National Park Service
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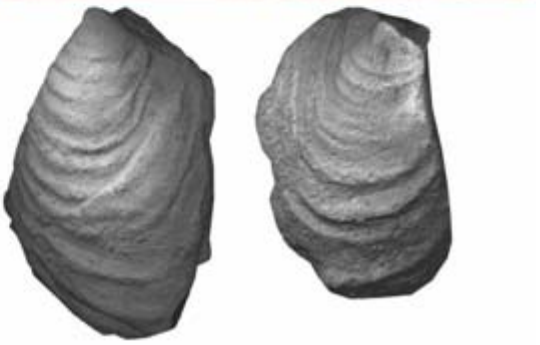
Natural Resource Program Center

Paleontological Resource Inventory and Monitoring
San Francisco Bay Area Network

Natural Resource Technical Report NPS/NRPC/NRTR—2008/078







ON THE COVER
Assorted fossils from the San Francisco Bay Area Network. For more information, see each park's respective section. **Top**: Fossil baleen whale skull (Pliocene-aged) on display at the Ken Patrick Visitor Center of Point Reyes National Seashore. Note interpretive panels for scale. NPS Photo courtesy Kirsten Kvam (PORE). **Bottom left**: Assortment of Jurassic and Cretaceous-aged radiolarians (microfossils) from the Marin Headlands Terrane within Golden Gate National Recreation Area. USGS Image (Portion of Plate 1, Murchey 1984). **Bottom Right**: Early Cretaceous bivalve *Inoceramus elliotti* discovered on Alcatraz Island, Golden Gate National Recreation Area. Photo courtesy William Elder (GOGA).

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William P. Elder
National Park Service
Golden Gate National Recreation Area
Fort Mason, Building 201
San Francisco, CA 94123-0022

Torrey Nyborg
Department of Earth and Biological Sciences
Loma Linda University
Loma Linda, CA 92350

Jason P. Kenworthy
National Park Service
Geologic Resources Division
Oregon State University
104 Wilkinson Hall
Corvallis, OR 97330

Vincent L. Santucci
National Park Service
George Washington Memorial Parkway
Turkey Run Park
McLean, VA 22101

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.

January 2008

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

The Natural Resource Publication series addresses natural resource topics that are of interest and applicability to a broad readership in the National Park Service and to others in the management of natural resources, including the scientific community, the public, and the NPS conservation and environmental constituencies. Manuscripts are peer-reviewed to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and is designed and published in a professional manner.

The Natural Resources Technical Reports series is used to disseminate the peer-reviewed results of scientific studies in the physical, biological, and social sciences for both the advancement of science and the achievement of the National Park Service's mission. The reports provide contributors with a forum for displaying comprehensive data that are often deleted from journals because of page limitations. Current examples of such reports include the results of research that addresses natural resource management issues; natural resource inventory and monitoring activities; resource assessment reports; scientific literature reviews; and peer reviewed proceedings of technical workshops, conferences, or symposia.

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Printed copies of reports in these series may be produced in a limited quantity and they are only available as long as the supply lasts. This report is also available from the San Francisco Bay Area I&M Network intranet (NPS access only) site (http://www1.nrintra.nps.gov/im/units/SFAN/index.cfm), or by sending a request to the address on the back cover.

Please cite this publication as:

Elder, W. P., T. Nyborg, J. P. Kenworthy, and V. L. Santucci. 2007. Paleontological Resource Inventory and Monitoring—San Francisco Bay Area Network. Natural Resource Technical Report NPS/NRPC/NRTR—2008/078. National Park Service, Fort Collins, Colorado.

NPS D-20, January 2008

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Abstract

Paleontological resources (fossils) are any remains of past life preserved in a geologic context. Paleontological resources are non-renewable resources found in more than 180 National Park Service units. Despite the abundance and diversity of these resources throughout the NPS, 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 appropriate management of these resources. This report presents a paleontological resource summary for the parks of the San Francisco Bay Area Network. The summary was compiled through extensive literature review and interviews with park staff and professional geologists and paleontologists. Preliminary paleontological resource management recommendations are also included for each park. Similar summaries have already been prepared for 16 other NPS Inventory and Monitoring Networks. The National Inventory and Monitoring Program provided funding to complete these paleontological resource summaries for each of the remaining networks.

A wide diversity of fossils are currently known from the following San Francisco Bay Area Network parks: Golden Gate National Recreation Area, John Muir National Historic Site, and Point Reyes National Seashore. Based on their underlying geology, fossils may potentially be found in Eugene O'Neill National Historic Site and Pinnacles National Monument. Fossils occur both *in situ* within geologic exposures within these parks and also within park collections. For example, geologic terranes within Golden Gate National Recreation Area preserve Mesozoic microfossils, invertebrate fossils, and trace fossils; all of which provide important paleoecological and geologic dating information. This information is invaluable for increasing knowledge regarding the time of emplacement and original provenance of the terranes. Cenozoic fossils include marine invertebrates, and terrestrial vertebrates and plants. Collections at John Muir National Historic Site include a piece of Triassic petrified wood from the Petrified Forest of Arizona prior to its preservation as a National Monument. Muir spent nearly one year in the area studying the fossils. The Cenozoic (Eocene-Pleistocene) sedimentary deposits within Point Reyes National Seashore preserve diverse marine fossils including biostratigraphically important microfossils, invertebrates, and vertebrates. The marine vertebrate record, in particular the marine mammals are well known from within the park and include a new species of balaenopterid whale found either within or immediately adjacent to the park. The Ken Patrick Visitor Center also has a Pliocene baleen whale fossil (in addition to other marine fossils) on display. More recent (Pleistocene-Holocene) paleoecological data retrieved from throughout the San Francisco Bay area, and within Point Reyes National Seashore, describes a cooler and moister late Pleistocene climate for coastal California.

Acknowledgements

The authors graciously thank all those individuals, both within and outside of the National Park Service who have contributed valuable information, comments, and suggestions for this report. Reports such as this are impossible without extensive input from those people who know the resources the best.

Special thanks to NPS park staff who provided extensive information, comments, suggestions, and/or reviewed their park's section: Ted Fremd (JODA) regarding GOGA; Kirsten Kvam (PORE); John Dell'Osso (PORE); Sarah Allen (PORE), Joel Despain (SEKI) regarding PINN; and David Blackburn (EUON and JOMU). Ted Fremd also reviewed the entire manuscript.

The continued valuable support and information provided by the NPS Geologic Resources Division (GRD), in particular Tim Connors, Sid Covington, Bruce Heise, Bob Higgins, Lindsay McClelland, Jim F. Wood, and Jim C. Woods is greatly appreciated.

A number of individuals from institutions outside of the NPS were also instrumental in the creation of this report. We extend our appreciation to Dr. Gordon Chan from the College of Marin for providing some preliminary information in 1993 regarding fossils from Point Reyes National Seashore. Dr. Vince Matthews of the Colorado Geological Survey provided information for Pinnacles National Monument. Additional thanks are extended to scientists at the U. S. Geological Survey. Phil Stoffer is acknowledged for providing information pertaining to the geology of Pinnacles National Monument, Earl Brabb for information on microfossil potential at East Bay parks, and Robert MacLaughlin and Charles Powell III for information on fossil potential in Golden Gate National Recreation Area. Phil Stoffer also reviewed the entire manuscript.

Special thanks to SFAN Network Coordinator Marcus Koenen whose support was instrumental in making this report a reality.

Finally, this report would not have been possible without the funding from the National I&M Program and the support of the SFAN Network and Geologic Resources Division. The enthusiasm and support of Bert Frost (Deputy Associate Director; NPS Natural Resource Science and Stewardship) and Gary Williams (National I&M Program Manager) is acknowledged. A sincere thanks is extended to Bert and Gary for providing the means upon which this work, and similar work, can be accomplished.

Introduction

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

The establishment of baseline paleontological resource data is essential for the appropriate management of fossils found within National Park Service (NPS) areas. Although more than 180 NPS areas have been identified with paleontological resources, few parks have adequate baseline paleontological resource data.

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

The San Francisco Bay Area Network includes seven National Park Service areas in California shown in Figure 1: Eugene O'Neill National Historic Site (EUON), Fort Point National Historic Site (FOPO), Golden Gate National Recreation Area (GOGA), John Muir National Historic Site (JOMU), Muir Woods National Monument (MUWO), Pinnacles National Monument (PINN), and Point Reyes National Seashore (PORE). Fort Point NHS and Muir Woods NM are administered by Golden Gate NRA and are addressed in GOGA's section. All together, the parks of the SFAN encompass nearly 72,035 ha (178,000 acres) and hosted more than 18.1 million visitors in FY2006.

While none of the parks were established specifically for paleontological resource stewardship, fossils are known from several of the SFAN parks including Golden Gate National Recreation Area and Point Reyes National Seashore. Eugene O'Neill National Historic Site and John Muir National Historic Site are likely to contain fossils in the underlying bedrock. Two NPS sites located within the SFAN geographical area but are not part of the I&M program include Port Chicago Naval Magazine National Memorial and Rosie the Riveter/World War II Homefront National Historical Park. Both sites lie largely on quaternary fill, but contain younger (few hundred-few thousand years old) deposits potentially preserving important paleoenvironmental data.

Collectively, the paleontological resources of the SFAN Network contribute much to a greater understanding of the history of life on earth. Continued paleontological resource inventories will serve to expand this ever-widening base of paleontological knowledge represented throughout the National Park Service. Although more than 180 parks have already been identified as containing paleontological resources, much of what is to be known about the history of life on earth remains to be discovered.

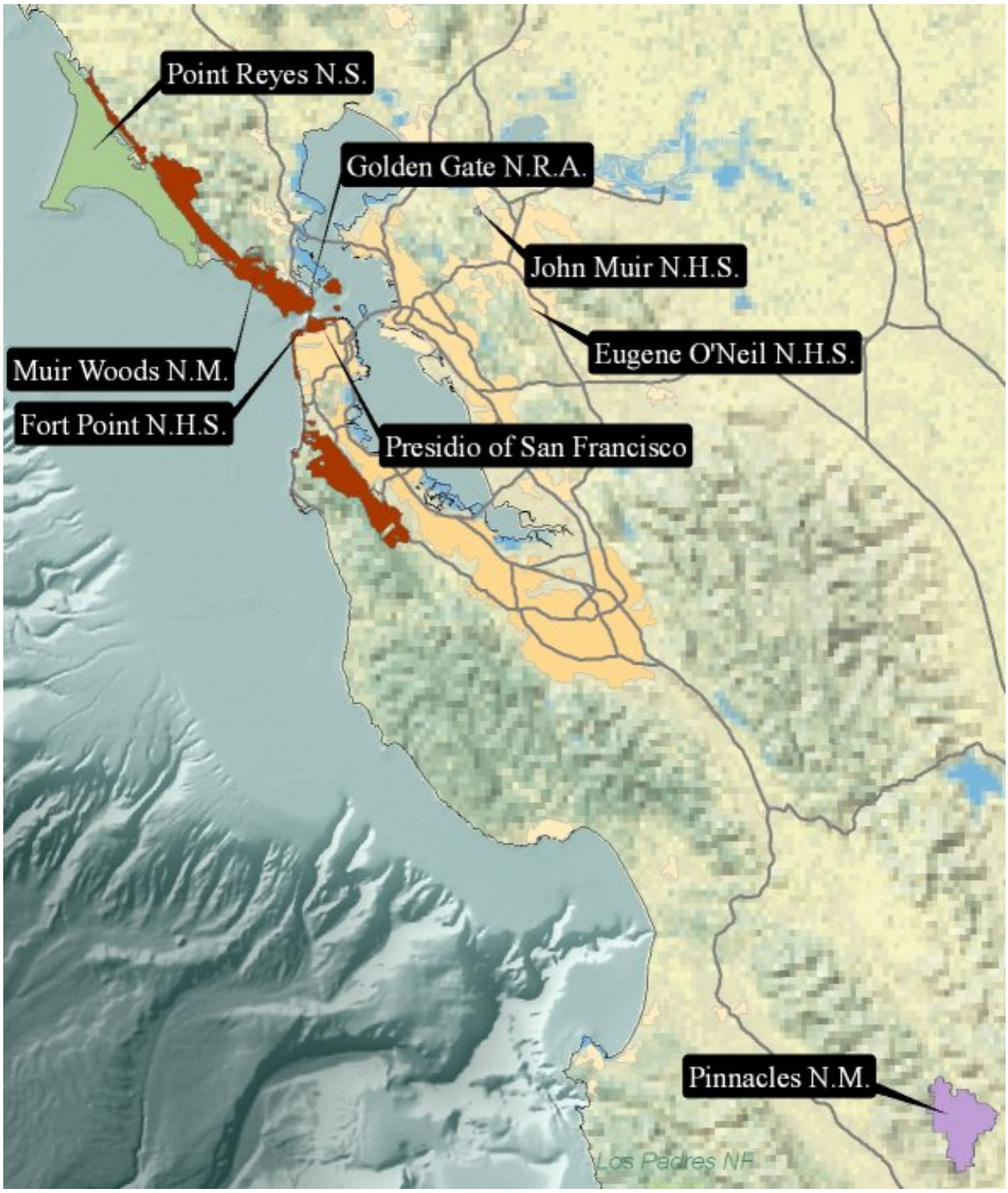


Figure 1. Map of SFAN network parks. Map courtesy SFAN staff.

Paleontological Resource Inventory Strategies and Methodology

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

Comprehensive Park-Specific Paleontological Resource Inventories

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

Servicewide Thematic Paleontological Resource Inventories

Servicewide thematic paleontological resource inventories compile data regarding specific types of paleontological resources that occur in parks throughout the NPS. The first thematic paleontological resource inventory was an inventory of fossil vertebrate tracks from NPS areas (Santucci et al. 1998). This thematic inventory identified 19 NPS units that preserve fossil vertebrate tracks. 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 paleontological resource 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 17 of the 32 I&M Networks including: the Chihuahuan Desert, Eastern Rivers and Mountains, Greater Yellowstone, Gulf Coast, Mediterranean Coast, Mid-Atlantic, Mojave Desert, National Capital Region, Northeast Coastal and Barrier, Northern Colorado Plateau, Pacific Island, Rocky Mountain, San Francisco Bay Area (this report), Sierra Nevada, Southern Plains, Southwestern Alaska, and Upper Columbia Basin networks. Research for summaries of the Appalachian Highlands, Arctic, Great Lakes, Northern Plains, and South Florida/Caribbean networks are currently underway (December 2007). NPS I&M Program funding is targeted to complete paleontological resource summaries for the remaining networks by FY2009. Citations for the completed reports are in the Additional References section.

I&M Network Paleontological Resource Inventory Methodology

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

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

The literature search also includes gray (unpublished) literature searches of individual park files, museum archives, local newspapers, field notes, etc. These are often excellent sources of anecdotal information about park resources. In addition to literature searches, interviews with park staff, university faculty, geologists from the USGS and state surveys, and even local amateur geologists or paleontologists can yield information regarding park paleontological resources. These interviews frequently result in capturing data that might otherwise be undocumented and potentially lost or unrecognized. Bibliographic searches include a search for geologic maps associated with each park. The NPS Geologic Resources Division maintains a database of geological map coverage for many parks (current contact is Tim Connors). In addition, the USGS National Geologic Map Database (NGMDB; see citation below in Additional References section) lists maps for a given geographic area or place name and provides information on where to obtain maps. Geologic maps show the types of rocks and the associated geological formations within a park area. These maps, alone, will often indicate the potential for paleontological resources to occur within a park.

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

The information from these various sources for each park is then compiled and summarized in a written report and developed into individual datasets. The reports undergo peer review by professional geologists, paleontologists, and staff from each park for accuracy before being submitted to the network. These reports are designed to consolidate baseline paleontological resource data for each park to support management operations and decision-making. Therefore, the reports are written in NPS language and in addition to the scientific information, the reports address issues of resource management, protection, and interpretation.

The paleontological resource inventory reports synthesize information regarding the scope and significance of fossils documented from each park. Fossils are assessed and organized based upon

taxonomy, stratigraphy, and paleoecology. Paleontological resources can be divided into four taxonomic groups: paleobotany (fossil plants), invertebrates (animals without backbones), vertebrates (animals with backbones), and trace fossils (evidence of biological activity such as tracks, traces, burrows, etc.). Fossils typically have a finite stratigraphic range and occurrence in geologic time (a geologic time scale is included in Appendix A). The period between the first and final occurrences of a fossil species is referred to as the stratigraphic range zone. Thus specific groups of fossils may be identified directly with a particular stratigraphic unit or stratigraphic range. Likewise, rock units often represent specific ancient sedimentary depositional environments. Paleoecologically, fossil groups may occur primarily, or in some instances only, in specific environmental conditions (temperature, aquatic, terrestrial, etc.). Thus many fossils may be useful as indicators of past environmental conditions. The reports are organized stratigraphically presenting the geologic and paleontologic information chronologically from oldest to youngest. Important fossils documented from localities outside a park are often reported in the park inventory, as these data may indicate the potential for fossils in similar stratigraphic units exposed within park boundaries.

Given the tremendous diversity of past life, the existence of life for over a billion years, and the range of environments to which life has adapted, there is a broad spectrum of research interests in paleontology. It is not surprising that most of what is to be learned about the history of life remains to be discovered. Through research, more than 180 NPS areas have been identified as containing paleontological resources. However, the paleontological research for a particular park may vary widely from an incidental fossil discovery to over a century of intensive paleontological investigations. The inventory reports include information on the history of paleontological research, descriptions of current cooperative projects, identification of any museums or universities serving as repositories for park fossils, and a comprehensive list of publications related to paleontological research associated with the park. The reports include all bibliographies that may be associated with a park's paleontological resources. However, bibliographic data are subdivided in the report into those cited in the narrative (References Cited) and other associated bibliographies (Additional References). The cooperative projects section highlights paleontological resources projects, if any, that the park has funded or supported. Formal datasets are established for known associated paleontological collections, research, or activities.

Paleontological Resource Management Legislation and Guidance

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

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

documents are listed in the Additional References section. The Geologic Resources Division is assembling a geologic resource monitoring manual that includes chapters on various geologic resources, including in situ paleontological resources, and a set of monitoring vital signs that may be applicable to a variety of parks. Monitoring represents the next phase in paleontological resource management, following the initial research inventory (represented by this report) of potential fossils and any subsequent field work to identify fossils within a park. Publication is expected by early 2008. Contact the Geologic Resources Division for more information or to obtain a copy of the report when it is available.

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

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General SFAN Information

SFAN I&M Network: http://www.nature.nps.gov/im/units/sfan/index.cfm

Geological Survey Websites

California Geological Survey: http://www.consrv.ca.gov/cgs/
U.S. Geological Survey: http://www.usgs.gov
USGS San Francisco Bay Region Geology Project: http://wrgis.wr.usgs.gov/wgmt/sfbay/index.html
Geological Society of America: http://www.geosociety.org
American Geological Institute: http://www.agiweb.org

Library catalogs

U.S. Geological Survey Library Catalog: http://library.usgs.gov/
Smithsonian Institution Libraries Catalog: http://www.siris.si.edu/

Museums

University of California Museum of Paleontology, Berkeley: www.ucmp.berkeley.edu/
California Academy of Science: www.calacademy.org
Natural History Museum of Los Angeles County: www.nhm.org/
Smithsonian National Museum of Natural History Dept. of Paleobiology: 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://www2.nature.nps.gov/geology/paleontology/paleo_5_1/index.htm#omnibus
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://www2.nature.nps.gov/geology/
NPS Paleontology Program: http://www2.nature.nps.gov/geology/paleontology/
NPS Park Paleontology Newsletter: http://www2.nature.nps.gov/geology/paleontology/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.
U.S. Geological Survey Geologic Terms Glossary:
http://wrgis.wr.usgs.gov/docs/parks/misc/glossarya.html
Topozone (interactive access to all USGS topographic maps): http://www.topozone.com
U.S. Geological Survey National Geologic Map Database (NGMDB): http://ngmdb.usgs.gov/
U.S. Geological Survey 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): http://gnis.usgs.gov/
Paleobiology Database (search for fossil taxonomy, localities, or geologic formations):
http://paleodb.org/cgi-bin/bridge.pl
Paleontology Portal (general fossil info based on geographic location or geologic time):
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Eugene O'Neill National Historical Site

Eugene O'Neill National Historic Site (EUON) was established in 1976 near Danville, California, to honor the famous American playwright. The site is located at Tao House, which O'Neill built and lived in from 1937 to 1944, and where he wrote several of his best known plays. The 5.3 ha (13 acre) site also includes grassland and oak woodland.

Baseline Paleontological Resource Inventories

Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held in September 2007. Paleontological scoping sessions have not been held for the park and there have been no formal paleontological resource surveys or inventories. Nevertheless, paleontological resources are known nearby from the rock units contained within EUON and there is potential for fossil discovery and recovery from within the park.

The recently compiled U.S. Geological Survey (USGS) Open File Report 94-622 covers the EUON area can be found and downloaded from the internet (Graymer et al. 1994). Bedrock in the historic site consists of Tertiary sediments that fall within Assemblage II – Hercules Area of Graymer et al. (1994). That report questionably assigned the unit underlying EUON to the Miocene Hombre Sandstone; the park boundary may extend west into the Rodeo Shale and the Briones Formation as well.

Park Collections

Bedrock is not known to be exposed in the park and there are no fossils known to exist within the park collections. Numerous fossil localities are documented in units nearby. These are listed in Parker et al. (2003) and on the University of California, Berkeley Museum of Paleontology web site (http://ucmpdb.berkeley.edu/loc.html) and the Los Angeles County Museum of Natural History collections web site (http://ip.nhm.org/ipdatabase/).

Hombre Sandstone (middle Miocene)

The middle Miocene Hombre Sandstone probably underlies all of EUON, but Graymer et al. (1994) questionably assigned this unit to the park area due to a large landslide that obscures the underlying bedrock. They described the Hombre as a massive, medium-grained shallow marine sandstone that weathers brown. The western edge of the park boundary may possibly extend into the younger middle Miocene Rodeo Shale, a brown, siliceous shale with yellow carbonate concretions, and D member of the upper Miocene Briones Formation, a massive, medium-grained sandstone with local conglomerate. The lower two units belong to the Monterey Group and the Briones Formation belongs to the San Pablo Group.

At nearby localities, these rock units are locally highly fossiliferous, with the sandstones containing abundant invertebrate fossils (see Clark 1915; Trask 1922; Weaver 1949), and the finer grained units containing foraminifera and diatoms indicative of the middle to upper Miocene Mohnian Stage (Weaver 1949; USGS, E. Brabb, Geologist Emeritus, pers. comm., 2006). Scattered fish scales and fish bone are also common in these rocks. In conclusion, Miocene fossil resources are likely to be present in the bedrock that underlies the soil that blankets EUON.

Paleontological Resource Management, Preliminary Recommendations

- Because of the high likelihood of fossils in the bedrock of EUON, any excavation of the bedrock in the park should be monitored for paleontologic material.
- The extensive soil cover in the park essentially precludes unauthorized collecting of fossils.

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Data Sets

Eugene O'Neill National Historic Site Paleontological Archives
5/1985–present. (hard copy data; reports; electronic data; photographs; maps; publications). Originated by Santucci, Vincent; status: Active.

Eugene O'Neill National Historic Site Museum Collections
1976-present. (museum specimen; associated specimen notes; collection records; maps; etc.). Originated by EUON staff; status: Active.

Golden Gate National Recreation Area

Golden Gate National Recreation Area (GOGA) was established in 1972, largely from former military lands, to preserve coastal beaches and shorelines and adjacent hills and mountains in the San Francisco Bay Area. Its lands extend from San Mateo County, south of San Francisco, to the Point Reyes Peninsula in Marin County, north of the Golden Gate. The park is still growing from new acquisitions and now covers approximately 31,565 ha (78,000 acres). Within the park's administrative boundaries are two other national park units, Muir Woods National Monument and Fort Point National Historic Site. The legislative boundary for GOGA far exceeds the lands managed by the park and includes areas, such as the San Francisco Watershed in San Mateo County, Angel Island State Park, and lands bounding Point Reyes National Seashore east of the San Andreas Fault that are managed by that park.

Baseline Paleontological Resource Inventories

Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held in September 2007. A formal paleontological resource survey and inventory at GOGA has been completed by Ted Fremd of the National Park Service. Fremd completed a preliminary summary of his findings (Fremd 2007). A final draft of the report is nearing completion. This and previous work indicates that the park has considerable paleontological resources and that there is potential for continued discovery.

Recently compiled geologic maps that cover the park area can be found and downloaded from the internet. They include U.S. Geological Survey (USGS) Miscellaneous Field Studies MF-2337 (Blake et al. 2000) and Open File Report 98-137 (Brabb et al. 1998). Older important mapping in the park includes USGS Map I-272 (Schlocker et. al. 1958) and Professional Paper 782 (Schlocker 1974).

Bedrock in the park is the Franciscan Complex, which is composed of a number of tectonostratigraphic terranes. Each terrane is characterized and separated from others by being composed of a suite of rocks with a specific petrographic composition, age range, and metamorphic grade. At least five Mesozoic Franciscan terranes underlie the park—Alcatraz Terrane, Marin Headlands Terrane, San Bruno Mountain Terrane, Permanente Terrane, and the Central Belt Mélange. Overlying the Franciscan rocks in some areas are, from oldest to youngest: an unnamed Paleocene sandstone unit present near San Pedro Point, the middle to lower Eocene Whiskey Hill Formation in Phleger Estate, the lower Pleistocene and upper Pliocene Merced Formation at Fort Funston, the lower Pleistocene and upper Pliocene Santa Clara Formation at Phleger Estate, and the Pleistocene Colma Formation present mainly at Fort Funston and the Presidio. In addition, there are numerous areas of Quaternary sand dunes, alluvium and other deposits that could yield vertebrate remains as well as invertebrates, plant material, and microfossils. Fossils have not been found in every one of these units, but there is potential in each.

Park Collections

Although there is only one paleontological specimen curated within GOGA museum collections, a single Cretaceous bivalve specimen collected in 1992 (GOGA 18502, *Inoceramus* sp.) from Alcatraz Island, there is fossil material collected from the area now occupied by the park present in a number of other repositories. Vertebrate, invertebrate or microfossil collections are present at the following institutions: the University of California Berkeley Museum of Paleontology, Natural History Museum of Los Angeles County, the California Academy of Sciences, the U.S. Geological Survey, and the Academy of Natural Sciences of Philadelphia.

Franciscan Terranes

In the Bay Area, terranes of the Franciscan Complex were accreted onto the margin of North America during the Mesozoic Era in the accretionary prism setting of a subduction complex (see papers in Blake 1984). The terranes are composed of oceanic rocks that may include igneous and metamorphic basement

material and marine sedimentary rocks. The Franciscan Complex is primarily composed of six rock types. Half of these rock types do not contain fossils: Basalt, a volcanic rock; serpentinite, metamorphosed mantle rock; and blueschist and other higher grade metamorphic rocks. Fossil-bearing rocks in the Franciscan include the following: Pelagic bedded chert deposits, primarily composed of the tests of single-celled Radiolaria; shallow to deep-water limestones from the top of seamounts preserved in the Permanente Terrane and which contain foraminifers and sometimes shallow marine invertebrates; and continental margin turbidite deposits composed of graywacke sandstone with lesser amounts of conglomerate and shale which rarely contain invertebrate and plant fossils, trace fossils, or foraminifers. Fossils are typically the only way to date these rocks. Therefore, any fossils found, particularly in the clastic rocks where they are extremely rare, can be of great significance for dating the rocks and providing paleoenvironmental information. The general lack of fossils in these marine rocks can be attributed to a number of factors, including poor environments for preservation of calcareous or phosphatic fossils in the oxygenated, deep-ocean depositional setting of many of these rocks, dissolution and some metamorphism during the accretion process, and very rapid rates of deposition diluting any fossils that did make their way down into the deep water turbidite deposits.

Alcatraz Terrane

The Alcatraz Terrane is predominately composed of graywacke sandstone with lesser amounts interbedded shale. This terrane underlies the GOGA Alcatraz Island site as well a large portion of San Francisco, including the GOGA sites at Fort Mason and the northeastern portion of the Presidio. The Alcatraz Terrane has produced several marine invertebrate fossils, all from Alcatraz Island. Elder (1998) reviewed the paleontologic findings at Alcatraz, which include two molluscan type species named from there—*Inoceramus elliotii* Gabb 1869 (also see Stewart 1930) and *Lucina alcatrazis* Anderson 1938. Armstrong and Gallagher (1977) further reported the bivalves *Buchia pacifica* and *Pleuromya* from the island, but which unfortunately have been lost since that report. The *Inoceramus* and *Buchia* are important in that they appear to provide an Early Cretaceous (Valanginian to Hauterivian) age for this terrane (see Elder 1998 for full discussion). A specimen of *Inoceramus elliotii* is figured on the cover of this report. Recent surveys of the island have not yielded additional material, but there is potential to turn up significant fossils finds in the future that may have further bearing on the age of this terrane block.

Marin Headlands Terrane

The Marin Headlands Terrane in GOGA is composed of bedded chert, graywacke, and basalt as well as some serpentinite (see Elder 2001 for a description of the terrane in GOGA). In the park, this terrane is exposed in the Marin Headlands and the southwestern corner of the Presidio. Fossils from this terrane collected in lands of the park have provided critical paleobiogeographic and age control for the transport history of this far-traveled block of ocean crust.

Chert makes up about half of the terrane in the park. Park cherts have produced over 60 species of Radiolaria as indicated and discussed by Pessagno (1977), Murchey (1984), Murchey and Jones (1984). These radiolarians provide age constraints from approximately 200 million years ago to 100 million years ago (Early Jurassic to Late Cretaceous) for deposition of the approximately 100 m (328 ft) of chert found in the Marin Headlands (Murchey 1984). The radiolarian assemblage also contains a significant number of tropical to subtropical species, implying that the rocks were deposited to the south of their present position, perhaps near the equator. An assortment of Radiolarian fossils from the Marin Headlands Terrane is figured on the cover of this report.

The graywacke sandstone of this terrane has also produced some invertebrate fossils in the park, albeit rarely. Hertlein (1956) reported the Cenomanian ammonite *Mantelliceras* from a boulder found on the beach at Fort Baker in the Marin Headlands (also see Matsumoto 1959 for a discussion of this fossil). Sandstone from this terrane exposed in the park in San Francisco near China Beach has also produced the Albian ammonite *Douvilleiceras mammillatum* (Schlocker et al. 1954). Schlocker (1974) also lists the gastropod *Paladmete* cf. *perferata* and a questionable *Inoceramus* from the same locality. Wright (1974) lists the belemnite *Acroteuthis* from the sandstone near the north end of Rodeo Beach. Oddly, this is a

Hauterivian cephalopod, which would not be expected from sandstone in the Marin Headlands Terrane, which are otherwise dated as mid-Cretaceous by the two ammonites listed above. The belemnite is more indicative of the Central Belt mélange found to the north. One possibility for this age discrepancy would be that the shell of this sturdy type of fossil was reworked into younger rocks of the Marin Headlands Terrane.

San Bruno Mountain Terrane

The San Bruno Mountain Terrane is primarily composed of thick to thin turbidite beds of graywacke sandstone and shale (Blake et al. 1984). In the park, this terrane is exposed in the Lands End and Sutro Baths areas. At present, no fossils have been found in this terrane that is presumed to be of Late Cretaceous age based on its position in the accretionary prism. Although no fossils are known from these rocks, it is possible that they may exist, and any paleontological material found in this terrane in the future will be of great significance for dating it.

Permanente Terrane

The Permanente Terrane is primarily composed of basalt, overlain by small amounts of Lower Cretaceous radiolarian chert, and the fossil-bearing mid to Late Cretaceous Calera Limestone (Blake et al. 1984). At some places graywacke sandstone appears to overly the Calera, but no fossils have been found from that rock type to date. In the park, the Permanente Terrane is exposed at Mori Point, on Sweeney and Milagra ridges, where it primarily consists of oceanic basalt. A sliver of this terrane is also present east of the San Andreas Fault in Olema Valley.

Chert from the Permanente Terrane has yielded Early Cretaceous Radiolaria (Murchey and Jones 1984), but the terrane is best known for its limestone blocks, known as the Calera Limestone in the Bay Area, which have yielded extensive foraminiferal assemblages including many planktonic species valuable in biostratigraphy (Thalmann 1942; Church 1952; Sliter 1984; Sliter 1989; Tarduno et. al. 1985). Sliter's work on thin sections of these limestones yielded excellent biostratigraphic control for the scattered blocks of limestone in the Permanente Terrane, including at the type Calera section adjacent to park lands at Mori Point. Here, the largest exposures of limestone in the Franciscan Complex are found in the Rockaway limestone quarry, which is being considered to become part of GOGA at Mori Point. Sliter (1984) determined that this block ranged from Early Cretaceous Aptian to Late Cretaceous Cenomanian age based on the presence of at least nine species of age significant planktonic foraminifers, and many other species have been identified. Some of this limestone block also is exposed in the park on the beach at the south end of Mori Point. In addition, foraminifers have been recovered from Permanente limestone blocks in Olema Valley, where a Late Cretaceous Cenomanian age is indicated (Bailey at al. 1964).

Central Terrane

The Central Terrane underlies most of GOGA north of the Marin Headlands, including Muir Woods. Called the Central Terrane by Blake et al. (1984), this block is composed of the sheared mélange that surrounds other terrane blocks as well as larger expanses of mélange that are composed predominately of sheared interbedded shale, sandstone, and radiolarian tuff, in which many small pieces of other local terranes too small to adequately map are included. Coastal exposures in the park from Muir Beach to Stinson Beach lie in the Central Belt mélange.

Radiolarian tuffs outside the park in Marin County have yielded Late Jurassic to Early Cretaceous Radiolaria comprising a different assemblage than that found in the Marin Headlands Terrane (Murchey and Jones 1984), and Passagno (1973, 1977) has also identified Radiolaria from chert within this terrane near park lands. Therefore, some chert within this terrane present inside the park has a high probability of yielding microfossils. Blake et al. (1984) also mention that dinoflagellates have been recovered from the matrix of the Central Terrane. Graywacke sandstone in this terrane within the park has yielded several invertebrate fossils, including Valanginian *Buchia pacifica* on Bolinas Ridge and *Buchia* sp. at Muir Beach (Bailey et al. 1964; Wright 1974; Wahrhaftig and Lehre 1974).

Unnamed Sandstone (Paleocene)

An unnamed Paleocene sandstone unit lies on granitic Salinian basement rocks just south of the Pilarcitos Fault near San Pedro Point and Devil's Slide. This area is currently in the process of being annexed by the park. The unit consists of rhythmically alternating beds of marine sandstone and shale, with some boulder and cobble conglomerates and has an estimated total thickness of 1160 m (3806 ft). The unit represents deep water submarine fan turbidite deposits.

This unit has produced a number of invertebrate fossils in the Shelter Cove and Point San Pedro areas and along Highway 1 at Devil's Slide (See Darrow 1963; Morgan 1981). Fossil finds here date back over 100 years with the Paleocene index fossil *Turritella pachecoensis* being noted at Shelter Cove by Lawson (1895, 1914) and Dickerson (1914). The large, high-spire gastropod species *Campanile greenullum* was named based on material found near Highway 1 by Hanna and Hertlien (1939). In addition, Morgan (1981) noted *Acila*, oysters, mussels, crustaceans, and echinoids. These are all shelf depth fossils that were transported to the submarine fan by turbidity currents. *In situ* fossils from this unit include the bathyal gastropod *Bathybembix* from strata at San Pedro Point, as well as deep water arenaceous foraminifers and trace fossils (Morgan 1981).

Whiskey Hill Formation (Lower-Middle Eocene)

The middle and lower Eocene Whiskey Hill Formation underlies most of the Phleger Estate site in San Mateo County. This unit has few exposures at the site due to the heavy vegetative cover. This marine formation is mostly composed of arkosic sandstone, with lesser amounts of claystone, glauconitic sandstone, and tuffaceous siltstone. The unit is as much as 900 m (2953 ft) thick.

No fossils have been reported from the Whiskey Hill Formation in the park. Rocks of equivalent age and depositional environments elsewhere in the state have locally produced abundant microfossils. Foraminifera and coccoliths were used to date the unit nearby at Stanford University (SLAC 2006a,b), and invertebrate fossils are also known from similar age rocks nearby, and there may be potential for vertebrate fossils (see Pampeyan 1993).

Merced Formation (upper Pliocene-lower Pleistocene)

The lower Pleistocene to upper Pliocene Merced Formation is exposed extensively along the coastal bluffs near Fort Funston in the park. This formation is composed of poorly indurated to friable sandstone, siltstone, and claystone, with some conglomerate lenses and a few beds of white volcanic ash. The Merced Formation is about 1525 m (5000 ft) thick in the sea cliffs north of Mussel Rock. This unit contains both terrestrial and marine deposits that represent up to 40 transgressive-regressive sea level cycles related to Pleistocene glacial and interglacial sea level changes and local tectonics. The lower part of the section south of Fort Funston is primarily marine deposits, but terrestrial influence increases up section to the north, where beach, bay, dune, stream and alluvial deposits are present. Several ash beds have allowed radiometric dates for the formation, which appears to range from near 3 million years old at its lowest exposures near Mussel Rock to perhaps less than 100,000 years old at its top near Ocean Beach (Anderson et al. 2001).

The Merced Formation contains varied and sometimes abundant paleontological resources. Vertebrate remains from the formation near Thornton Beach, just south of the park, include *Mammuthus columbi* or *M. haroldcooki* (wooly mammoth) and *Megalonyx* (giant ground sloth) (Hall 1965; Rodda and Baghai 1993). Savage (1951) also noted *Mammut* cf. *americanum* (mastodon), *Mammuthus*, and *Equus* (horse) from a locality near the north end of the outcrop belt at Fleishhacker beach that may be from either the uppermost Merced of the overlying Colma Formation. The University of California, Museum of Paleontology online collections (http://ucmpdb.berkeley.edu/) also lists additional vertebrate sites from the Merced Formation at Fort Funston that contain many of these same vertebrates with the addition of *Hemiauchenia* (camel) and *Glossotherium* (ground sloth). Vertebrate tracks also have been described from the Merced, including canid, split-toed ungulate and mammoth (Hunter et al.1984; Anderson et al. 2001). These vertebrate tracks were mentioned in an inventory of additional vertebrate tracks within NPS units

(Santucci et al. 2006). Invertebrate trace fossils from the formation include *Thalassinoides*, *Ophiomorpha* (Crustacean), and *Macaronichnus* (Polychaete).

The Merced Formation contains a rich Pleistocene invertebrate fauna, particularly from one bed known as the "upper gastropod bed," which actually contains numerous bivalves. This bed is exposed on the beach at Fort Funston and contains the following and more species: *Macoma nasuta*, *Protothaca staminea*, *Saxodomus nuttalli*, *Pecten bellus* (all bivalves); *Acanthina spirata*, *Polinices lewisii*, *Nucella laminate*, *Mitrella carinata*, *Olivella pedroana* (gastropods) (Wahrhaftig 1987; see Hall 1965 for a more complete listing). At Fort Funston, fossil sand dollars (*Scutellaster*) are frequently found on the beach. Older exposures to the south of Thornton Beach contain this extinct Plio-Pleistocene sand dollar, but it also may be present in rocks offshore that wash on to the beach after storms (Wahrhaftig 1987). The Los Angeles County Museum online collections web site (http://ip.nhm.org/) also lists many invertebrate species collected from the Merced Formation near Fort Funston. The formation also no doubt contains many microfossils as well.

Santa Clara Formation (upper Pliocene-lower Pleistocene)

A small area adjacent to the San Andreas Fault in the Phleger Estate site of GOGA is underlain by the lower Pleistocene and upper Pliocene Santa Clara Formation. Exposures of this formation are extremely poor to nonexistent in the park. This terrestrial unit is up to 500 m (1640 ft) thick and is composed of fluvial conglomerate, sandstone, siltstone, and locally lacustrine mudstone. Conglomerate consists mainly of cobbles of mainly chert, greenstone, and graywacke with some schist, serpentinite, and limestone. Sarna-Wojcicki (1976) found a tuff bed in the Santa Clara Formation near Woodside, and correlated it with a similar tuff, Rockland ash, in the Merced Formation. The Santa Clara Formation is known to contain abundant plant fossils and woody debris. Lower beds locally contain freshwater pelecypods, gastropods, plant fossils and vertebrate fossils of late Pliocene (Blancan) age (McLaughlin et al. 2001; Adam et al. 1982).

Colma Formation (Pleistocene)

The Pleistocene Colma Formation locally forms a thin veneer over rocks of the Franciscan Complex on the Golden Gate headlands of the San Francisco Peninsula. The formation extends to Angel Island and to the southern San Francisco peninsula, where it overlies the Pleistocene Merced Formation at the top of the bluffs at the north end of Fort Funston. Scattered exposures of the Colma are present throughout the Presidio overlying the Franciscan Complex. This unit predominately consists of poorly consolidated sands that probably originated in a variety of environments ranging from shallow bay, streams beds, to dune and valley slopes (Schlocker 1974). The formation is thought to represent rocks ranging from 125,000 to about 20,000 years old.

Vertebrate fossils are known from the Colma, including mammoth, bison and ground sloth remains from various locations in San Francisco (Rodda and Baghai 1993; Hall 1965). Hay (1927) reported *Mammuthus columbi* apparently from Colma deposits at Cliff House Beach within the park. Diatoms and pollen from the Colma also were noted in the Rodda and Baghai (1993) study, and a juniper tree was identified in the Colma outside the park (Schlocker 1974).

Miscellaneous Quaternary units

There are numerous Quaternary units scattered around the park, including marine terraces, sand dunes, and fluvial, alluvial, lacustrine, estuarine, and debris deposits. These all have the potential to contain many types of fossil remains including vertebrates.

Paleontological Resource Management, Preliminary Recommendations

- Given the diversity of paleontological resources in GOGA, as well as the potential for unauthorized collection, a field-based inventory of paleontological resources from the park is recommended.
- The field work could be accomplished by establishing a cooperative agreement with one or more of the dominant natural history museums with paleontological expertise, such as the University of California Museum of Paleontology at Berkeley. Graduate students could be hired non-competitively using the SCEP hiring authorities and supervised by a partnership of a faculty advisor and a park natural scientist. The NPS Geologic Resources Division can help advertise, recruit, and provide technical assistance for these positions.
- Interviews with the dominant specialists within each discipline that have worked in the park would provide considerable background. These interviews should be documented and archived by the park.
- The park would benefit from an effort to locate specimens that have already been retrieved and stored in other repositories. Molds of the holotypes and/or other significant specimens could be made and casts placed in the museum collections. Scientifically significant material encountered in the field should be stabilized *in situ* or retrieved and curated into dedicated storage if threatened.
- Park staff should continue to be made aware of the potential for discovery of fossil material during other field work, particularly along sea bluffs, road cuts, streams, creeks, gullies, and erosional features of the park.
- The establishment of a study collection of fossils from the local area could be beneficial. A field-based inventory could provide specimens for such an endeavor.
- Results of a field inventory can be used to create paleontological resource monitoring prescriptions, should the park establish a program of paleontological resource monitoring.

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John Muir National Historic Site

John Muir National Historic Site (JOMU) was established in 1964 at Martinez, California, at the Victorian home of John Muir to commemorate the noted author's contributions as a preservationist. The historic site includes the nine acre home site with orchards and the Martinez adobe, a part of California's Spanish heritage, and the adjacent 132 ha (326 acre) Mount Wanda oak woodland area, which as acquired in 1993.

Baseline Paleontological Resource Inventories

Geologic scoping sessions, coordinated by the NPS Geologic Resources Division, were held for JOMU in September 2007. Paleontological scoping sessions have not been held for the park and there have been no formal paleontological resource surveys or inventories. Nevertheless, paleontological resources are known nearby from the rock units contained within JOMU and there is potential for fossil discovery and recovery from within the park.

The recently compiled U.S. Geological Survey (USGS) Open File Report 94-622 covers the geology of the park area and can be found and downloaded from the internet (Graymer et al. 1994). Weaver (1949) provided important older mapping for rocks adjacent to and immediately north of the park site as well as fossil lists for units at JOMU, but collected to the north of the park. Bedrock in the historic site consists of Cretaceous rocks of the Great Valley Sequence and overlying Lower Tertiary sediments that fall within Assemblage IV – Martinez Area of Graymer et al. (1994).

Park Collections

Bedrock exposures are limited in JOMU, most lying in the Mt. Wanda area. No fossils collected from the site exist within the park collections. However, the units that underlie the park are known to be highly fossiliferous locally and numerous fossil localities in these units nearby are listed in Parker et al. (2003) and on the University of California, Berkeley Museum of Paleontology (http://ucmpdb.berkeley.edu/loc.html) and Los Angeles County Museum of Natural History collections (http://ip.nhm.org/ipdatabase/) web sites. The University of Washington, Burke Museum also houses collections made by Weaver adjacent to the park and collections from some of the earlier studies of these rocks in the area are also housed at the Smithsonian Institution and the Academy of Natural Sciences of Philadelphia.

One specimen of Triassic petrified wood from the famous Petrified Forest of Arizona is contained within the park collections. The existence of this specimen in the JOMU collection is symbolic of the year long venture that John Muir and his daughters made to Arizona between the summers of 1905 and 1906. Lubick (1996) provides an historical account of Muir's visit to Petrified Forest prior to the areas establishment as a national monument by President Theodore Roosevelt in 1906 under the authority granted in the Antiquities Act.

After the death of his wife in 1905, John Muir traveled to the dry desert climate of Arizona in order that his daughter Helen may recover from a respiratory disorder. Although Muir intended to develop an article for publication on the petrified forests, his interests lay more in the discovery and study of the fossil forests. Muir completed courses in geology as a student at the University of Wisconsin and used this knowledge to undertake excavations of fossils near Adamana, Arizona. Muir captured his observations of the petrified forest in his correspondence, notebooks, and sketchbooks. The most important contribution of Muir during his work in the petrified forest was the discovery and naming of the Blue Forest (now Blue Mesa), a rich deposit of petrified logs exposed approximately 10 km south of Adamana (Lubick 1996).

After his departure from Adamana and the Forest Hotel in August 1906, John Muir contacted paleontologist John C. Merriam of the University of California. Muir presented Merriam with a small collection of vertebrate fossils he had collected from the petrified forest. These remains were identified as

phytosaur and placed in the university's paleontology collection. Muir never completed or published an article about the petrified forest.

Great Valley Sequence (Cretaceous)

Rocks of the Great Valley Sequence underlie most of the Mt. Wanda area of JOMU. Two marine Great Valley units are present in this area: 1) an unnamed Cretaceous sandstone [Kus in Graymer et al. (1994)] consisting of sandstone, siltstone, and shale; which is overlain by 2) an unnamed Cretaceous quartz arenite sandstone [Kcs in Graymer et al. (1994)], described as a gray, massive quartz arenite. These units lie at the top of the Cretaceous sequence in the area and are probably Campanian to Maastrichtian in age. No fossils are known from the Cretaceous rocks exposed in the park, but rocks of similar age nearby have produced diverse invertebrate and microfossils. Weaver (1949, p. 44) lists several localities slightly north of the park, possibly lying in the Kus unit, with diverse molluscan assemblages (Loc. 2566 & 2567, Univ. of Washington). These fossils need to be reviewed and placed in modern nomenclature before an accurate age determination can be made from them. However, Matsumoto (1960) noted that Gabb (1864) described an ammonite specimen collected near Martinez as *Baculites chicoensis*, but Matsumoto considered it to be *Eobaculites ootacodensis* of Maastrichtian age. The predominately sandstone units in the park are probably mostly too coarse to yield good microfossil assemblages, but a siltstone and shale unit found between the Kus and Kcs units only 0.8 km (0.5 mile) southwest of the park has yielded a diverse foraminiferal fauna of Upper Campanian age (USGS MF 7776;USGS, E. Brabb, Geologists Emeritus, pers. comm., 2006). Thus, there is good potential for Cretaceous invertebrate and microfossil resources within the park. Plant, pollen, and trace fossils are also likely to be present in the Great Valley Sequence rocks of the park.

Lower Vine Hill Sandstone (Paleocene)

The Paleocene lower Vine Hill Sandstone, described as a glauconitic marine sandstone [Tvhl in Graymer et al. (1994)] probably underlies the house area of the park and a small area on the north flank of Mt. Wanda. Rocks of Paleocene age are very rare in California, and the rocks of this age in the Martinez area provided important fossil material for documenting the first fossils known from this period on the West Coast. Studies of these fossils include some of the pivotal early studies dating back to Gabb (1869), and including White (1889), Stanton (1896), Dickerson (1914), Nelson (1925), and Watson (1942). Weaver (1949, p. 54-55) lists several localities from what is now called the Vine Hill Formation that contain relatively diverse invertebrate faunas. Although no fossils are known to have been found in these rocks in the park, there is potential. The deposits in the park are probably too coarse for microfossils, which have also been found in some finer-grained portions of the Vine Hill Formation to the east on JOMU (Weaver 1949).

Paleontological Resource Management, Preliminary Recommendations

- Because of the high likelihood of fossils in the bedrock of JOMU, park staff should be made aware of the potential for discovery of fossil material and any excavation of the bedrock in the park should be monitored for paleontological material.
- A field-based inventory of paleontological resources from the park is recommended.
- Results of the field inventory can be used to create paleontological resource monitoring prescriptions, should the park establish a program of paleontological resource monitoring.

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Pinnacles National Monument

Pinnacles National Monument is located between Salinas and San Benito Valleys in the Gabilan Mountains. Pinnacles National Monument was set aside as a National Monument by Theodore Roosevelt in 1908 and has been considerably added to since that time. Pinnacles National Monument is named for its topography of rock spires, crags and pinnacles of sharp relief. The high relief pinnacles represent volcanic breccias broken up by numerous joints and cemented with silica from flowing waters between the joints. The result is a landscape of pinnacles that stands out from the surrounding valley. The first published report on the area was made by the explorer Captain George Vancouver who noted the "unusual mountain" that is Pinnacles National Monument today (Vancouver 1794).

Baseline Paleontological Resource Inventory

Pinnacles National Monument contains metamorphic, plutonic rocks and to a lesser degree unmetamorphosed sedimentary rocks. Geologic Resource Evaluation scoping sessions, sponsored by the NPS Geologic Resources Division were held for PINN in September of 2007. While volcanic and metamorphic rocks dominate the park, fossils are known from the park in an unusual occurrence within the Neenach (Pinnacles) Volcanics, described below. There is some potential that future research may uncover fossils within sedimentary rocks of the Monterey Formation or within the talus caves. Phil Stoffer (USGS, Menlo Park) indicated that he had not seen fossils within PINN, but would not be surprised if they were found in the park (USGS, P. Stoffer, Geologist, pers. comm., 2007). Stoffer also noted that the Miocene and Pliocene formations surrounding the park are particularly fossiliferous and that stream beds in the area are known to yield fossils.

Dibblee (1979) produced a geologic map of the Bickmore Canyon quadrangle covering half of PINN. Andrews (1936) produced a geologic guide to the park, and numerous other road guides and geologic descriptions exist for the park and surrounding area including Hinds (1952), Stoffer and Gordon (2001) and Stoffer (2002).

The oldest exposed rocks within the Park are Paleozoic granitic basement rocks. Overlying the granitic basement rocks is the Paleozoic Gabilan Limestone (Trask 1926). Cretaceous and early Tertiary sediments are absent due to nondeposition or erosion. In early middle Miocene rhyolitic magma erupted through fissures in the granitic basement rocks along with pyroclastics that gave rise to the characteristic pinnacles within the monument. These Miocene volcanic deposits are collectively known as the Pinnacles or Neenach Volcanics. Pleistocene terrace gravels were deposited about the edges of the central volcanic mass.

Gabilan Limestone (Paleozoic)

Stratigraphically, the Gabilan Limestone (also spelled Gavilan) is found just above the granitic basement rocks within Pinnacles National Monument. Unfortunately the original rocks have been metamorphosed and any fossil content obliterated. Lime deposits were originally interbedded with mud and sands, which are now represented by mica schists and quartzites (Andrews 1936).

Pinnacles (Neenach) Volcanics (Miocene)

The Pinnalces/Neenach Volcanics make up the dramatically weathered volcanic deposits that are the park's namesake. Interestingly, the volcanic rocks found within PINN were originally part of the Neenach Volcano found 314 km (195 miles!) to the southeast. The San Andreas Fault subsequently split the Neenach Volcano, with half (what is now PINN) traveling that distance with the Pacific Plate to the northwest over the last 20 million years.

Generally fossils are not associated with volcanic rocks, however they can occur in some ash fall deposits or even as tree molds in lavas (e.g. Craters of the Moon National Monument and many of the Hawaiian

NPS units). Some clasts in the dacite breccia (fine-grained volcanic rock) of the Neenach Volcanics resemble fossil wood and may in fact be woody material (USGS, P. Stoffer, Geologist, pers. comm., 2007).

Vince Matthews (Colorado Geological Survey; pers. comm., 2007) described an interesting fossil occurrence within the park. Ostracode fossils (small bivalved crustaceans) are rare to abundant in some of the tuff (consolidated volcanic ash) deposits northwest of park headquarters. While many ostracode families are marine, some are found in freshwater or even damp leaf litter or soils. The discovery of ostracodes, graded bedding, rip-up and flame structures suggest underwater deposition for the tuff (V. Matthews, pers. comm., 2007). Additional fossil-like fragments, visible in thin sections, are found in the breccia in the northern area of the park. Further research into these occurrences will likely yield additional information.

Temblor Formation (Miocene)

Within Pinnacles National Monument the Temblor Formation consists of fanglomerates and gravel deposits of continental origin best exposed east of the Chalone Creek Fault (Andrews 1936). Andrews (1936) noted the "lack of fossils" in the Temblor within PINN.

Monterey Formation (Miocene)

In Bear Valley, immediately adjacent to the eastern boundary of PINN, the Temblor Formation is conformably overlain by white, chalky, diatomaceous shales and interbedded sandstone considered to be part of the Monterey Shales of Kerr and Shenck (1925) and representing the only marine deposits within the area but outside current PINN boundary. The shale is rich in the diatom *Coscinodiscus incretus* and fragments of the bivalve *Arca* sp., an echinoid, fish bones and scales (Kerr and Shenck 1925). Hanna (1928) described the fossil assemblage found at the formation's type locality near Monterey. He did not mention fossils from southern San Benito County near PINN, however he mentioned that most Miocene shales in California were fossiliferous. Interestingly, the Monterey Formation was the first formation to be named in California and also produced the first fossil described from California in 1853 (Hanna 1928). Given their exposure immediately adjacent to PINN, future field investigations may determine whether Monterey Shales and associated fossils may be present within the park.

Terrace Deposits and Talus Caves (Pleistocene)

Terrace deposits composed chiefly of fragments derived from volcanic rocks occur at several places near the central volcanic mass of PINN (Andrews 1936). Andrews (1936) did not report any paleontological resources from the terrace deposits. Pleistocene *Equus* remains were discovered in Pleistocene-aged deposits in San Benito County on the east side of the San Andreas Fault (Kerr and Schenck 1925).

Talus caves are an interesting geomorphic feature within PINN near Chalone Creek. The caves formed by stream erosion along vertical joints associated with strands of the San Andreas Fault and by toppling of "cyclopean boulders" during large earthquakes (Hinds 1952; Rogers 2003; Rogers et al. 2003). Three of the features are quite large with lengths ranging from 176 m (577 ft) to 1754 m (5755 ft). While paleontological resources are not described specifically from the caves, the presence of bats is noted by Rogers et al. (2003). Depending on how long they have inhabited the caves, bat fossils may be found. Field reconnaissance could determine the presence of such fossils. Rogers (2003) also noted the presence of packrat (*Neotoma*) droppings in the cave. Packrat middens are important paleontological resources as they record local paleoecological conditions. Middens are known from many caves throughout the NPS (Santucci et al. 2001), but none are yet documented within PINN.

Sand, Gravel and Alluvium (Recent)

Recent deposits include sands and gravels of Chelone Creek and tributaries as well as alluvium on the east side of PINN (Andrews 1936). As such deposits are recent, *in situ* paleontological resources are not expected. However if Chelone Creek cuts through fossiliferous layers, fossils may be found in the alluvial deposits of the creek. Stream banks near the park have produced Miocene and Pliocene fossils outside of PINN (USGS, P. Stoffer, Geologist, pers. comm., 2007).

Paleontological Resource Management, Preliminary Recommendations

- A field-based investigation is recommended to determine if fossils are indeed found within the potentially fossiliferous units listed above.
- Additional research into the ostracodes and potential fossils in the Miocene volcanics in the park may yield further insight into these uncommon fossil occurrences.
- The field work could be accomplished by establishing a cooperative agreement with one or more of the dominant natural history museums or the USGS. The NPS Geologic Resources Division can help advertise, recruit, and provide technical assistance for this work.

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Point Reyes National Seashore

The Point Reyes Peninsula is a roughly triangular shaped land projection located in Marin County, California, bounded in the east by the San Andreas Fault zone and the west by the Pacific Ocean. Established by Congress in 1962 the Point Reyes National Seashore (PORE) encompasses 28,751 ha (71,046 acres) of beaches, sea-cliffs, coastal dunes, grasslands, and Douglas fir forests. The principal topography consists of linear depressions of the Olema Valley, Bolinas Lagoon, and Tomales Bay in the fault zone, and the high land of Inverness Ridge, immediately west of these depressions, and the promontory of Point Reyes.

Baseline Paleontological Resource Inventories

Geologic resource scoping sessions for PORE were held in September 2007. Formal paleontological resource inventories have likewise not yet been conducted for the park. Nevertheless, fossils are known from PORE including a number of marine mammal fossils on display at the Ken Patrick Visitor Center (figured on the cover of this report) along Drake's Bay. In addition, and as described below, a number of paleontological localities are located outside of, but proximal to, the park. A field-based paleontological resource inventory may be undertaken during 2007 (NPS, K. Kvam, PORE Museum Curator, pers. comm., 2007). There is excellent potential for additional fossils to be found within the park.

The first scientific report of the Point Reyes Peninsula was from the 1855 Report of the Superintendent of the Coast Survey by Blake (1856), which contained a geologic map and cross section of Point Reyes and vicinity. F. M. Anderson (1899) published "Geology of the Point Reyes Peninsula" which gave the first detailed geologic description of the rock units in the Point Reyes area.

The next major geologic paper was the Geology of the Point Reyes Peninsula, Marin County, California by Galloway (1977), which included a 1:48,000 geologic map of the Point Reyes Peninsula. Clark et al. (1984, 1997) used mapping and seismic profiling to further refine the geology of the Point Reyes Peninsula into distinct facies. Clark and Brabb (1997) published an online digital database of their geologic map of PORE and vicinity, including a printable PDF version.

The geology of the area is dominated by the San Andreas Fault zone, which forms the eastern boundary of the Point Reyes Peninsula between Bolinas Lagoon in the south and Tomales Bay in the north, separating the Pacific and North American plates. Hall and Hughes (1980) noted that some of the greatest displacement (some 4-5 m (13-16 ft)!) along the San Andreas during the 1906 earthquake was near Point Reyes Station, now PORE headquarters.

The oldest rocks of the area are the metamorphosed crystalline limestones, quartzites and schists that are roof pendants in the granite along Inverness Ridge from Mount Wittenburg to Tomales Point (Galloway 1977). These rocks were originally sandstone and limestone that were later intruded by granite and metamorphosed about 80 million years ago (Galloway 1977). Resting nonconformably upon the crystalline basement are fossiliferous Tertiary marine sedimentary rocks that comprise three sequences, separated by unconformities (Clark and Brabb 1997). The early Eocene Point Reyes Conglomerate is the oldest sequence followed by a middle and upper Miocene sedimentary sequence consisting of the Laird Sandstone and Monterey Formation and finally the upper Miocene and Pliocene sedimentary sequence referred to as the Drakes Bay Formation by Galloway (1977) and later divided into the Santa Margarita Sandstone, Santa Cruz Mudstone and the Purisima Formation by Clark et al. (1984) and Clark and Brabb (1997).

Park Collections and Visitor Center Displays

According to the park curator (NPS, K. Kvam, PORE Museum Curator, pers. comm., 2007) there are at least 15 paleontology specimens within PORE collections. In addition, the Ken Patrick Visitor Center

displays a fossil baleen whale skull (figured on cover of this report) and additional marine fossil specimens.

Point Reyes Conglomerate (Eocene)

The Point Reyes Conglomerate is exposed only in the extreme western portion of the peninsula unconformably overlying granitic basement rocks. The Point Reyes Conglomerate consists mainly of coarse, sandy conglomerate beds separated by strata of laminated silty micaceous, fine sand, with occasional thin shale beds (Galloway 1977). Carbonized plant remains and seeds are common in the silty micaceous sand layers, while foraminifera are found in the shaley layers. Galloway (1977) includes species lists for both the foraminifera (important biostratigraphic fossils) and plants.

Laird Sandstone (Miocene)

Lying unconformably on the granitic basement and below the Monterey Shale, the Laird Sandstone was first described by Weaver (1949). The Laird Sandstone outcrops in bluffs beside the road between Abbotts Lagoon and Pierce Ranch and in sea-cliff exposures on the west coast of the peninsula west of Laird's Landing, at the north end of Point Reyes Beach. Mollusks and echinoids (Clark et al. 1997) and casts of a few small marine bivalves identified by Galloway (1977) as *Cardium* are the only fossils reported from the Laird Sandstone.

Monterey Formation (Miocene)

The Monterey Formation consists of cherts, porcelanites, organic shales, and thin hard sandstones (Taliaferro 1951). All three stages (Luisian, Mohnian, and Delmontian stages) of the Monterey Formation are exposed on the Point Reyes Peninsula (Blake 1856; Anderson 1899; Weaver 1949). Shale units of the Monterey are thin bedded, micaceous and weather white. They contain fish remains/scales, foraminifera, and diatoms (Galloway 1977). Foraminifera, diatoms and mollusks are common within the Monterey rocks at several localities on the Point Reyes Peninsula. Again, Galloway (1977) presents a list of important fossil species. In addition to fragments of the echinoid *Brisaster* and *Scutellaster*, the mud shrimp *Callianassa* and pinnotherid crab *Pinnixa*, fragments of whale bone, and a cetacean skull have been reported from the vicinity of Duxbury Point to Abalone Point.

Santa Margarita Sandstone, Santa Cruz Mudstone, and Purisma Formation (Drakes Bay Formation; Miocene-Pliocene)

Clark et al. (1984) divided the Drakes Bay Formation of Galloway (1977) into the Santa Margarita Sandstone, the Santa Cruz Mudstone and the Purisima Formation; all three units have type localities east of the San Andreas Fault to the south of San Francisco (Clark and Brabb 1997 mapped it as such). These formations make up the white cliffs of Drakes Bay, which Sir Francis Drake saw in 1579. The formations, as a whole, consist of glauconite-bearing greensands that grade upward into shales which grade upward into white siltstones and mudstones (Galloway 1977).

The formations are highly fossiliferous, with vertebrate fossils including large teleost fish, sea lion and dolphin skulls, *Charchardon* shark teeth, and abundant marine mammal skulls, vertebrae, and bone material. In addition, numerous mollusks, echinoderms, foraminifera, radiolarians, diatoms, plant remains including carbonized wood and conifer cones have also been described. See Galloway (1977) for a list of fossils reported from the Drakes Bay Formation. Specific fossils from the subdivided Drakes Bay Formation are summarized below, including important fauna found within and near PORE summarized by Repenning and Tedford (1977) and Ziegler et al. (1997).

Repenning and Tedford (1977) described *Thalassoleon macnallyae* (new species) of otarioid seal from the Drakes Bay Formation of Galloway (1977) near Drakes Beach within PORE. They also assigned the glauconite (a greenish mineral indicative of slow sedimentation) beds is to the latest Miocene. These beds also contain an "odobenid" (walrus) questionably referred to *Dusignathus santacruzensis* by Repenning and Tedford (1977). Repenning and Tedford (1977) suggest that Galloway's age estimate is too old and that the formation is likely the same age as the Purisma Formation (4-6.7 Ma).

In 1976 C.V. Zeigler discovered the remains of a fossil whale in the sea cliffs near Bolinas, California. The whale skeleton took eight years to excavate as the bones were naturally exposed. The specimen was prepared and is now on exhibit at the College of Marin Science Center. Zeigler et al. (1997) described this whale specimen as a new species of balaenopterid whale, *Parabalaenoptera baulinensis* from the Santa Cruz Mudstone exposures at Bolinas Point either within or immediately adjacent to PORE boundaries. *P. baulinensis* is one of the most complete balaenopterids yet described. Domning's (1978) dugongid sea cow came from the same area of Bolinas Point. Zeigler et al. (1997) utilized associated diatoms to estimate the age of the whale to approximately 6.8-6.0 Ma. Additional fossils found within the same strata as *P. baulinensi*s include bivalves tentatively identified as *Acesta*. Zeigler et al. (1997) also noted that the Santa Cruz Mudstone contains gastropods, bivalves, echinoderms, isopods, crab claws, decapod shrimp parts, fish teeth and bones and isolated mammal bones.

Axelrod (1971) described fossil pine cones from the "upper Drakes Bay Formation" now likely assigned to the Purisma Formation. The fossils were collected within what is now the park along Drakes Bay. They resemble modern pines at Monterey. Axelrod (1971) summarized the exceptional record of terrestrial vegetation from late Neogene and Quaternary (Miocene-Holocene) deposits throughout the San Francisco Bay Region.

Merced Formation (Upper Pliocene-Pleistocene)

The Merced Formation is confined to the San Andreas Fault zone near Bolinas (Higgins 1961) extending for about 11.3 km to the northwest. The Merced Formation at Bolinas consists of soft sands and silts forming low-relief rounded topographic features that are easily eroded by wave action. The sea cliffs at Bolinas have produced a number of fossils including whale skulls, sea lion, porpoise, bony fish, sharks, feathers, crustaceans, echinoderms, bivalves, gastropods, foraminifera, sponge spicules, radiolaria, plant remains, carbonized wood, and molds of diatoms (Galloway, 1977). A fossil baleen whale skull cast from the Merced Formation is in the Ken Patrick Visitor Center (NPS, K. Kvam, PORE Museum Curator, pers. comm., 2007).

Millerton Formation (Pleistocene)

The Millerton Formation consists of discontinuous marine and nonmarine deposits exposed on the headlands on the northeast shore of Tomales Bay (Galloway 1977). The Millerton Formation is highly fossiliferous (see Johnson 1962; Mason 1934) including bivalves, gastropods, scaphopods and arthropods. These fossiliferous sand, clay, and gravel beds were named and described by Dickerson (1922) and recombined by Weaver (1949). Axelrod (1971) described a rich floral record from the Millerton Formation along Tomales Bay, particularly on the eastern side, immediately adjacent to PORE and within the authorized boundary for GOGA. Axelrod lists more than two dozen species of a closed canopy pine forest, dominated by Monterey Pine from the Millerton Formation. A radiocarbon age of 29,050 ± 1,000 years was obtained from a pine cone from Millerton Head (Axelrod 1971).

Olema Creek Formation (Pleistocene)

The Olema Creek Formation consists of siltstone and claystone beds which outcrop in Olema Creek between the Boyd Stewart Ranch and the Vedanta retreat. Tree trunks and freshwater diatoms have been found within this formation (Galloway 1977). Colson (1994) suggested the Olema Creek Formation is primarily fluvial (river-deposited) rather than lacustrine (lake-deposited) as described by Galloway (1977).

Pollen Paleoecology (Pleistocene-Holocene)

Rypins et al. (1989) reported an important fossil pollen (palynology) assemblage collected from sediment cores at three localities within PORE including Coast Trail Pond, Sculptured Beach, and Secret Beach. Their samples were radiocarbon-dated, utilizing wood and charcoal, revealing a 12,300 year pollen record from the sites. Rypins et al. (1989) pollen assemblage includes the Pleistocene-Holocene transition (10,000 years ago) and records a marked environmental change from a closed canopy forest of

Pseudotsuga and *Abies* to a coastal scrub and grassland similar to the modern flora. Overall 50 different pollen types were collected by the authors. The change noted within PORE is consistent with other studies as summarized by Rypins et al. (1989) suggesting a cooler and moister late Pleistocene climate for coastal California. Mudie and Byrne (1980) utilized pollen of the introduced (alien) plants sheep sorrel (*Rumex acetosella*), plantain (*Plantago lanceolata*), *Eucalyptus* spp., *Acacia* spp. and Japanese dwarf black pine (*Pinus thumbergi*) as chronological markers to estimate sedimentation rates over the last few hundred years. Their study included six salt marshes in central and southern California, three of which are within/near PORE: Drake's Estero, Lake Ranch, and Bolinas Lagoon.

Sand, Gravel, and Alluvium (Recent)

The Drakes Bay is overlain by sand dunes, beach deposits and marine terrace deposits of Pleistocene to Holocene age. Fossils are not known from these deposits. Grove and Niemi (1999) did utilize "detrital sticks" from Recent alluvial deposits near the Vendanta Retreat to obtain radiocarbon dates (~1800 years before present) to compare stream flow patterns near the San Andreas Fault.

Paleontological Resource Management, Preliminary Recommendations

- Given the diversity of fossil resources known from the park and the potential for continued fossil discovery,a field-based inventory of paleontological resources from the park is recommended.
- The field work could be accomplished by establishing a cooperative agreement with one or more of the dominant natural history museums, universities, or USGS. The NPS Geologic Resources Division can help advertise, recruit, and provide technical assistance for these efforts.
- Results of the field inventory can be used to create paleontological resource monitoring prescriptions, should the park establish a program of paleontological resource monitoring.
- Interviews with the dominant specialists within each discipline that have worked in the park would provide considerable background. These interviews should be documented and archived by the park.
- The park would benefit from an effort to locate specimens that have already been retrieved and stored in other repositories. Molds of the holotypes and/or other significant specimens could be made and casts placed in the museum collections. Scientifically significant material encountered in the field should be stabilized *in situ* or retrieved and curated into dedicated storage if threatened.

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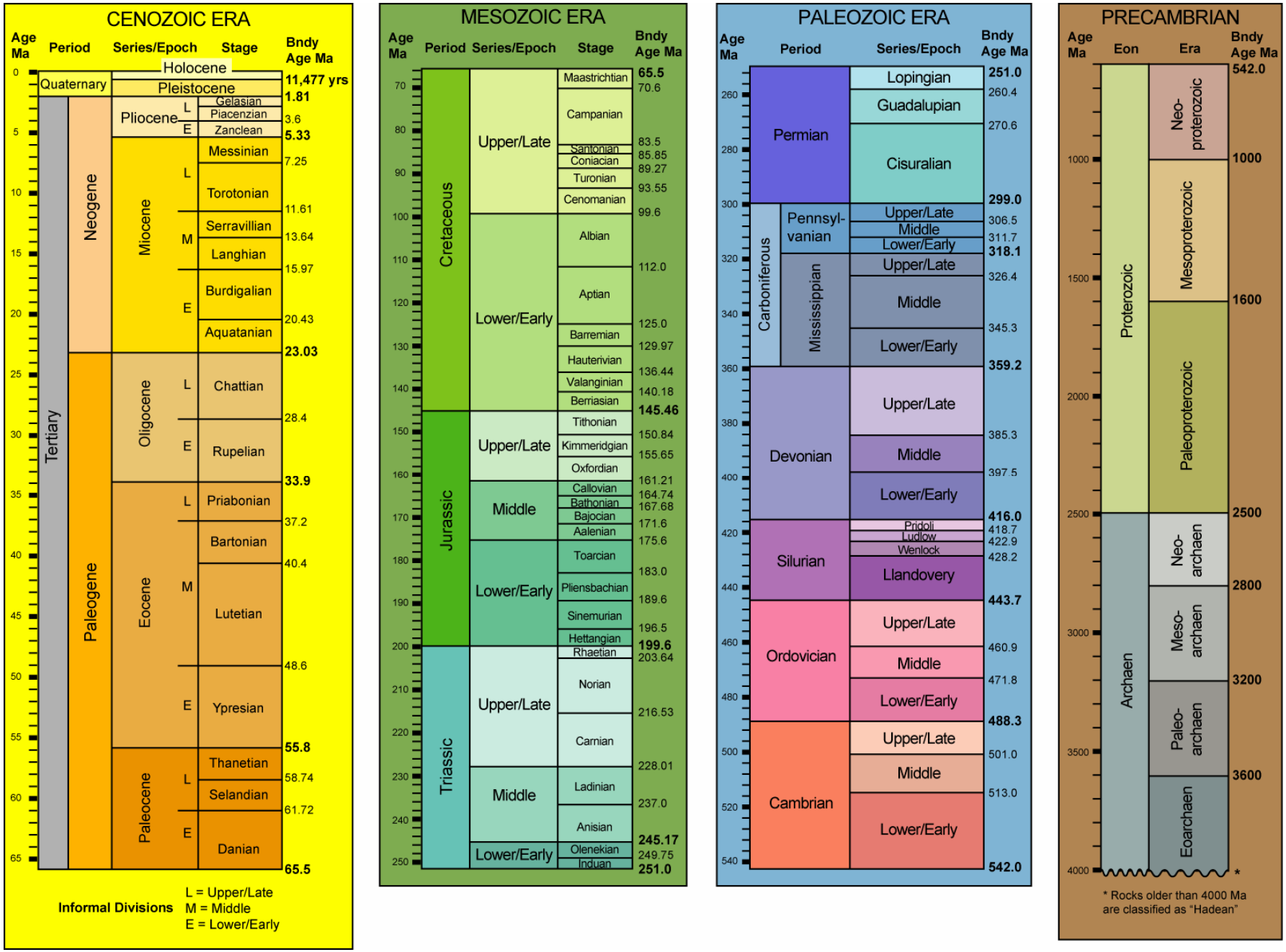


Figure 2. Geologic Time Scale. *Ma = Millions of years old. Bndy Age = Boundary Age*. Colors are USGS standard colors found on geologic maps. Modified from 1999 Geological Society of America Time scale (www.geosociety.org/science/timescale/timescl.pdf). Boundary dates and additional information from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

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.

NPS D-20, January 2008

National Park Service
U.S. Department of the Interior

Natural Resource Program Center



Natural Resource Program Center
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525

www.nature.nps.gov