province, a seismically active portion of northwestern Washington. The Olympic Mountains lie to the southwest and the Northern Cascade Range lies to the east. The Fraser Lowland is the northern extension of the Puget Trough in the Canadian province of British Columbia.

During the Mesozoic Era (see the appendix for a geologic time scale), a subduction zone formed along the western margin of North America's ancient coastline. The subducting slab of oceanic crust, the Farallon Plate, transported and ultimately sutured a variety of terranes (fault-bounded lithospheric blocks) to the mainland. The complex series of thrust blocks comprising the San Juan Archipelago stretches 80 km (50 mi) into the mainland. The rocks of San Juan Island were formed when the Insular Superterrane was thrust into the North American Plate. The Insular Superterrane consists of a number of microterranes (including the Haro, Turtleback, Deadman Bay, Garrison, and Decatur microterranes). Each terrane had its own distinct geologic history before colliding with North America. These microterranes consist mostly of medium-grade metamorphic rocks, which generally are not known for their fossil-preservation potential. However, because of the region's structurally complex geology and because lithologic contacts here are obscured by waterways and a thick veneer of younger deposits, the analysis of fossil assemblages becomes crucial in understanding the geologic history of the area.

To summarize the work of Cowan and Brandon (1994), the east-west trending Haro Thrust Fault juxtaposes the Haro Terrane, which crops out near Davison Head, against the Deadman Bay Terrane. Rocks of the Deadman Bay Terrane underlie more recently deposited unconsolidated sediments from just south of Davidson Head. Outcrops extend from around the west side of Youngs Hill in English Camp, along the west coast of the island, and as far south as South Beach in American Camp. The Deadman Bay Terrane is situated structurally beneath the Decatur Terrane and is juxtaposed against the Constitution Formation along the Eagle Cove Thrust Fault (part of the nonlinear Rosario Thrust Fault). The Constitution Formation underlies recent unconsolidated sediments on the majority of San Juan Island. The Buck Bay Fault, a minor extensional fault, trends roughly north-south through American Camp and juxtaposes the Decatur Terrane and the Lopez Structural Complex. The latter crops out intermittently on the westernmost portion of the promontory (Brandon et al. 1988; Cowan and Brandon 1994).

A thick blanket of unconsolidated sediments deposited during the Quaternary Period (see the appendix for a geologic time scale) covers most of San Juan Island; these sediments are predominantly glacially derived. Deposits of the Puget Lowland have been interpreted to represent between two and four middle and late Pleistocene glaciations (e.g. Willis 1898; Hansen and Mackin 1949; Crandell et al. 1958; Pessl 1989 referring to Armstrong et al. 1965); most, if not all of which, relate to the last major glaciation, known as the Fraser Glaciation. Deposition of most of what is seen on San Juan Island today occurred during the most recent glacial advance and retreat (Fraser Glaciation), the Vashon Stade (advance) and Everson Interstade (ice retreat and marine invasion)

The region's Fraser-age deposits preserve a record of the dynamic interaction of several geologic processes including fluctuations in global sea level (eustasy), the advance and retreat of glaciers, and localized flexure of the earth's crust under the mass of the enormous continental ice sheets (isostasy). In the literature, there is some debate as to the interpretation of various deposits, the timing of Quaternary events, and which of the aforementioned processes dominated deposition at a given time (e.g. Alley 1979; Easterbrook 1969; Easterbrook 2003; Riedel 2007; Clark and Steig 2008). Fossil remains including marine invertebrates, vertebrate megafauna, plant material, and pollen, gathered from Quaternary glacial deposits throughout the Puget Lowland, are useful in establishing geochronology, resolving stratigraphic relations, reconstructing ancient ecosystems, and understanding earth's climate history.

As described by Dethier et al. (1996), the surficial geology of San Juan Islands includes outwash from braided streams that flowed from the advancing Puget lobe of the continental ice sheet. As the Puget lobe continued to advance, glacial till was deposited on top of the outwash. The lobe reached its maximum extent approximately 15,000 radiocarbon years ago, near Olympia, Washington. The ice began to retreat more rapidly approximately 13,000 years ago. Some localities preserve marine invertebrates that are commingled with glacial deposits among disturbed bedding, recording intervals of marine and ice-margin interaction. The Everson Interstade (relative-warm period during ice retreat) followed the Vashon Stade (relative-cold period during ice advance). During the Everson warm period, wave erosion during isostatic uplift carved beaches that are now well above sea level (as seen at Mt. Finlayson, American Camp) and caused erosion of the surficial glacial deposits during the Holocene. Finlayson is a glacial moraine (as was Pear Point to the north) composed of ice-contact marine fans (a 90 m (300 ft) stack of gravel with some sand) that built up into a delta from an ice margin that was at equilibrium just to the north. There is nothing like it in the northern Puget lowland—relative sea level at that point was almost 90 m (300 ft) higher than today, because the land was isostatically depressed. Within the next 500 to 2000 years relative sea level fell to at least 40 to 60 m (130 to 200 ft) below modern levels, before rising again, probably about 10,000 years ago (D. Dethier., pers. comm., April 2009). Easterbrook has produced numerous reports describing Pleistocene chronology within the Puget Lowland since 1968.

It is important to note that some sedimentary deposition occurred during times of known human occupation of the region (e.g. Wilson et al. 2007, 2009), thus, the potential exists for SAJH's invertebrate and vertebrate paleontological resources to occur within a cultural context.

Sources of Paleontological Resources

Fossils have been documented from the following geologic formations and museum collections within SAJH. These fossils present opportunities for resource management (including field surveys, inventory, and monitoring), education, interpretation, and continued or future scientific research in the park.

Quaternary deposits (Pleistocene-Holocene)

Field studies of surficial deposits on San Juan Island were conducted between 1992 and 1994 (Dethier et al. 1996); Maps were published as Open-File Report 96-7 by the Washington State Department of Natural Resources, Division of Geology and Earth Resources (DGER). Fossils are known to occur in SAJH from the following Quaternary recessional (sea level dropping) marine deposits of the Vashon Stade and Everson Interstade: glaciomarine outwash, glaciomarine diamicton ("diamicton" is a term used by geologists to describe deposits that are of unsorted or poorly sorted grainsize; they are typically "massive,"

as they do not exhibit bedding or other sedimentary structures), marine subtidal deposits, and emergence deposits. (Please note that the radiocarbon ages reported here are not calibrated, nor are they corrected for marine reservoir effects; calibrated ages could be 2,000 years older than those reported. This is a particularly important consideration when comparing ages obtained through different studies.)

Glaciomarine outwash

These deposits of well-sorted gravels and sands exhibit cross bedding; beds dip to the south, were subsequently faulted (not tectonically), and are locally fossiliferous. Within SAJH, they are exposed along a south-facing beach, due south of Mount Finlayson. The deposition of marine outwash is estimated to have occurred 13,200 years ago (radiocarbon age, not calibrated or corrected for marine reservoir effects). Fossils such as bivalves and barnacles are known from other localities on San Juan Island. (Dethier and others, 1996).

Glaciomarine diamicton

These deposits of poorly sorted massive pebbly silts are locally highly fossiliferous, and are estimated to have formed 13,100 – 12,800 years ago (radiocarbon age, not calibrated or corrected for marine reservoir effects). The majority of American Camp is veneered by 3-15 m (10-50 ft) of this polygenetic deposit. Within SAJH, fossils were collected from a marine diamicton outcrop at a field locality (DW-21) situated along Griffin Bay between Jakles Lagoon and Old Town Lagoon. The fauna (Bivalves: *Nuculana*, *Mytilus*, *Clinocardium*, *Serripes*, *Macoma*, *Mya*, *Hiattella*. Polychaete worms: *Serpula*. Barnacles: *Balanus*. Urchins: *Strongylocentrus*) “lived in moderately deep to subtidal water when calving ice was present before about 13,000 years ago” (Dethier et al. 1996; radiocarbon age, not calibrated or corrected for marine reservoir effects).

Marine subtidal deposits

These deposits of 3-5 m (10-15 ft) thick massive to cross-stratified beds are comprised of sorted sands and silts that often overlie glacio-marine diamict, and are estimated to have been deposited 12,900 - 12,500 years ago (radiocarbon age, not calibrated or corrected for marine reservoir effects). Within SAJH, fossils (Bivalves: *Macoma*, *Saxidomus*, *Mya*. Gastropods: *Trichotropis*. Polychaete worms: *Serpula*. Barnacles: *Balanus*) were collected from marine subtidal deposits at a field locality (DW-14) situated along a south facing beach, due south of Mount Finlayson (Dethier et al. 1996).

Emergence deposits

These deposits consist of sorted and locally cross-stratified gravel and sand beds of variable thicknesses that unconformably overlie till or marine deposits and grade upward to eolian sands. Some sites contain shell fragments (*Saxidomus* sp.) which have been dated to 12,800 - 12,300 years old (radiocarbon age, not calibrated or corrected for marine reservoir effects). Within SAJH, fossil-rich emergence deposits occur at a field locality (DW-21) situated along Griffin Bay between Jakles Lagoon and Old Town Lagoon. *Saxidomus* “lived in shallow subtidal to intertidal water during the period of rapid emergence about 12,500 years ago” (Dethier et al. 1996; age not corrected or calibrated).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within SAJH, but are documented from these units outside of the park. Future field investigations within the park may yield fossils from one or more (or none) of the following geologic units.

Rocks of the Turtleback Complex (Paleozoic)

Slivers of the Paleozoic Turtleback Complex can be found in fault zones near Garrison Bay and at the tip of Cape San Juan (D. Cowan, University of Washington, pers. comm., February 13, 2009). In general, the Turtleback Complex is an extensively intruded volcanoclastic and sedimentary unit. Its core is comprised of crystalline intrusive rocks, overlain by volcanics (belonging to the East Sound Group); sedimentary packages are fossiliferous. Analyses of zircon crystals indicate that older Turtleback units formed during the Devonian Period, and younger units formed during the Permo-Triassic (Whetten et al. 1978; Brandon

et al. 1988). Although no documented fossil occurrence from the Turtleback Complex is known within SAJH, fossil preservation is plausible in the marine sedimentary components, so it is possible that future field investigations within SAJH may lead to new paleontological discoveries.

Garrison Schist (Pre-Permian; Permian or Early Triassic metamorphic age)

Imbricate blocks of this medium to high grade mafic schist outcrop along the Rosario Fault Zone in the area of the Bell Point Loop Trail and within the Lopez Fault Zone at the tip of Cape San Juan. The schist is associated with rare lenses of marble (metamorphosed limestone). Originally deposited in marine environments, limestones frequently preserve marine invertebrates. However, fossils are typically obscured or destroyed when subjected to metamorphic pressures and temperatures, and as such they may not be found within the park's exposures. Although no documented fossil occurrence from the Garrison Schist is known within SAJH, fossil preservation is plausible, so it is possible that future field investigations within SAJH may lead to new paleontological discoveries.

Deadman Bay Terrane (Permian-Late Triassic)

The Deadman Bay Terrane consists of pillow lavas with minor interbeds of ribbon chert and limestone. The older unit, Deadman Bay Volcanics, is dominated by submarine basalt flows with sedimentary lenses. The age range of this terrane has been established using the index fossils fusulinids, radiolaria, and conodonts (Whetten et al. 1978; Danner 1985, 1994; Brandon 1980; Brandon et al. 1983).

During the breakup of the Pangean supercontinent, a narrow seaway known as "Tethys" formed between present-day North Africa and Asia. Limestones interbedded in the Deadman Bay Volcanics yield Permian fusulinids of the Tethyan faunal province. This indicates that the Deadman Bay Terrane is exotic to North America, as it contains fossils that are more commonly associated with rocks that outcrop in Asia (Danner 1966). Whetten et al. (1978) point out that the fusulinids were collected as "float" and may have eroded from other lithologic units. However, the exotic origin of the Deadman Bay Terrane is further supported by the presence of Tethyan calcareous algae (Johnson and Danner 1966).

The younger unit of the Deadman Bay Terrane is known as the Orcas Formation, or Orcas Chert (Triassic-Jurassic). Some authors describe the Orcas Formation as an overlying unit, distinct from the Deadman Bay (Logan 2003). The Orcas Formation is exposed around the western side of Young Hill and along a draw to Garrison Bay. It consists of mudstone and sandstone, with ribbon chert, minor limestones, and pillow lavas. Radiolaria are present in the Orcas (Whetten et al. 1978; Brandon 1980; Brandon et al. 1988). Conodonts also occur within the Orcas Formation (Brandon et al. 1983).

Decatur Terrane (Jurassic-Early Cretaceous)

The Decatur Terrane contains the Fidalgo Ophiolite Complex which consists of crystalline rocks, intermediate and mafic volcanics, and marine sediments. It also includes the massive limestones of the Lummi Formation. Radiolaria from chert at the base of the Lummi Formation are Late Jurassic in age (Whetten et al. 1978; D. Cowan, pers. comm., February 13, 2009); Late Jurassic-Early Cretaceous belemnites were collected from conglomerate units (Danner 1966).

Constitution Formation (Jurassic-Early Cretaceous)

The Constitution Formation (Jurassic-Early Cretaceous) is a volcanoclastic sequence that is exposed within SAJH at Young Hill and Bell Point, and is interpreted as a fault-slice (D. Cowan, pers. comm., February 13, 2009). Metamorphosed marine sediments of the Constitution Formation include sandstone, argillite, mudstone, and conglomerate, interbedded with pillow lavas and ribbon chert. Radiolarian chert in the highest member of the Constitution Formation establishes the age of the unit (Whetten et al. 1978). Triassic (Carnian) conodonts occur in limestone olistoliths of the lower unit (Brandon 1980; Brandon et al. 1988).

Rocks of the Lopez Complex (Jurassic-Cretaceous)

The Lopez Structural Complex includes slices of Turtleback Terrane, Garrison Schist, and marine sedimentary rocks derived from the Lummi Formation of the Decatur Terrane. Cretaceous bivalves

(*Buchia*) and foraminifera, as well as Jurassic and Cretaceous radiolarians, are reported from exposures of this complex on other islands (Whetten et al. 1978.)

Quaternary deposits (Pleistocene-Holocene)

Marine and terrestrial invertebrates are recorded from glacial, glaciofluvial, and glaciomarine deposits throughout the San Juan Islands (Dethier et al. 1996). Analyses of fossils and fossil assemblages help scientists to arrive at a more complete understanding of the region's paleoclimate, paleoecology, and geochronology. Analyses of pollen assemblages aid in paleoclimatic and paleoecological reconstructions. Pollen including fir (*Abies*), alder (*Alnus*), spruce (*Picea*), lodgepole pine (*Pinus contorta*), poplar (*Populus*), Douglas fir (*Pseudotsuga menziesii*), willow (*Salix*), buffaloberry shrub (*Shepherdia*), and mountain and western hemlocks (*Tsuga heterophylla* and *Tsuga mertensiana*) have been identified from Quaternary deposits on San Juan and neighboring islands (Barnosky et al. 1987; Hansen 1943, 1947; Heusser et al. 1985; Mathewes 1985; Peterson et al. 1983; Whitlock 1992). Organic material (including peat and woody fragments) found in any of these deposits can be radiometrically dated to establish an absolute age. Establishing absolute dates would help resolve temporal correlations. Where possible, combining absolute ages with information from associated fossil assemblages (pollen, plants, vertebrates, or invertebrates) brings focus to the picture of a region's ecological history.

A publication by Wilson et al. (2009) recently identified the remains of Quaternary megafauna from sites on neighboring islands. Taxa in the study include *Bison antiquus*, *Megalonyx jeffersonii*, and *Arctodus simus* (M. C. Wilson, Douglas College and Simon Fraser University, pers. comm., February 3-6, 2009; D. Dethier, Williams College, pers. comm., February 2, 2009; G. McDonald, NPS-NRPC, pers. comm., February 10, 2009). These fossil finds indicate that at one time, a corridor may have linked some of the islands with the mainland. If a land corridor existed, allowing dispersal of such large mammals, it seems reasonable to expect that the remains of other smaller mammals could also be preserved on the islands. However, M. C. Wilson describes that the corridor was not a complete land bridge and that it was likely interrupted by water. As such, only larger animals were able to pass through, hence Wilson's terminology, "filter corridor" (M. C. Wilson, pers. comm., April 21, 2009).

More significantly, for the purposes of this report, personal communication with Michael Wilson and other collaborators clarifies that the remains of Quaternary megafauna have, in fact, been recovered from a site on San Juan Island, but have not yet been published. The jaw bone belonging to a bear was discovered on private land located approximately halfway between Friday Harbor and Cattle Point (D. Dethier, Williams College, pers. comm., February 2, 2009). The bear (*Arctodus simus*) was found in association with bison vertebrae; associated shell material yields dates generally similar to those of the Orcas bison finds, i.e. 11,750 to 10,800 years before present (M. Wilson, pers. comm., February 5, 2009). At present, the remains are in the care of the Burke Museum, University of Washington.

There has been much interest in the *in situ* Pleistocene-Holocene mammal fossils of this region. Some experts have speculated that the arrangement, breakage, and proportion of bones, shows evidence of human alteration (i.e. butchering). If this is the case, the dates obtained from the bones may indicate that humans occupied the region earlier than previously thought (Wilson et al. 2007).

All known Quaternary megafauna from the islands have been recovered from wetlands (M. Wilson, pers. comm., February 6, 2009). Because wetlands exhibit a wide range in chemistry, the potential to preserve fossils within them varies significantly. Calcium carbonate (found in shells) neutralizes the acidic conditions which prevail in many wetlands, thus slowing the process of diagenesis (Meltzer and Dunnell 1987). It follows, then, that wetlands with a higher occurrence of shells tend to better preserve bones and other faunal remains.

A number of studies have focused on the taphonomy (processes of fossilization) and diagenesis (processes of post-depositional alteration) of the invertebrates found in and around San Juan Island. In some cases, live organisms are collected and their role in diagenesis is observed. In other cases, "modern" and "subfossil" remains are collected and analyzed in regard to their preservation potential. Kowalewski and

Labarbera (2004) elegantly explain the breadth, depth, and significance of these studies in a dedicated issue of *Palaios*. Examples of previous work follow. Puchalski (2003) compared the relative abundances of two species of chitons (*Mopalia muscosa* and *Katharina tunicata*) collected from False Bay and Cattle Point to identify which extrinsic factors might play a role in the organisms' preservation. Krause (2003) compared life and death assemblages of the modern brachiopod *Terebratalia transversa* to investigate morphological biases in the fossil record. Dent and Uhen (1993) examined the effect of tidal processes on the transport and orientation of the bivalves *Macoma nasuta* and *Clinocardium* sp. within False Bay. Subfossil limpets (gastropods) collected from San Juan Island were compared with fossil material collected from other localities to ascertain the characteristics of predatory drill holes left by muricid snails (Schiffbauer et al. 2008), and analyses of vertebrate assemblages and paleoclimate have been discerned from owl pellets (Terry 2004). Friday Harbor Laboratories (University of Washington), located within 16 km (10 mi) from SAJH, often collects research specimens locally from San Juan and other islands; these fauna are likely to be present within SAJH, as well.

Park Collections

SAJH paleontological specimens are curated by the North Cascades NPS Complex in Marblemount, Washington (Kelly Cahill is current curatorial contact) and housed at the University of Washington's Burke Museum of Natural History and Culture (Seattle).

While field mapping the geology of San Juan Island, Dr. David Dethier (Williams College) collected 39 paleontological specimens (catalog numbers SAJH 166188 - SAJH 166226) from the Everson Formation (Everson Glaciomarine Drift) at two localities near Cattle Point. Specimens collected by Dethier include one bryozoan, 23 bivalves, eight gastropods, two arthropods, one urchin, two tube worms, and two polychaetes.

More than 700,000 specimens comprise SAJH's archeological collections. Kristine Bovy and Brian Pegg both conducted Master's theses on archeological sites within English Camp (University of Washington and Simon Fraser University, respectively). The specimens analyzed in those theses are maintained in collections at the Burke Museum.

External Collections

A search of the online database of collections managed by University of California Museum of Paleontology at Berkeley reveals that a number of invertebrates, including holotypes ("type" or originally described specimen) and hypotypes (other published and described specimens), were collected from San Juan Island prior to the SAJH's 1966 designation.

Fossil invertebrate specimens were collected by John Damon Shaw while conducting graduate field studies in the San Juan Archipelago (see Shaw 1972). Collections made by Shaw are maintained at the Burke Museum. Several localities are situated along or near Jakles Lagoon and another locality is situated approximately 1.5 km (1 mi) east of South Beach. Specimens include pelecypods (*Nuculana fossa*, *Chlamys* (*Chlamys*) *hastata hericius*, *Chlamys* sp., *Mytilus* (*Mytilus*) *edulis*, *Clinocardium* (*Cerastoderma*) *corbis*, *Clinocardium corbis*?, *Clinocardium ciliatum*, *Clinocardium ciliatum*?, *Serripes groenlandicus*, *Protothaca tenerrima*, *Protothaca tenerrima*?, *Protothaca staminea*?, *Saxidomus nuttalli* var. *giganteus*, *Macoma nasuta*, *Macoma incongrua*, ?*Macoma* sp., *Mya truncata*, *Mya arenaria*, ?*Mya* sp. *Hiatella arctica*, and *Hiatella pholadis*), gastropods (*Mitrella* cf. *M. carnata gausapta*, *Trichotropis cancellata*, *Natica* (*Tectonatica*) *clausa*, and *Acmaea persona*), tube worms (Polychaeta: *Serpula vermicularis*), barnacles (Cirripedia: *Balanus crenatus*, *Balanus* sp.), and urchin (Echinoidea: *Strongylocentrotus*). (Please note that tentative taxonomic identifications are, by convention, indicated with a "?".)

Cultural Resource Contexts

Other Quaternary fossils known from SAJH are found in association with archeological sites. Such items are just one example of fossils found in cultural resource contexts; Kenworthy and Santucci (2006)

present an overview and cite selected examples from throughout the NPS. Within SAJH, shell middens are known from alongside Garrison Bay in English Camp, and from a gravel bank above a beach at Cattle Point. The sites may have been in use for thousands of years throughout the Holocene. Phases of human occupation in the region are characterized by varying proportions of stratified artifacts and faunal remains at these and other refuse sites (e.g. shells, fish, birds, terrestrial and marine mammals, and the types and shapes of artifacts). Associations of artifacts and organic remains (e.g. pollen) help to establish chronology as well as the ecological and anthropological history of the area. The site at English Camp was excavated prior to the establishment of SAJH, by Arden King and by Carroll Burroughs, both University of Washington faculty members (Stein 2000). The site at American Camp has been the subject of several archeological investigations, both before and after SAJH was established. Researchers include Adan Treganza (San Francisco State University), Roderick Sprague (University of Idaho), Stephen Kenady (private sector), and Julie Stein (University of Washington). Material from the locality yields radiometric dates of approximately 600 A.D. (Stein 2000). More recently, Bovy (2002) analyzed more than 48,000 fragments of fish, bird, mammal, and other bones recovered from six units of the locality. Her paper discusses the disproportionate abundance of distal wing bones found in shell middens. Bovy's report identifies that bones belonging to sea ducks (e.g. Oldsquaw - *Clangula*, scoters-*Melanitta*, goldeneyes-*Bucephala*, mergansers-subfamily Merginae), gulls-family Laridae, and perching birds-order Passeriformes (e.g. crows and common raven) have been found within SAJH's archeological sites.

Paleontological Resource Management, Preliminary Recommendations

- The National Park Service Geologic Resources Division sponsored a Geologic Resources Inventory (GRI) scoping meeting for SAJH and other NCCN parks which took place in Seattle, Washington, on September 10, 2002. GRI map data was discussed at the meeting; other geologic needs were not identified at that time. SAJH has not been the subject of a scoping report. GRI has not yet produced a final report for SAJH.
- The park should consider future field inventories for paleontological resources to more fully document in situ occurrences of fossils. The park may consider a formal site documentation and condition assessment for significant fossil localities. Monitoring of significant sites should be undertaken at least once a year in the future. A forthcoming (2009) Geologic Resource Monitoring Manual by the Geological Society of America and NPS Geologic Resources Division includes a section on paleontological resource monitoring (Santucci et al. in press).
- Park staff should be encouraged to observe the surface deposits for fossil material while conducting their usual duties. Staff should photodocument and potentially monitor any occurrences of paleontological resources. Fossils and their associated geologic context (rock matrix) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts. Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist.
- Contact the NPS Geologic Resources Division for paleontological resource management assistance.

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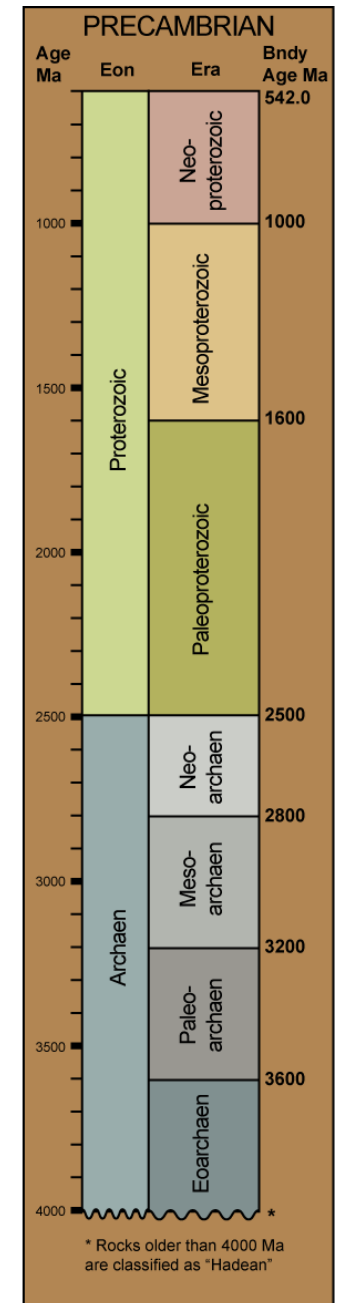
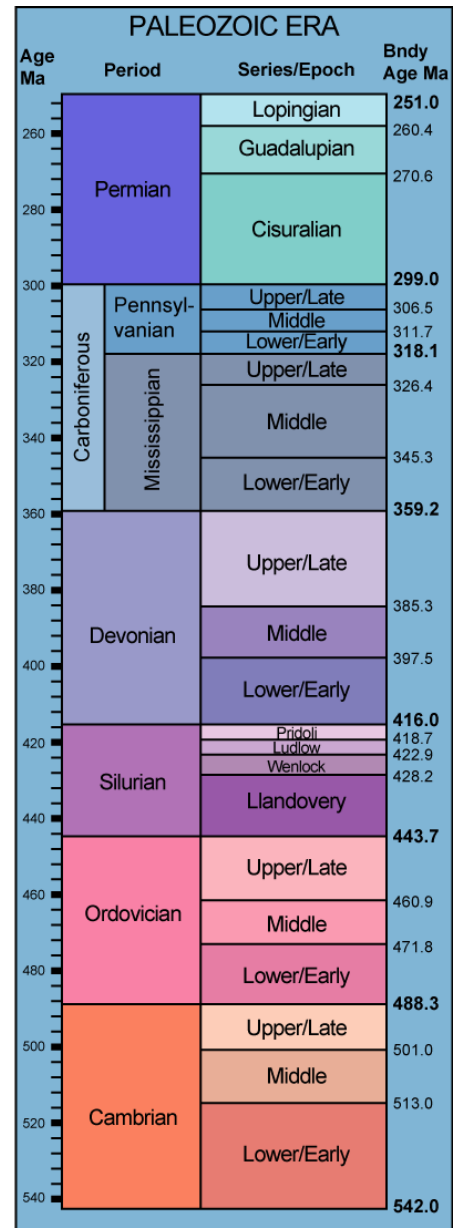
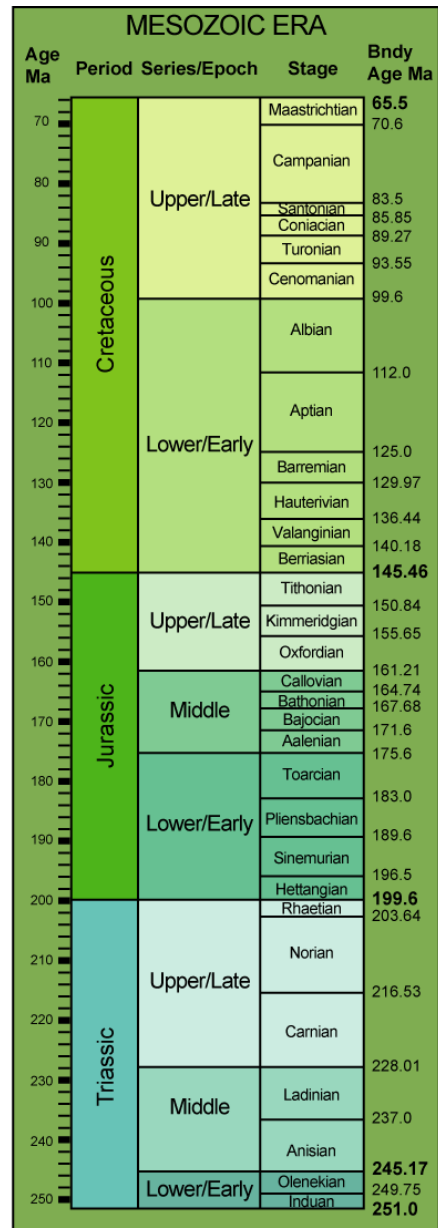
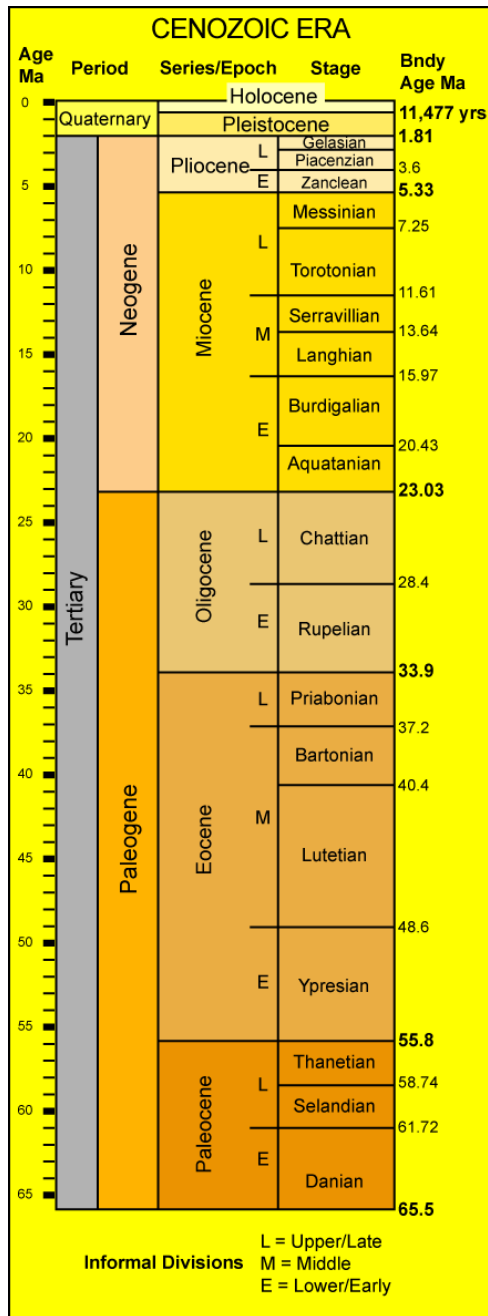
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Burke Museum of Natural History and Culture, University of Washington.
1996 – present. (museum specimens; associated specimen and collections records; field notes; etc.) Originated by Burke Museum staff; status: Active.

University of California Museum of Paleontology at Berkeley.
1966 – present. (museum specimens; associated specimen and collections records; field notes; etc.) Originated by UCMP staff; status: Active.

San Juan Island National Historical Park Digital Geologic Map
2008–present. (geologic map data; electronic files; GIS metadata). Originated by NPS-Geologic Resource Inventory staff; status: Active. Online. <http://science.nature.nps.gov/nrdata/datastore.cfm?ID=46135>



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

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

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