



Paleontological Resource Inventory and Monitoring

Mediterranean Coast Network

Natural Resource Technical Report NPS/MEDN/NRTR—2012/640



ON THE COVER

Fossil owl pellets from Arlington Springs on Santa Rosa Island, Channel Islands National Park (CHIS) yield thousands of bones of the “giant deer mouse” *Peromyscus nesodytes*, known only from Quaternary fossils found at CHIS (photo courtesy John Johnson, Santa Barbara Museum of Natural History).

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NOTE:

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

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

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Abstract

Paleontological resources (fossils) are any remains of past life preserved in a geologic context. Paleontological resources are non-renewable resources found in at least 237 National Park System units. Despite the abundance and diversity of these resources throughout the National Park Service (NPS), until recently few parks have had 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 Mediterranean Coast Network (MEDN). 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. Summaries have now been prepared for all of the 32 NPS Inventory and Monitoring Networks.

The parks of the MEDN are extensively fossiliferous, with some of the best Cenozoic fossil records in the National Park System. Fossil discoveries were first made as far back as the middle 19th century, in the area that would become Cabrillo National Monument (CABR), and fossils of the famous pygmy mammoths of Channel Islands National Park (CHIS) were first reported in 1873. Systematic study on fossils from the MEDN began during the first decade of the 20th century, with specimens from CHIS and Santa Monica Mountains National Recreation Area (SAMO). Several new taxa were named in these early publications, and new taxa have continued to be described; as of this report, 58 genera, species, or subspecific taxa have been named from MEDN fossils, including seaweeds, mollusks, crabs, sea urchins, bony fish, mice, and mammoths. Most fossil occurrences in the MEDN are from the Late Cretaceous (99.6 to 65.5 Ma [million years ago]) (see the appendix for a geological timescale) through the Cenozoic (65.5 Ma to the present), with no fossils older than the Late Jurassic (161.2 to 145.5 Ma), and no rock outcrops older than the Middle Jurassic (175.6 to 161.2 Ma). The time frames with the most complete records are the

Late Cretaceous to the end of the Eocene (65.5 to 33.9 Ma), the Miocene (23.0 to 5.3 Ma), and the Quaternary (younger than 2.6 Ma); the first and last of these three time frames are represented at all three MEDN units, and the second is represented at CHIS and SAMO. Fossils from MEDN parks can be found at many museums and universities in southern California. Connections between paleontological resources and cultural resources have mostly been addressed in the context of the arrival of humans (Santa Rosa Island of CHIS has yielded human fossils that are among the oldest known in North America, from approximately 13,000 years ago), and whether they influenced the extinction of CHIS's pygmy mammoths.

Of the three MEDN units, fossils from CHIS are probably most widely known. This is because of the pygmy mammoth, *Mammuthus exilis*, found nowhere else. However, fossils are abundant at CABR and SAMO as well, and many geoscience enthusiasts of southern California got their start hunting for invertebrate fossils in the various undeveloped areas of the Santa Monica Mountains that later became part of SAMO. Most fossils from the MEDN units are the remains of invertebrates (particularly mollusks) or various types of single-celled organisms, represented by microfossils such as coccoliths (mineralized algal structural plates) and foraminiferal tests ("shells" secreted by foraminifera, amoeba-like protists). Smaller but still significant occurrences of plant fossils, vertebrate fossils, and trace fossils are also present. A mix of these five fossil categories is found in and around all three MEDN units. CABR is noted for its Cretaceous invertebrate trace fossils, as well as an unexpected cycad leaf. Microfossils and invertebrates are abundant throughout the geological record of CHIS's five islands, with important Quaternary plant and vertebrate discoveries as well. SAMO's fossil record is dominated by invertebrates, with Miocene and Quaternary vertebrates and plants including an important Miocene fish assemblage and a largely-unpublished Pleistocene vertebrate assemblage, as well as rare Miocene seaweed fossils. It is also notable for the combination of extensive fossil resources in and around an urban setting. Together, the fossil records of the three MEDN units give a nearly continuous picture of the area's biota from the second half of the Late Cretaceous to the present.

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Dedication



This volume is dedicated to National Park Service ranger, visual information specialist, geologist and friend, Alison (Koch) Mims. For more than a decade, Alison has contributed to an increased awareness, management and protection of National Park Service fossils. During assignments at Fossil Butte National Monument and Santa Monica Mountains National Recreation Area, and for the NPS Geologic Resources Division, Alison helped to establish new strategies for the inventory and monitoring of paleontological resources. She was involved helping to pilot the Inventory & Monitoring Network-based paleontological resource inventories for the Northern Colorado Plateau, Mediterranean Coast, Greater Yellowstone, Southern Plains, Eastern Rivers and Mountains, and Rocky Mountain networks. Alison coordinated the first park-specific paleontological resource inventory, for Santa Monica Mountains National Recreation Area (2004). Alison helped to develop a strategy for paleontological resource monitoring for the NPS and piloted monitoring projects at Fossil Butte National Monument, Curecanti National Recreation Area, Yellowstone National Park, and other areas. More recently, Alison has helped to promote National Fossil Day planning and produced a video featuring the National Fossil Day song. Through the sustained work by Alison, the NPS has become a leader in the management of paleontological resources on federal lands.

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 scientific, educational, and interpretive value. In the National Park Service (NPS) there are three fossil context categories: in situ (fossils found in rock layers), in museum collections, or in cultural resource contexts (building stones, archeological resources, historic documents, and ethnographic legends or stories). This report addresses fossil discoveries in all of these contexts.

The establishment of baseline paleontological resource data is essential for the appropriate management of fossils found within National Park System units. Although at least 237 units 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 Mediterranean Coast I&M Network (MEDN).

The Mediterranean Coast Network includes three NPS areas in southern California as shown in Figure 1: Cabrillo National Monument (CABR), Channel Islands National Park (CHIS), and Santa Monica Mountains National Recreation Area (SAMO). The MEDN parks detailed in this report range in size from just under 65 ha (160 acres) (CABR) to nearly 101,000 ha (250,000 acres) (CHIS). CABR was established to memorialize an explorer, while CHIS and SAMO were primarily established to protect natural features. Together, the NPS units of the MEDN protect areas belonging to the rare Mediterranean coast biome, known for a combination of distinct geography (mid-latitude west coast), climate (mild rainy winters and warm dry summers, with cool offshore ocean currents), and vegetation (evergreen or drought-adapted deciduous shrublands). All three of the units have some form of paleontological resources, and CHIS and SAMO are extensively fossiliferous.

MEDN Geological Background

The geologic history of the MEDN (discussed in greater detail in the individual park summaries) is well-represented by outcrops from the Late Cretaceous to the present, with rarer rocks as old as the Middle Jurassic (see the appendix for a geological time scale). Like other I&M networks on the West Coast, the geological history of the MEDN includes dramatic large-scale tectonic events. For much of the period represented by outcrops at CABR, CHIS, and SAMO, an oceanic plate known as the Farallon plate was being subducted beneath the North American plate along the west coast of North America. The interactions of the disappearing Farallon plate, the North American plate, and the Pacific plate to the west form the background to the local geology of the three MEDN units. The MEDN is composed of terranes (distinct blocks of continental crust) that had accreted to western North America by the late Mesozoic. CABR is located within the Peninsular Ranges terrane, and CHIS and SAMO are within the Transverse Ranges terrane. The two terranes were substantially closer during the late Mesozoic and early Cenozoic; the future northern Channel Islands were probably a short distance south of the eventual location of San Diego (and CABR) during the late Cretaceous, and were approximately adjacent to the future site of the city during the Eocene. A reorganization of plate boundaries during the middle Cenozoic caused the Transverse Ranges terrane to be wrenched out of place, rotated approximately 90° clockwise, and moved northward.

Jurassic rocks can be found in CHIS and SAMO. They are mostly metamorphic and igneous rocks originally from oceanic volcanic arcs and associated areas. A few rare invertebrate fossils are known from the SAMO area, in the Santa Monica Slate, but for the most part metamorphism has destroyed the fossils of the sedimentary rocks deposited near the volcanoes. The convergent tectonic activity that has long influenced the geology of western North America led to episodes of igneous activity during the Late Jurassic and Early Cretaceous, producing intrusive igneous bodies within CHIS (Willows Plutonic Complex, 162 Ma [million years ago]; Alamos Tonalite, 141 Ma) and SAMO (unnamed granitic rocks, 102 Ma). Unmetamorphosed Upper Cretaceous sedimentary rocks are found at all three MEDN units, and make up most of the bedrock of CABR. The Upper Cretaceous rocks of CABR and CHIS were deposited on and around similar submarine fans that formed between a subduction zone to the west and an Andean-style continental margin mountain chain to the east. Those of SAMO show changing deposition from terrestrial environments to submarine fans in response to subsidence (sinking) and a marine transgression (advance). A variety of marine organisms populated the sea, particularly foraminifera, mollusks, and echinoderms.

Following the Cretaceous, deposition is not recorded at CABR until the Pleistocene, over 60 million years later, but excellent

records of deposition for the great majority of the Cenozoic can be observed within CHIS and SAMO. These rocks, like the Cretaceous rocks, often include fossils of marine organisms such as foraminifera, mollusks, and echinoderms. Opposing forces of subsidence and uplift, and marine transgressions and regressions, alternated many times during the Cenozoic, at various scales of extent and time. The earliest part of the Paleocene is not well known. It is not known to be represented at CHIS, but some terrestrial rocks from SAMO may date to this time. Uplift and marine regression (retreat) limited the potential for deposition. Subsidence and marine transgression once again led to deposition in both parks for the latter part of the Paleocene. Coarser sediments at CHIS and nondeposition and terrestrial deposition at SAMO provide evidence for a period of uplift and regression during the Early and Middle Eocene. Basin depth increased during the latter half of the Eocene at CHIS, but not at SAMO. Beginning in the early middle Eocene, sea level in the SAMO area dropped from a combination of local uplift and ice buildup on Antarctica. The western Transverse Ranges block was progressively uplifted because of the approaching East Pacific Rise spreading center. For many millions of years, beginning in the Mesozoic, the Farallon plate had been subducting beneath the North American plate along the latter's western margin. By the Middle Eocene, the Farallon plate had been mostly subducted, and the East Pacific Rise, which formed its western boundary with the Pacific plate, was approaching the North American plate. The East Pacific Rise was topographically a high part of the sea floor, due to high heat flow. Its approach and partial subduction lifted the western North American plate, bringing on a period of erosion during the Late Eocene and Early Oligocene. Increased friction between the subducting plate boundaries slowed the rate of subduction. Erosion and renewed subsidence reduced the elevation of the uplifted areas, allowing alluvial and fluvial redbed deposits of the Sespe Formation to be deposited throughout the SAMO area and parts of CHIS during the middle part of the Oligocene. These terrestrial rocks include a variety of mammal fossils. At the same time as the East Pacific Rise began to interact with western North America, increasing friction between plates and thinning of the subducting Farallon plate caused portions of the plate to fragmented off, becoming microplates. The microplate under the Transverse Ranges is the Monterey microplate. It was too small to be subducted; instead, it became attached to (captured by) the Pacific plate at the East Pacific Rise at approximately 30 Ma. This event would eventually lead to the Transverse Ranges' transverse orientation, among other things. The sea returned to CHIS and SAMO toward the end of the Oligocene. At SAMO, for the next few million years (into the Early Miocene), terrestrial and marine deposition alternated as the sea transgressed and regressed. Deposition at CHIS appears to have remained submarine over the same time frame, and may have become progressively deeper.

The Miocene of CHIS and SAMO are marked by volcanism and tectonic movement. These events followed from the capture of

the Monterey microplate by the Pacific plate during the Oligocene. The capture of the microplate caused a reorganization of the numerous small continental blocks along the southwestern margin of the North American plate. The Transverse Ranges block was wrenched out of position at about 19 Ma and rotated clockwise. This rotation and associated rifting allowed the underlying asthenosphere to well up, leading to decompression melting and widespread volcanism; the volcanism was the source of the volcanic rocks that make up a significant portion of the bedrock of the western Santa Monica Mountains and northern Channel Islands. A large volcano grew from the sea floor in the area of the future western Santa Monica Mountains and eventually rose above sea level. The volcano formed an island that was of similar size to the Hawaiian volcanoes and had an elevation of over 1,500 m (4,900 ft) above sea level. Volcanism ended by about 16 Ma, and rotation ended by approximately 12 Ma. By the time motion stopped, the Transverse Ranges block had rotated roughly 90° clockwise, and moved a few degrees north (unlike the northern Channel Islands, the southern Channel Islands, including CHIS's Santa Barbara Island, are part of another crustal block and have not been rotated). The tectonic basin now known as the Los Angeles Basin formed during these events. It began subsiding around 18 Ma, and stopped subsiding only about 3 Ma. Following the volcanic activity, more marine sediments were deposited over the continental shelf and slope settings, forming submarine fans and draping basin plains. SAMO has significant fossils of seaweed and fish from this time. The Pliocene is sparsely represented at CHIS and SAMO; the two areas are thought to have been topographic highs during that time. The Santa Monica Mountains were uplifted during the Pliocene.

The Pleistocene and Holocene geology of CABR, CHIS, and SAMO record a series of coastal sea-level fluctuations, responding to the interaction of local uplift and global sea level changes driven by changes in glaciation. These sea-level events are represented by marine terraces. Because of uplift, they may be many tens of meters removed from their original elevations. CABR is noted for its excellent examples of terraces, formed by marine highstands dating to approximately 855,000, 120,000, and 80,000 years ago. Similar terraces are found at CHIS and SAMO. The four northern Channel Islands were probably above sea level for most of the Pleistocene, and underwent gradual uplift during the epoch. Although sea level never dropped far enough to connect the islands to the mainland, the northern Channel Islands would have had greatly expanded land areas during times of low sea levels, and were probably connected into a single large island (Santarosae) during the last glacial period, which reached its maximum around 20,000 years ago. A small fauna of gastropods, salamanders, lizards, snakes, birds (particularly raptors and waterfowl), rodents, bats, and mammoths inhabited Pleistocene Santarosae. Archeological evidence indicates that humans arrived in the northern Channel Islands at least 13,000 years ago. Pollen indicates a pine and cypress forest was present when people first arrived on the islands. This forest was replaced approximately 12,000 years

ago by grassland and scrub as the climate warmed. On the mainland, coastal California may have been an ice-age refugium, with a stable long-term Mediterranean climate. The late Quaternary of the Los Angeles area is known for its assemblage of now-extinct large mammals, particularly well represented at Rancho La Brea. These animals may have gone extinct through a combination of a shift to a warmer, drier climate and overhunting by humans.

Paleontological resources have been reported from MEDN lands from a scientific perspective since the mid-19th century, when fossils were first found near CABR. Publication began in earnest around the turn of the 20th century, with description of mollusks from CHIS and SAMO. Many institutions in southern California have or have had significant collections of fossils from MEDN units (several institutions have transferred fossil collections to others over the years). Paleontological research

has been episodic. A paleontological survey at SAMO took place after the original network survey report was complete, taking advantage of one of the upswings in interest. Two new taxa have been published from SAMO since then. Ongoing research on the various environmental and climatic changes that took place at the Pleistocene–Holocene boundary on CHIS islands have also produced new fossil finds.

Collectively, the paleontological resources of the MEDN 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 at least 237 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.

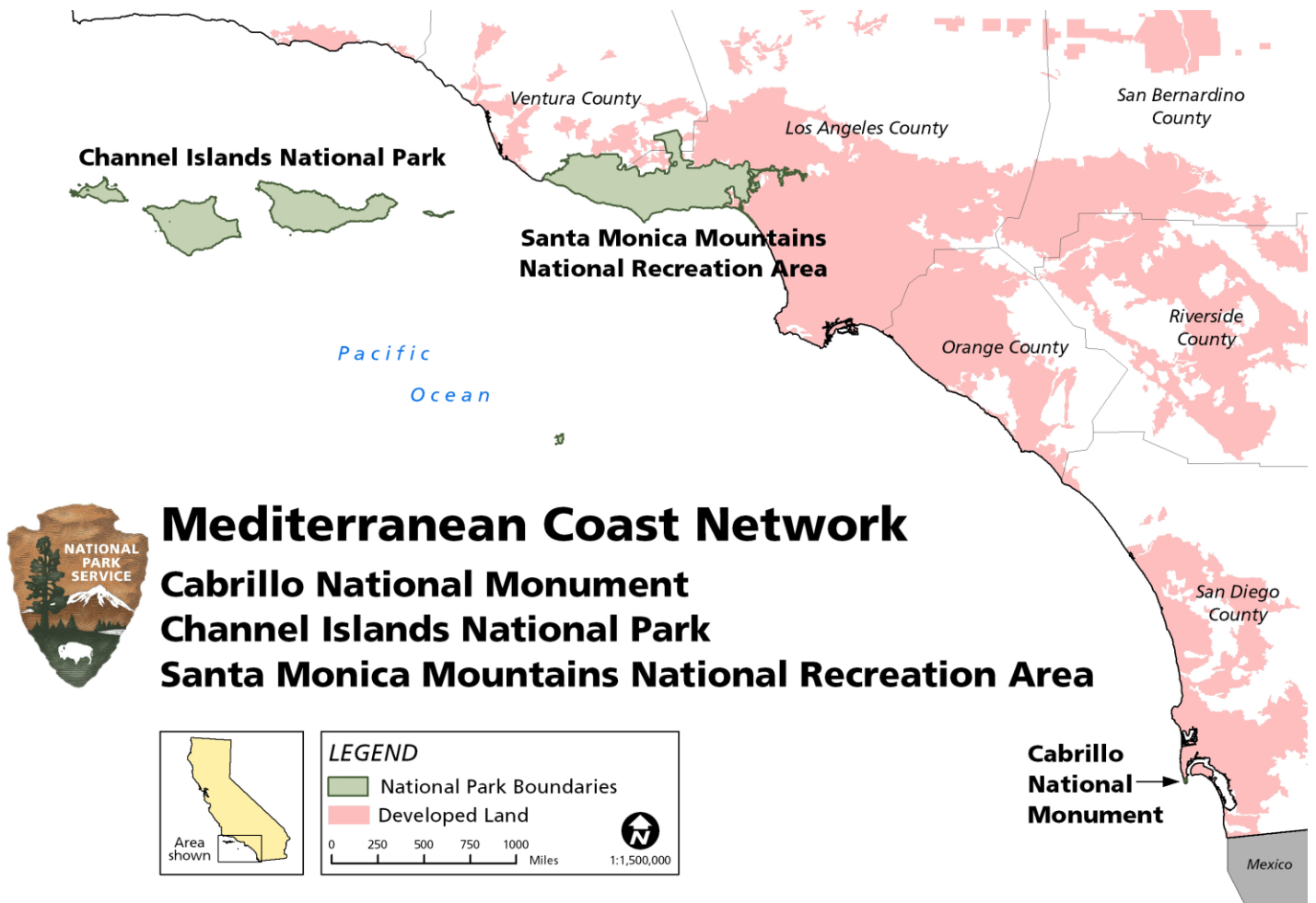


Figure 1. Map of Mediterranean Coast Network parks. Courtesy MEDN Staff.

Report Organization and Methodology

This report summarizes the paleontological resources of the Mediterranean Coast Inventory & Monitoring Network (MEDN). The report consolidates baseline paleontological resource data for each network park to support management operations, planning and science-based decision-making as required by NPS Management Policies and the Paleontological Resources Preservation Act (2009). This section of the report details the organization of the report and summarizes how the report was written.

Each network report includes an abstract, introduction with geologic background, methodology chapter (this chapter), description of resource management strategies, and individual park narratives, which are described below. Some network reports include information for non-network parks, those that are not officially part of the Inventory and Monitoring Network, but are within the geographic boundaries of the network. Such parks were included in instances where paleontological resources were documented. For more information regarding different paleontological resource inventory strategies, refer to the Paleontological Resource Management chapter.

This 2012 Mediterranean Coast Network Paleontological Resource Inventory report represents a substantial update of the previous MEDN paleontology summary completed by Koch and Santucci (2003). The Methodology section, below, describes the changes between the original report and this document.

Organization of the Park Narratives

Each park narrative contains the following sections.

Geologic Background

The Geologic Background section contains basic geographic information for the park and lists pertinent geology and paleontology references. A brief geologic history is included to provide context for the fossils discovered within or near the park.

Sources of Paleontological Resources

The Sources of Paleontological Resources section reviews each fossil-bearing rock unit within the park. The history of paleontological resource field work in the park is summarized. A brief geologic description is included as well as the scope and significance of paleontological resources known to occur within the park. The section is organized stratigraphically from oldest rock unit to youngest.

Potential Sources of Paleontological Resources

The rock units listed in the “Potential Sources” section are units mapped within the park which potentially contain fossils. Although fossils have not been previously documented from those units within the park, fossils have been discovered within

those units at localities outside of the park. In some cases the lack of documented fossils within a particular park or a specific geologic unit in a park, may simply be due to the fact that field inventories for fossils have never been undertaken in the park. As with the “Sources” section, the geologic units are listed stratigraphically from oldest to youngest.

Park Collections

The Park Collections section summarizes museum collections of fossils associated with the park. Such collections may be housed within the park or in external museum or university repositories. Fossil collections maintained by the park may include specimens discovered from both within and outside the park. It is important to recognize that the park’s museum Scope of Collections may include fossils from localities outside of the park boundaries.. Regional museums and other outside repositories may curate fossils collected within the park prior to or subsequent to the park’s establishment. Both contexts are included in the report. The Smithsonian Institution National Museum of Natural History and U.S. Geological Survey maintain significant collections of National Park Service fossils.

Cultural Resource Contexts

Resource stewardship strategies and management plans typically address paleontological resources which are known to occur within the rocks of the park. However, fossils may also occur in a variety of cultural resource contexts including: in association with archeological resources, ethnographic stories and legends, prehistoric and historic structures, or other documented historical occurrences. Fossils may be found as tools, jewelry, spiritual or ceremonial objects, or other cultural objects in archeological sites. A few ethnographic stories and legends told by American Indians and “mountain men” of the American West incorporate fossils. Building stones often contain fossils. In addition, archives, journals, memoirs, and photographs include other historical accounts of fossils in NPS areas. Kenworthy and Santucci (2006) summarizes such occurrences and provides examples.

Paleontological Resource Management, Preliminary Recommendations

In addition to geology and paleontology content, the authors suggest “next steps” for paleontological resource management and stewardship at each park. The recommendations are based on discussion with park staff and other geologists or paleontologists, or as part of broader NPS paleontological resource management strategies. These strategies are summarized in the next chapter. Parks may choose to address the recommendations based upon available staff time, training, and budget. Contact the NPS Geologic Resources Division for technical assistance or further guidance.

Literature Cited and Additional References

Each park narrative has a bibliography which is divided into two sections. References mentioned in the park narrative are included in the Literature Cited section. References discovered during the data-mining process that maybe of secondary value or interest are listed in the Additional References section. These publications were not included in the narrative but are relevant to the park, commonly containing additional detail beyond the scope of the narrative.

Data Sets

The Data Sets section includes a list of research projects, museum collections, NPS Geologic Resources Inventory-produced geologic map data, archives, or other files and information relevant to the fossils of a particular park.

Figures, Photographs and Graphics

The first network-based paleontological resource summaries (completed between 2002 and 2011) did not include figures, photographs or other graphics aside from the report cover and a network map. This second generation of Inventory & Monitoring Network based paleontological resource inventory reports includes basic geologic maps, stratigraphic columns, paleontological resource summary tables, and photographs for each park when available. Many of the geologic maps are adapted from the NPS Geologic Resources Inventory (GRI) map data for each park. These data are available in GIS format and support accompanying GRI reports, all of which are available from the GRI publications page:

http://www.nature.nps.gov/geology/inventory/gre_publications.cfm. The stratigraphic columns illustrates a compiled section of all the rock units mapped in the park along with rock unit name, age, map symbol, thickness, and lithology. Also new to the second generation network-based reports is a summary table listing all the fossiliferous geologic units within the park, fossils collected within the park and the inferred depositional environment. Photographs of park fossils are inserted where appropriate.

Report Methodology

Inventory & Monitoring Network-based paleontological resource inventories compile baseline paleontological resource data for each of the parks within a particular network, and as such require considerable research and data mining. To minimize costs, field work is not normally conducted as part of the report preparation process. This section details the research methodology and report preparation, review, publication and distribution for network-based paleontological inventories.

Between 2002 and 2011, network-based inventories were completed for all of the 32 I&M networks. In 2001, the Northern Colorado Plateau Network technical committee supported a modest funding proposal to develop a prototype paleontological resource inventory for the network. Koch and Santucci (2002) represented the first attempt at compiling

baseline paleontological resource data at a network level. That report laid the foundation upon which similar work would be completed for each of the I&M Networks in the National Park System. Between 2002 and 2006, 13 network reports were completed using small amounts of funds provided from each network. Funding from the NPS I&M Program was designated to systematically complete the remaining 19 reports between 2006 and 2011.

This second generation report represents a substantial revision of the original Mediterranean Coast Network summary, completed in 2003 (Koch and Santucci 2003). This updated Network-based paleontological resource inventory report represents a new template and format for future revisions to other network summaries.

Although field work is still not typically performed in association with Network-based reports, in a few instances field work complimented the original park inventories. In some cases, field work has been conducted in response to recommendations provided in the initial Network-based paleontological resource inventory reports. Any new field data are incorporated into the updated reports.

Research

One of the most important components of any paleontological resource inventory is an intensive literature search and data mining. The American Geological Institute's GeoRef is the leading database for geology references, indexing more than 3.3 million references to North American geology dating back to the 1660s. To compile the appropriate literature base for this report, the authors conducted intensive GeoRef searches for general and park-specific publications.

Additional databases or information catalogs include the NPS Integrated Resource Management Applications (IRMA) portal (<https://irma.nps.gov/App/Portal/Home>), the U.S. Geological Survey (USGS) library system (<http://library.usgs.gov/>) and publications warehouse (<http://pubs.er.usgs.gov/>), as well as museum, university, and other institutional libraries and archives.

The literature search also includes unpublished material, or "gray literature," from park files, museum archives, local newspapers, field notes and other sources. 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 often yield unpublished information regarding park paleontological resources. These interviews frequently result in capturing data that might otherwise be undocumented and potentially lost or unrecognized.

Report authors develop a comprehensive list of geologic units within each park by consulting published geologic maps and other sources. 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. The NPS Geologic Resources Inventory (GRI) program is producing standardized digital geologic map data (GIS) for all Inventory and Monitoring Program parks. When available, the updated network-based paleontological resource inventory reports adapt GRI map data for each of the parks.

The nomenclature for geologic formations evolves over time and can differ based upon different geological interpretations. To maximize consistency with other NPS geology products, this report generally followed the geologic nomenclature used in GRI maps and report when they were available. The USGS maintains the National Geologic Map Database (NGMDB), which includes a searchable lexicon of valid geologic formation names (http://ngmdb.usgs.gov/Geolex/geolex_home.html). 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.

Narrative

Information from these various sources is compiled into a narrative report for each park. The narrative is organized according to the scheme detailed earlier in this section.

Review

The park narratives and compiled report are extensively peer reviewed by professional geologists or paleontologists, as well as NPS staff from each park and the Geologic Resources Division. Upon completion of a compiled, draft report, network staff have the opportunity to provide review. Network staff also determine if the previous technical review was adequate for publication.

Publication and Distribution

The peer-reviewed, network-approved reports are published in the NPS Natural Resource Technical Report series. To minimize production costs, hard copies are not generally produced. The reports are distributed in PDF format to park and network staff and available to other NPS staff via the Integrated Resource Management Applications portal. Report reviewers and paleontologists working in the parks may also receive copies. The reports are not intended for, or distributed to, the general public due to the sensitive nature of paleontological resource locality information.

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Inventory and Monitoring Strategies and Resource Management Guidance

Paleontological Resource Inventory Strategies

In order to better document fossil occurrences and to provide baseline paleontological resource data to National Park Service areas, the NPS Geologic Resources Division (GRD) and the NPS Inventory and Monitoring Division (I&M) have established three paleontological resource inventory strategies. These strategies include: comprehensive park-specific inventories, Servicewide thematic inventories, and Inventory and Monitoring Network-based summaries.

Comprehensive Park-Specific Surveys

Comprehensive park-specific surveys identify all known paleontological resources within a single NPS 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. The surveys commonly include sections addressing: park geology, paleontological resources inventory (species list and other compilations), localities, museum collections and curation, interpretation, management and protection, and recommendations. Paleontological resource training for park staff is an important component of many comprehensive park paleontological resource inventories.

Park-specific comprehensive paleontological resource inventories have been completed for Amistad National Recreation Area (Visaggi et al. 2009), Arches National Park (Swanson et al. 2005), Bighorn Canyon National Recreation Area (Santucci et al. 1999), Chesapeake and Ohio Canal National Historical Park (Clites and Santucci 2010), Death Valley National Park (Nyborg and Santucci 1999), Santa Monica Mountains National Recreation Area (Koch et al. 2004), Walnut Canyon National Monument (Santucci and Santucci 2001), Yellowstone National Park (Santucci 1998, the first park to have such a survey completed), and Zion National Park (DeBlieux et al. 2005). As of April 2012, similar paleontological resource inventories are currently underway at Big Bend National Park, Glacier Bay National Park and Preserve, and Golden Gate National Recreation Area.

Servicewide Thematic Inventories

Servicewide thematic paleontological resource inventories compile data regarding specific types of paleontological resources that occur in parks throughout the NPS. These reports offer brief summaries of each occurrence of a particular type or category of fossils documented within a particular park. These reports are based primarily on literature review and communication with park staff and professional geologists and paleontologists.

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). Servicewide thematic inventories have also been initiated for fossil fish (Hunt et al. 2006), fossil coprolites (Hunt et al. 2012), fossil packrat middens (Tweet et al. in prep.), and fossils found in cultural resource contexts (Kenworthy and Santucci 2006).

Inventory and Monitoring Network-Based Summaries

Network-based paleontological resource inventories compile baseline paleontological resource data for each of the parks within a particular I&M Network. Between 2002 and 2011, Network-based inventories were completed for all 32 I&M networks. This report represents an overhaul and substantial revision of the Mediterranean Coast I&M Network report, the second I&M Network report completed. For more information on the content of network-based summaries and how they are completed, refer to the “Report Organization and Methodology” chapter. Citations for the completed reports are listed in the Literature Cited section.

A comprehensive summary report is currently being developed to present an overview and highlights of the 10 year effort to document fossils throughout the NPS based on the network-based strategy. Four summary reports are planned, including reports which present data based on geologic time, taxonomy, museum collections and fossil type specimens. These reports are anticipated to be finalized in 2013.

Paleontological Resource Monitoring Strategies

Following the compilation of baseline paleontological resource inventories, monitoring of fossil localities represents the next phase in paleontological resource management. Santucci and Koch (2003) presented a preliminary strategy for monitoring paleontological resources and identified natural and human-related impacts to fossils. Santucci et al. (2009) presented a more comprehensive strategy for paleontological resource monitoring which identified natural and human-related stressors upon paleontological resources, described five vital signs, and provided examples of study design and case studies. The five vital signs include: (1) erosion (geologic factors); (2) erosion (climatic factors); (3) catastrophic geohazards; (4) hydrology/bathymetry; and (5) human access/public use. The vital signs discussions provide detailed recommendations for

resource managers, incorporating expertise, personnel, and equipment needed, approximate cost, and labor intensity. Santucci et al. (2009) is one chapter in the Geological Monitoring manual that provides guidance for monitoring various geologic resources and processes. The manual (Young and Norby 2009) was published by the NPS Geologic Resources Division and Geological Society of America.

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. Science-based management of resources identified through these inventories is mandated by many NPS policies including the newly enacted Paleontological Resource Preservation Act (PRPA).

2009 Paleontological Resource Preservation Act

The Paleontological Resource Preservation Act (P.L. 111-11; “PRPA”) was signed into law on March 30, 2009 as part of the Omnibus Public Lands Act of 2009. PRPA will serve as explicit authority for the management, protection and interpretation of paleontological resources in parks. PRPA regulations are currently (March 2012) being finalized by the National Park Service, Bureau of Land Management and the U.S. Forest Service. 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

NPS Management Policies

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 (<http://www.nps.gov/policy/MP2006.pdf>).

Other Resources

Paleontological resource management issues were the subject of a Report of the Secretary of the Interior in May 2000, viewable online at: <http://www.blm.gov/heritage/docum/fossilrpt.pdf>. That report was prepared in response to a Congressional request for an assessment of the need for a unified federal policy on the collection, storage and preservation of fossils and for standards that would maximize the availability of fossils for scientific study.

The Paleontological Resources Management section of Natural Resource Management Reference Manual 77 provides guidance and additional information regarding the implementation and continuation of paleontological resource management programs (<http://www.nature.nps.gov/rm77/paleo.cfm>).

As described above, Santucci et al. (2009) provided guidance for paleontological resource monitoring.

The NPS manages more than 445,000 catalogued fossil specimens in collections across the country. Many thousands more specimens await cataloging. For information regarding fossils in museum collections, refer to the NPS Museum management handbook, particularly Part I, Appendix U (<http://www.nps.gov/museum/publications/handbook.html>).

Education and Outreach Opportunities

Fossils occupy an enduring place in the hearts and mind of the public, presenting excellent opportunities for education and outreach. These opportunities support provisions in the Paleontological Resources Preservation Act (above) as well as the NPS natural resource stewardship mission. The NPS Geologic Resources Division coordinates two fossil-related

education and outreach opportunities with a national scope: National Fossil Day and the Junior Paleontologist program. National Fossil Day is a celebration organized to promote public awareness and stewardship of fossils, as well as to foster a greater appreciation of their scientific and educational value. Learn more at the NFD website:

<http://nature.nps.gov/geology/nationalfossilday/index.cfm>. The Junior Paleontologist program (part of the Junior Ranger program) provides opportunities for children to explore the ways that paleontologists work, learn about earth's history, and protect fossils and the rocks in which they are found. For more information, visit the Junior Paleontologist program webpage: <http://nature.nps.gov/geology/nationalfossilday/jrpaleo.cfm>. Contact the Geologic Resources Division for information on how to participate in either program.

In conclusion, 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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Citations for I&M Network-Based Summaries

Citations are listed alphabetically by network

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Sierra Nevada Network (SIEN)

General MEDN Information

Mediterranean Coast I&M Network: <http://science.nature.nps.gov/im/units/MEDN/index.cfm>

Geological Survey Websites

California Geological Survey: <http://www.conservation.ca.gov/cgs/Pages/Index.aspx>

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

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Library catalogs

Smithsonian Institution Research Information System: <http://www.siris.si.edu/>

U.S. Geological Survey Library Catalog: <http://library.usgs.gov/>

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Santa Barbara Museum of Natural History: <http://www.sbnature.org/>

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National Park Service Museum Collections Catalog: <http://www.museum.nps.gov/splashsearch.htm>

Smithsonian National Museum of Natural History Dept. of Paleobiology: <http://paleobiology.si.edu/>

Other Websites of Interest for MEDN Geology

California Council of Geoscience Organizations: <http://ccgo.org/>

Coast Geological Society: <http://www.coastgeologicalsociety.org/>

Dibblee Foundation: <http://www.sbnature.org/dibblee/>

Northern California Geological Society: <http://www.ncgeolsoc.org/>

San Diego Association of Geologists: <http://www.sandiegogeologists.org/>

San Joaquin Geological Society: <http://www.sjgs.com/>

South Coast Geological Society: <http://www.southcoastgeo.org/>

University Geoscience Departments in California: http://www.conservation.ca.gov/cgs/information/Pages/ca_univ_geoscience.aspx

Resource Management/Legislation Documents

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

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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/>

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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>

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Other Geology/Paleontology Tools

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NeoMap (Neogene Mammal Mapping Portal): <http://www.ucmp.berkeley.edu/neomap/>

Neotoma (Quaternary fossil database): <http://www.neotomadb.org/>

NOAA Paleoclimatology: <http://www.ncdc.noaa.gov/paleo/paleo.html>

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

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

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

U.S. Geological Survey digital state geology maps: <http://tin.er.usgs.gov/geology/state/>

U.S. Geological Survey Geologic Terms Glossary: <http://www.nature.nps.gov/geology/usgsnps/misc/glossaryAtoC.html#A>

U.S. Geological Survey Paleontological Terms Glossary: <http://geology.er.usgs.gov/paleo/glossary.shtml>

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”).

U.S. Geological Survey Publications Warehouse (many USGS publications are available online): <http://pubs.er.usgs.gov/>

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Cabrillo National Monument

Cabrillo National Monument (CABR) in southern California was established to memorialize Juan Rodriguez Cabrillo and his 1542 voyage of exploration. It also protects the Old Point Loma Lighthouse and a variety of natural resources, including an area of intertidal habitats (CABR Figure 1). CABR was proclaimed October 14, 1913, and was transferred from the War Department to the National Park Service on August 10, 1933. Its boundaries have changed several times, on February 2, 1959, September 28, 1974, and July 3, 2000. CABR currently encompasses 64.73 ha (159.94 acres), all of which is under federal administration (CABR Figure 2).

Geologic Background

CABR is located in San Diego County at the southern tip of Point Loma, a north-south trending peninsula that separates San Diego Bay on the east from the Pacific Ocean to the west. Downtown San Diego is just over 8 km (5 miles) to the northeast, across the bay. North Island Naval Air Station, and the city of Coronado at the north end of the Silver Strand, are just east of the southern tip of Point Loma. A broad coastal plain, marked by flat-topped mesas dissected by west-flowing ephemeral streams and rivers, extends from the shoreline east to foothills of the Peninsular Ranges.



CABR Figure 1. An intertidal area of CABR (photo courtesy Thomas Deméré).

A geologic resource evaluation scoping session, coordinated by the Geologic Resources Division of the National Park Service (NPS), was held for CABR during May 2008 (KellerLynn 2008). The initial paleontological resource inventory and summary was prepared by Koch and Santucci (2003). Other references that describe the paleontology and geology of CABR or its immediate vicinity at the end of Point Loma include Berry (1922), Stephens (1929), Webb (1937), Matsumoto (1959, 1960), Anderson (1962), Valentine (1961), Valentine and Meade (1961), Sliter (1968), Bukry and Kennedy (1969), Kennedy and Moore (1971), Bowersox (1974), Kern and Warne (1974), Ku and Kern (1974), Kennedy (1975a, 1975b), Wilson (1976), Kern (1977), Dawson (1978), Nilsen and Abbott (1979), Sundberg (1979), Popenoe and Saul (1987), Bannon et al. (1989), Kern and Rockwell (1992), Saul and Popenoe (1992),

Bukry (1993), Muhs et al. (1994, 2002, 2003), Abbott (1999), Rahman and Droser (2003), Hunt et al. (2006), von Dassow and Droser (2006), Kennedy and Tan (2008), Taylor (2008), and Squires and Saul (2009). Point Loma as a whole is both extensively fossiliferous and extensively documented in the literature.

The geologic history recorded in the sedimentary rocks exposed at CABR is confined to the Late Cretaceous and Pleistocene (see the appendix for a geologic time scale). The San Diego area is part of the Peninsular Ranges terrane (distinct block of continental crust). It is sometimes reported that the terrane was not accreted to the North American craton until the middle of the Cenozoic (Morris et al. 1986; Lund and Bottjer 1992; Ford and Kirkland 2001), but it now appears that the terrane had accreted by the time CABR's Late Cretaceous rocks were being deposited (Grove and Bebout 1995; Tan and Kodama 1998; Symons et al. 2003; Vaughn et al. 2005).

The Upper Cretaceous rocks of CABR were deposited on a submarine sediment fan, in part by west-flowing sediment gravity flows (Nilsen and Abbott 1979; Bartling and Abbott 1983). The water depth at this time may have been 900 to 1000 m (2,900 to 3,300 ft) (Almgren 1973). Sediment came from the ancestral Peninsular Ranges to the east (Nilsen and Abbott 1979), which during Late Cretaceous time formed a Andean-style mountain range just landward of an active subduction zone. The ancient Farallon oceanic plate was being subducted beneath the North American continental plate causing regional uplift and exposure of older plutonic (granitic) rocks (Abbott 1999). This mountain-building episode, known as the Laramide Orogeny (Girty 1987), also affected large areas of western North America as far east as present-day Colorado. Meanwhile, the ancient Point Loma submarine fan was depositing sediment into a deepening marine basin. The fan prograded across the floor of this basin and over time formed a thick accumulation of turbidite sandstones, middle-fan channel-fill sandstones and mudstones, and inner-fan channel-fill conglomerates (Nilsen and Abbott 1979).

A hiatus of approximately 70 million years separates the Cretaceous rocks of CABR from the much younger veneer of Pleistocene landforms and unconsolidated deposits. Although only partially documented within CABR, the Upper Cretaceous–Eocene geology of San Diego is related to the

Upper Cretaceous–Eocene geology of Channel Islands National Park (CHIS; see the CHIS summary in this report for more details). The islands, which are part of a small crustal block that has moved north and rotated clockwise since the Late Cretaceous, would have been a short distance south of San Diego during the Late Cretaceous, and record the deposition of a similar submarine fan (Bartling and Abbott 1983). Later, during the Eocene, the block had moved north far enough to juxtapose the future site of the islands with the San Diego area, resulting in the accumulation of the same type of conglomerates (Bartling and Abbott 1983).

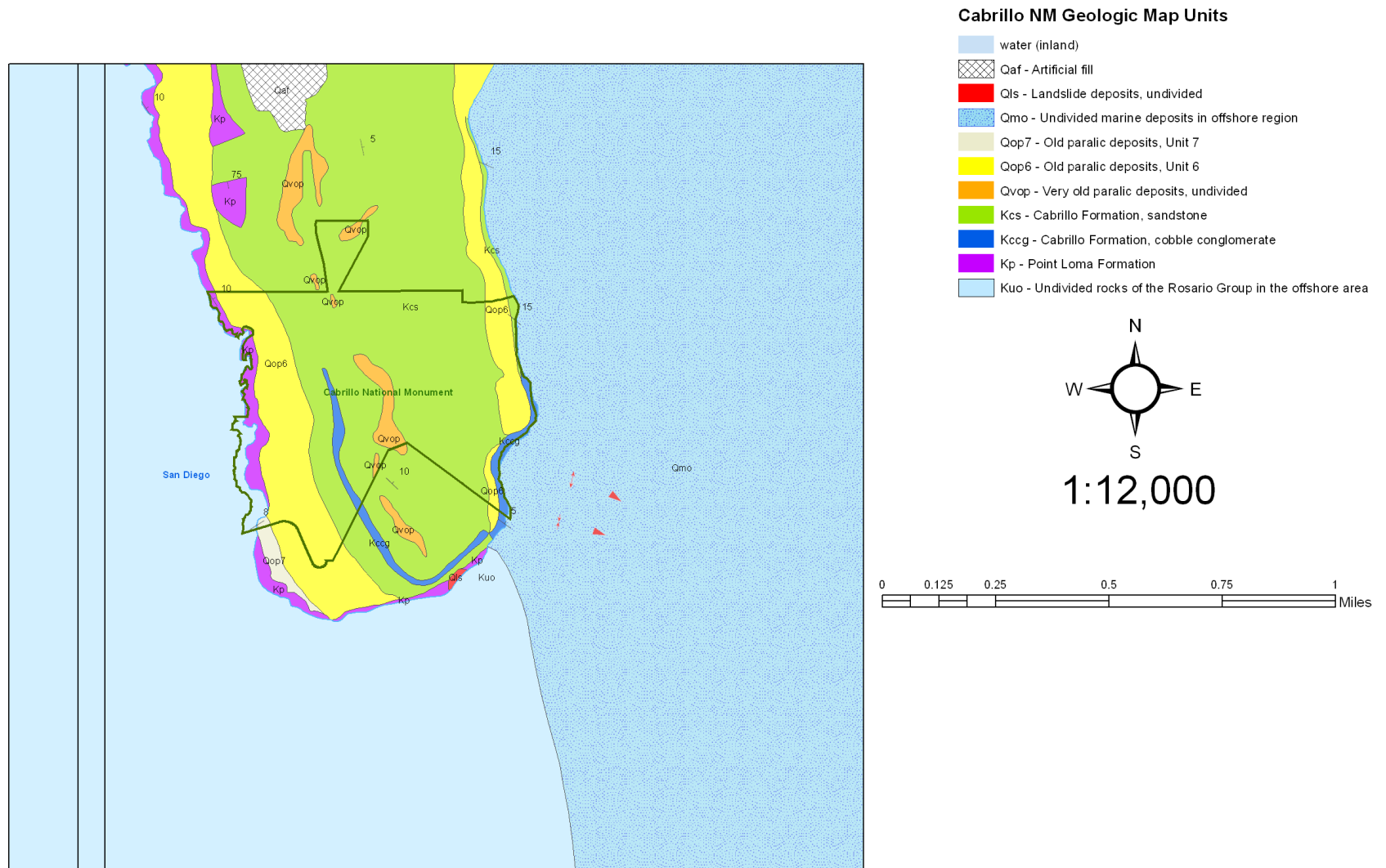
The Pleistocene geology of the San Diego area includes a series of uplifted marine terraces; CABR has excellent examples of some of these terraces (T. Deméré, pers. comm., November 2011). Sixteen marine terraces and associated deposits are known from San Diego County, ranging from perhaps 1.29 Ma (million years) to 80,000 years old (Kern and Rockwell 1992). Several terraces are exposed within CABR, including, from oldest to youngest, the Linda Vista, Nestor, and Bird Rock terraces (KellerLynn 2008). They date to approximately 855,000 years ago (Linda Vista), 120,000 years ago (Nestor), and 80,000 years ago (Bird Rock) (Kern 1977; Wehmiller et al. 1977; Kennedy et al. 1982; Kern and Rockwell 1992). The various terraces are now much higher than their original elevations; the San Diego region is being uplifted at an average rate of 0.13–0.14 m (5–6 in) per thousand years (Kern and Rockwell 1992).

The beginning of the Holocene coincided with the arrival of humans to the area; humans were present in the Carlsbad area 55 km (34 miles) to the north by the Early Holocene (Rick and Erlandson 2000).

Geologic units exposed within CABR include, from oldest to youngest: the Point Loma Formation and Cabrillo Formation of the Rosario Group (Upper Cretaceous); lower–middle Pleistocene paralic (coastal) deposits; and two sets of upper Pleistocene paralic deposits (Kennedy 1975b; Kennedy and Tan 2008) (CABR Figure 3). The terminology for the paralic deposits has changed over time. Kennedy (1975a, 1975b) included the oldest paralic deposits in the Lindavista Formation, and the younger paralic deposits in the Bay Point Formation. Later, Kennedy and Tan (2008) attached no formal names to the deposits, and differentiated two units within Kennedy’s (1975a, 1975b) Bay Point Formation. The older formation names are still widely used, although the city of San Diego has switched to using the generic terms (T. Deméré, pers. comm., November 2011). Because the pre-existing NPS digital geological map of CABR uses the generic terms, this document will use these terms as well to maintain continuity. However, the older terms will be described. The Point Loma Formation, Cabrillo Formation, and upper Pleistocene paralic deposits are fossiliferous within CABR (CABR Table 1), which also has specimens in museum collections.



CABR Figure 2. Geography of CABR (NPS).



CABR Figure 3: Schematic geological map of CABR. Map graphic adapted from digital geologic map data available at the following URL:
<https://irma.nps.gov/App/Reference/Profile?Code=1047843>.

Formation	Age	Fossils Within CABR	Depositional Environment
Old paralic deposits of Units 6 and 7 (Bay Point Formation)	late Pleistocene	Sponges, coral, bryozoans, chitons, bivalves, gastropods, barnacles, crabs, echinoids, and bony fish	Coastal marine settings
Undivided very old paralic deposits (Lindavista Formation)	early–middle Pleistocene	None to date; coastal marine invertebrates are most likely	Coastal marine settings
Cabrillo Formation	Late Cretaceous	Wood fragments, coral, brachiopods, bivalves, ammonites, gastropods, echinoderms, and a shark tooth (fossils from a set of localities including areas within and just outside of CABR; most fossil are probably reworked from older units)	Submarine fan settings
Point Loma Formation	Late Cretaceous	A cycad leaf and invertebrate trace fossils	Submarine fan settings

CABR Table 1. Concise tabulation of CABR stratigraphy, fossils, and depositional setting; details and references can be found in the text.

Sources of Paleontological Resources

The fossils of CABR present opportunities for education, interpretation, and continued or future scientific research in the monument. Fossils have been described since the late 19th century from Point Loma. Cooper (1894) discussed some of the early collecting. Among the 19th century material Cooper noted is a specimen of the coiled ammonite *Heteroceras* found associated with a coal shaft north of CABR on the west coast of the peninsula, and a specimen of the straight ammonite *Baculites chicoensis* collected on the surface near the lighthouse. Several species of Cretaceous invertebrates were named during this early period. Cooper (1894) named the bivalves *Crassatella lomana*, *Corbula triangulata*, and *Crenella santana*, and the gastropods *Cerithium fairbanksi*, *Stomatia intermedia*, *Calliostoma kempiana*, *Siphonaria capuloides*, and *Tornatella normalis* from Point Loma, and Anderson (1902) named the gastropod *Halotis lomaensis* from the Upper Cretaceous Cabrillo Formation (then referred to as the “Chico Formation” because of their similarity to Cretaceous rocks in northern California).

Recalling the “flying ammonite” (see the Park Collections section), another large ammonite has been found recently near the southwest corner of the monument, just within or just outside of the boundary (T. Deméré, pers. comm., November 2011). Fossils constantly erode from the Pleistocene marine terrace deposits of the monument (T. Deméré, pers. comm., November 2011).

Rosario Group: Point Loma Formation (Upper Cretaceous)

The Point Loma Formation is exposed along the west side of Point Loma. It was named from a locality just outside of CABR, near the extreme southern tip of the peninsula below the new Point Loma lighthouse (Kennedy and Moore 1971; Kennedy 1975a). Approximately 83 m (270 ft) of the formation is exposed above sea level at this locality, with at least another 190 m (620 ft) present below low tide. This unit is composed of interbedded layers of dusky yellow sandstone and olive-gray clay-rich shale, with beds about 30 cm (12 in) thick (Kennedy 1975a). On the south end of Point Loma, the lower half includes interbedded sandstone and mudstone, and the upper half is mostly mudstone (Kern and Warne 1974). The contact with the overlying Cabrillo Formation is conformable (Kennedy 1975a). These two formations were not differentiated until 1971 (Kennedy and Moore 1971); before this, these two units were called the Rosario Formation. Fossils in the formation indicate a Late Cretaceous age (middle or late Campanian to early Maastrichtian) (Kennedy 1975a). Fossils from just north of CABR, at the Point Loma Waste Water Treatment Plant, date to about 75.5 to 74.5 Ma, and slightly younger fossils are present in the steep slope behind the plant (Bukry 1993).

The Point Loma Formation formed as a submarine fan (Bannon et al. 1989) that accumulated on the outer continental shelf, slope, and rise (Kennedy and Moore 1971). It includes mudstones interpreted as representing the continental slope and basin plain, and sandstones representing lagoonal, shelf, fan

lobe, and fan channel settings (Nilsen and Abbott 1979). Foraminifera (amoeba-like protists that form “shells”) from strata exposed at the tip of Point Loma indicate a bathyal environment (broadly, the continental slope), with some specimens of sublittoral foraminifera transported downslope from the adjacent continental shelf (Sliter 1968). The formation’s foraminiferal assemblage has been compared to that of the modern assemblage on the continental slope and in deep basins in the eastern Pacific Ocean (Sliter 1975). The formation’s trace fossils also generally indicate bathyal settings (Kern and Warme 1974). Limited biological disturbances of the sediment (bioturbation) indicate that the oxygen content of the water was low (Sliter 1975).

Marine microfossils and mollusks are well represented in the Point Loma Formation, although many other types of fossils have been found. Single-celled organisms are represented by coccoliths (structural plates from some types of algae, also known as calcareous nannofossils) (Bukry 1993, 1994) and foraminifera (Anderson 1962; Sliter 1968, 1975). Terrestrial plants are represented by a cycad leaf recovered from CABR (Koch and Santucci 2003), angiosperm leaves (T. Deméré, pers. comm., February 2012), and wood (Kern and Warme 1974; Nilsen and Abbott 1979). Marine invertebrates are represented by bryozoans (moss animals) (Taylor 2008), brachiopods (lamp shells) (Nilsen and Abbott 1979), bivalves (Sundberg 1981; Saul and Popenoe 1992; Squires and Saul 2009), ammonites (including coiled and straight [*Baculites*] forms; Matsumoto 1959, 1960), gastropods (Popenoe and Saul 1987; Loch 1989; Saul 1988), scaphopods (tusk shells) (Coombs and Deméré 1996), crabs (Bishop 1988), ostracodes (seed shrimp) (Coombs and Deméré 1996), echinoids (sea urchins) (Sundberg 1979; Coombs and Deméré 1996), and trace fossils (Kern and Warme 1974), including possible worm tubes (Sliter 1975). Most trace fossils are found in mudstone (Kern and Warme 1974). The vertebrate assemblage includes sharks (Coombs and Deméré 1996), holocephalians (ratfish and related cartilaginous fish) (T. Deméré, pers. comm., November 2011), ray-finned fish (Coombs and Deméré 1996), mosasaurs (Hilton 2003), and dinosaurs, including hadrosaurs (Ford 1999; Hilton 2003) and the armored dinosaur *Aletopelta coombsi* (the first dinosaur named from California), which is either an ankylosaurid (Ford and Kirkland 2001) or a nodosaurid (Coombs and Deméré 1996; Hawakaya et al. 2005).

The Point Loma Formation is fossiliferous within CABR. The most unusual fossil is a large cycad leaf, collected by R. A. Cerutti and B. O. Riney in 1994 from a tide pool (Koch and Santucci 2003). It is currently on display at the San Diego Natural History Museum (SDNHM 48361, from SDNHM locality 3774; CABR Figure 4) (T. Deméré, pers. comm., November 2011). Abundant invertebrate trace fossils, particularly of the trace genera *Ophiomorpha* and *Thalassinoides*, can be found in outcrops around the monument’s tide pools (CABR Figure 5) (B. Pister, CABR Chief of Natural and Cultural Resources Management, pers.

comm., December 2011; D. Vaughn, Senior Project Geologist, Geotechnical Exploration Inc., and CABR volunteer, pers. comm., December 2011). These trace fossils are found in densities of 2 to 10 per m²; wave action continually exposes new trace fossils and erodes previously exposed examples (D. Vaughn, pers. comm., December 2011). Greater Point Loma has been an important area for Point Loma Formation fossils, including coccoliths (Bukry 1993), foraminifera (Sliter 1968), bryozoans (Taylor 2008), bivalves (Saul and Popenoe 1992; Squires and Saul 2009), ammonites (Matsumoto 1960; Bannon et al. 1989), gastropods (Popenoe and Saul 1987), and trace fossils (Kern and Warme 1974). Large ammonites with attached bivalves, and a partial mosasaur lower jaw have been found north of the monument boundary (Koch and Santucci 2003; KellerLynn 2008), as well as one of the rare hadrosaur specimens (Hilton 2003; T. Deméré, pers. comm., November 2011).



CABR Figure 4. A cycad leaf from the Point Loma Formation of CABR (SDNHM 48361) (VLS).



CABR Figure 5. *Ophiomorpha* in the Point Loma Formation at CABR (photo courtesy Donald Vaughn).

Rosario Group: Cabrillo Formation (Upper Cretaceous)

The Cabrillo Formation is exposed in central CABR (Kennedy 1975b; Kennedy and Tan 2008). It was named from a locality 250 m (820 ft) east of the new Point Loma lighthouse, where it is 81 m (270 ft) thick and composed of structureless (massive) sandstone and cross-bedded conglomerate. Farther north, the formation reaches a thickness of 170 m (560 ft) (Kennedy 1975a). Sandstone-dominated and conglomerate-dominated sections can be differentiated, and both are present at CABR (Kennedy 1975b; Kennedy and Tan 2008). Mudstones are also included in the formation (Dawson 1978; Nilsen and Abbott 1979). The unit has a Maastrichtian age (Taylor 2008).

The Cabrillo Formation represents continued deposition of the submarine fan that was active during deposition of the Point Loma Formation (Nilsen and Abbott 1979; Girty 1987; Bannon et al. 1989). New facies include mudstones from turbidity currents and conglomerate from fan channel fills (Nilsen and Abbott 1979). The lowest part of the formation was part of the inner section of the submarine fan (Girty 1987; Bannon et al. 1989).

The Cabrillo Formation is not generally as fossiliferous as the Point Loma Formation. Fossils reported from the formation include coccoliths (Bukry and Kennedy 1969), foraminifera (Anderson 1962), wood fragments (Dawson 1978), corals (Dawson 1978; Sundberg 1979), bryozoans (Taylor 2008), brachiopods (Dawson 1978), bivalves (Dawson 1978; Bannon et al. 1989; Kennedy and Shiller 2011), ammonites, gastropods (Dawson 1978; Bannon et al. 1989), echinoderms (Dawson 1978), a shark tooth (Koch and Santucci 2003; Hunt et al. 2006), and a fragment of turtle shell (Hilton 2003). Many fossils discovered in the Cabrillo Formation are reworked, from the underlying Point Loma Formation or from older deposits of the Cabrillo Formation itself (Dawson 1978; T. Deméré, pers. comm., November 2011). For example, fossils reported by Dawson (1978) primarily came from rip-up clasts (rock fragments) of siltstone, meaning they had already undergone some lithification (becoming stone) once before. The only fossils not found in clasts were rare examples of abraded and damaged shells, belonging to robust shallow-water bivalves like *Coralliochama orcutti*, *Ostrea* sp., and *Spondylus striatus* (Dawson 1978). Similarly, a single bivalve shell was the only fossil reported by Kennedy (1975a) that was not reworked.

The Cabrillo Formation is fossiliferous within CABR. Dawson (1978) reported wood fragments, coral, brachiopods, bivalves, ammonites, gastropods, and echinoderms from a series of localities along the sea cliffs on the east side of Point Loma, extending into CABR (SDNHM locality 2823; T. Deméré, pers. comm., November 2011); he collected many specimens, now at the SDNHM. A shark tooth, from the genus *Squalicorax*, was found in a clast recovered from a channel cut into sandstone (Koch and Santucci 2003) either just within or just outside of northern CABR (SDNHM specimen 35963, SDNHM locality

3272; T. Deméré, pers. comm., November 2011). It too is probably reworked (T. Deméré, pers. comm., November 2011). Point Loma in general has yielded many fossils from the Cabrillo Formation. Aside from Dawson's (1978) finds and the shark tooth, coccoliths (Bukry and Kennedy 1969), foraminifera (Anderson 1962), and bryozoans (Taylor 2008) have also been reported from the formation on the peninsula.

Old paralic deposits of Unit 6 and 7 (Bay Point Formation [*sensu lato*]) (late Pleistocene)

The upper Pleistocene paralic deposits of CABR are associated with two major marine terraces: the older Nestor Terrace, at elevations of about 22 to 23 m (72 to 75 ft) above sea level, and the younger Bird Rock Terrace, at about 9 to 11 m (30 to 36 ft) above sea level. Around San Diego, these deposits consist of siltstone, sandstone, and conglomerate, deposited in strandline, beach, and estuarine settings, and as colluvium (sediment transported by gravity, such as around slopes and cliffs) (Kennedy and Tan 2008). These deposits, particularly those associated with the Nestor Terrace, are also known as the Bay Point Formation (see for example Kennedy 1975a, 1975b). At CABR, the Bay Point Formation is complex and includes marine sediments grading up to nonmarine sediments (T. Deméré, pers. comm., November 2011). There are no Pleistocene deposits younger than the Bird Rock Terrace than can be mapped at a scale of 1:24,000 at CABR (Kennedy 1975b; Kennedy and Tan 2008).

The Nestor and Bird Rock terraces were formed during sea-level highstands that date to approximately 120,000 and 80,000 years ago, respectively (Wehmiller et al. 1977; Kennedy et al. 1982; Muhs et al. 1994, 2002). The marine terraces cut during these highstands are found around the world (Muhs et al. 1994). The Nestor Terrace highstand was perhaps 6 m (20 ft) higher than the modern sea level (Muhs et al. 1994), and appears to be associated with water temperatures similar to those found off of San Diego today (Muhs et al. 2006), or slightly warmer (Kennedy et al. 1982; Kennedy 1999). During Nestor Terrace time, Point Loma was an island (Kern 1977). The Bird Rock Terrace sea level highstand was 2 m (7 ft) or more lower than the modern sea level (Kern and Rockwell 1992), and the water was cooler (Kennedy et al. 1982; Kennedy 1999; Muhs et al. 2006; Kennedy and Rockwell 2009). An intermediate 100,000-year-old terrace is not as well preserved (Muhs et al. 1994), but is present on Point Loma (Muhs et al. 2003). These terraces were all formed during the last interglacial complex, preceding the most recent extensive glaciation (Muhs et al. 2002). Older publications sometimes refer to them as being from the Sangamon (Kern et al. 1971; Moore 1972), a term derived from an interglacial soil in Sangamon Co., Illinois, but no longer used for marine deposits of the last interglacial period.

The upper Pleistocene paralic deposits of the San Diego area are extensively fossiliferous. Approximately 275 species have been identified from the Nestor Terrace (Kern 1977), and more than 250 from the Bird Rock Terrace (Kennedy and Shiller 2011).

The Nestor Terrace assemblage includes corals, chitons (sea cradles), bivalves, gastropods, scaphopods, barnacles (Kern 1977), crabs (T. Deméré, pers. comm., November 2011), echinoids, and worm tubes (Kern 1977). The Bird Rock Terrace assemblage includes coralline algae, corals, bryozoans, brachiopods, chitons, bivalves, gastropods, scaphopods, polychaete worms, barnacles, decapod crustaceans (crabs, lobsters, and allies), echinoids, sponge borings, shark teeth, stingray teeth and stingers, and bony fish otoliths and miscellaneous bones (Kennedy and Shiller 2011). The Bay Point Formation (in the broad sense) as a whole has a fossil assemblage including foraminifera (Kern 1971; Bowersox 1974; Kennedy 1975a), sponges, corals, brachiopods (Kennedy and Shiller 2011), chitons, bivalves (Kern et al. 1971), scaphopods (Valentine 1959), ostracodes (Holden 1968; Kern 1971; Bowersox 1974; Kennedy 1975a), echinoids (Valentine 1959; Kennedy and Shiller 2011), worm tubes, the ray *Myliobatis* (Kern et al. 1971), and shark teeth. Rare land mammals including tapirs (Jefferson 1989), ground sloths, mastodons, mammoths, horses, and camels (T. Deméré, pers. comm., November 2011) have been found in nonmarine sediments broadly assigned to the Bay Point Formation. Reworked Pliocene fossils have also been reported by Stephens (1929) and Kern et al. (1971).

The upper Pleistocene deposits of CABR are very fossiliferous. The SDNHM has four fossil localities from the Nestor Terrace within CABR (SDNHM localities 58, 121, 457, and 5635) (T. Deméré, pers. comm., November 2011). Bivalve and gastropod fossils from localities 58 and 121 were reported as far back as 1929 (Stephens 1929). Locality 58 has yielded the gastropod *Littorina*, locality 121 yielded 13 taxa of bivalves and gastropods, and locality 457 yielded the coral *Balanophyllia elegans*, the chitons *Lepidozona californiensis* and *Stenoplax conspicua*, 41 taxa of bivalves and gastropods, the barnacle *Tetraclita* sp., and the crab *Pachygrapsus crassipes*, according to the SDNHM online collections database

(<http://www.sdnhm.org/research/paleontology/searchdata.html>). SDNHM locality 5635 is the same as San Diego State University (SDSU) locality F2521, a Nestor Terrace locality discussed by Kern (1977). SDSU locality F2525 yielded 5 chiton species, 13 bivalve species, 38 gastropod species, the barnacle *Tetraclita rubescens*, and the echinoids *Dendraster excentricus* and *Strongylocentrotus* sp. (Kern 1977). The records of the SDNHM for locality 5635 add sponges, bryozoans, decapod crustaceans, and bony fish to the list. SDNHM locality 5635 has unusual fossils from a more protected facies of the unit, and warrants additional investigation (T. Deméré, pers. comm., November 2011).

Fossils from the younger Bird Rock Terrace have been recovered from locations just north of CABR on Point Loma and as far north as Ocean Beach (Kennedy and Rockwell 2009; Kennedy and Shiller 2011). Fossils include sponges, corals, bryozoans, brachiopods, chitons, bivalves, gastropods, scaphopods, polychaete worms, barnacles, decapod crustaceans, echinoids, shark and ray teeth, and bony fish remains (Webb 1937; Kennedy and Shiller 2011). Muhs et al. (1994, 2002) obtained uranium-thorium dates on corals from the Bird Rock and Nestor terraces north and south of CABR on Point Loma. Corals that have yielded 100,000-year dates have also been recorded by Muhs et al. (2003). The solitary coral *Balanophyllia elegans* is often used for dating the terraces (Muhs et al. 1994, 2002). Gastropods from the Nestor Terrace on Point Loma have been found encrusted by contemporaneous bryozoans, worms, barnacles, and other gastropods (Rahman and Droser 2003). Worm-encrusted Pleistocene bivalves have also been found around the peninsula (von Dassow and Droser 2006). Other accounts of late Pleistocene fossils from Point Loma include Berry (1922), Valentine (1961), Valentine and Meade (1961), Bowersox (1974), and numerous unpublished paleontological monitoring and mitigation reports for the City of San Diego Development Services Department.

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the lower–middle Pleistocene paralic deposits within CABR. However, this unit is known to preserve fossils elsewhere in the San Diego area, and future field investigations within the monument may recover fossils from it.

Undivided very old paralic deposits (Lindavista Formation) (lower–middle Pleistocene)

The lower–middle Pleistocene paralic deposits of CABR and the vicinity were formed on wave-cut platforms and preserved by uplift (Kennedy and Tan 2008). Within CABR, they are found in relatively small areas at the higher elevations of the monument (Kennedy 1975b; Kennedy and Tan 2008). These deposits have also been referred to as the Lindavista Formation (Hanna 1926; Kennedy 1975a), and are associated with the

Linda Vista Terrace, which is found at about 120 m (390 ft) above sea level (Moore 1972; Kern and Rockwell 1992). Deposits on the terrace are about 2 to 10 m (7 to 33 ft) thick (Moore 1972), and date to a highstand that occurred approximately 855,000 years ago (Kern and Rockwell 1992). The Lindavista Formation is noted for the hematite cement that binds its sediments and provides some resistance to erosion (Hanna 1926; Kennedy 1975a).

The fossil assemblage of the Lindavista Formation is not as diverse as that of the younger terrace units discussed previously, and it is not known to be fossiliferous at CABR. Fossils include bivalves, gastropods, barnacles, echinoids, and worm tubes (Kennedy 1973). The best material is known from the Tierrasanta community near Murphy Canyon, over 23 km (14

miles) to the northeast (Kennedy 1973). The assemblage suggests littoral to shallow sublittoral depths derived from two main habitats, an “exposed open coast sandy beach, and a cobble or rocky bottom” (Kennedy 1973). Rare remains of marine vertebrates, including shark teeth and baleen whale ribs, have been recovered from the Lindavista Formation in Mira Mesa, over 27 km (17 miles) northeast of CABR (T. Deméré, pers. comm., February 2012). Land animals are not known from

the Lindavista Formation, but slightly older rocks in eastern San Diego County have yielded extensive vertebrate fossils, as part of what is known as the Vallecito Creek Local Fauna. Thousands of vertebrate specimens from over 2,000 localities are known, including remains of sharks, bony fish, frogs, turtles, lizards, and diverse birds and mammals (Cassiliano 1999). These fossils are indicative of the vertebrates that existed at about the time of the formation of the Linda Vista Terrace.

Park Collections

Cultural artifacts make up almost all of CABR’s collections (B. Pister, pers. comm., January 2012). Formerly, the Visitor Center had a cast of a fossil known informally as the “flying ammonite” on display. The actual fossil was collected near CABR from the rocky beach on the east side of Point Loma in 1975 and is in the collections of the Natural History Museum of Los Angeles County, Los Angeles (LACM) (Wilson 1976). It received its nickname because a helicopter was used to recover it from the boulder beach where it was found. It is a specimen of the species *Pachydiscus catarinae*; a much smaller individual was found within it, and possibly represents a juvenile that was being brooded inside the adult’s shell, in a similar manner to the modern paper nautilus (Wilson 1976). The cast is not on display as of January 2012, and its whereabouts are unknown (B. Pister, pers. comm., January 2012).

Several institutions have records of fossil localities within CABR: the LACM (G. Kennedy, Brian F. Smith & Associates, Inc., pers. comm., March 2012); the San Diego Natural History Museum (SDNHM; CABR Figure 6) (Stephens 1929; Dawson 1978; T. Deméré, pers. comm., November 2011); San Diego State University (SDSU) (Kern 1977); and the University of California Museum of Paleontology, Berkeley (UCMP), which has fossils collected from CABR that were previously at USGS-Menlo Park (G. Kennedy, pers. comm., March 2012). SDSU fossils from CABR can be found in the collections of the LACM and SDNHM. Additionally, Cooper’s (1894) fossils, some of which may be from CABR, are probably at the California Academy of Science (CAS) in San Francisco, and fossils collected from the tip of Point Loma for various graduate projects may have been at UCLA at one time (G. Kennedy, pers. comm., March 2012); UCLA collections are now at LACM.

CABR Figure 6: Several drawers of NPS fossils at the SDNHM, including CABR specimens (VLS).



The LACM has fossils from three Pleistocene-age terrace localities collected by Thomas Deméré for the then-San Diego State College (now University): LACM IP5139, 5140, and 5142 (G. Kennedy, pers. comm., March 2012). Specimens from CABR are on display at the SDNHM, including the cycad leaf from the Point Loma Formation (Koch and Santucci 2003). SDNHM collections include 1,765 specimens from CABR localities: 145 specimens of the gastropod *Littorina* from locality 58, on the Nestor Terrace; 81 specimens of bivalves and gastropods from locality 121, on the Nestor Terrace; 169 specimens of marine invertebrates, mostly bivalves and gastropods, from locality 457 on the Nestor Terrace; 211

specimens of marine invertebrates from locality 2823, in the Cabrillo Formation; the *Squalicorax* tooth from locality 3272, in the Cabrillo Formation; the cycad leaf from locality 3774, in the Point Loma Formation; and 1,157 specimens of marine animals, mostly bivalves and gastropods, from locality 5635 on the Nestor Terrace. Locality 5635 is another site which was collected originally as an SDSU site (T. Deméré, pers. comm., November 2011). The UCMP has in its collections fossils from USGS-Menlo Park site USGS M6705, another Pleistocene site from the east site of Point Loma in CABR (G. Kennedy, pers. comm., March 2012).

Cultural Resource Contexts

CABR has the potential for fossil-cultural resource associations, but none have been recognized yet. Archeological investigations elsewhere on the southern California coast have found examples of human-created shell middens and biological materials fashioned into tools and other artifacts dating back to the latest Pleistocene, so there is the possibility that such materials may be

found at CABR. Channel Islands National Park (CHIS) has outstanding examples of these associations; see the CHIS summary in this report for more details. Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Paleontological Resource Management, Preliminary Recommendations

- Coastal erosion and landslides are important threats to paleontological resources at CABR. There is little that can be done to mitigate in the case of erosion because fossils that erode from the sea cliffs are removed almost immediately by coastal processes (KellerLynn 2008). The monument may want to consider establishing some sort of protocol for salvaging significant fossils in imminent danger of erosion. Thomas Deméré (pers. comm., November 2011) suggested that preparing detailed descriptions of measured stratigraphic sections (bed-by-bed descriptions of exposures) could effectively summarize the distribution of fossiliferous zones in the sedimentary rocks of CABR, which would help focus management efforts.
- Invertebrate trace fossils are located in the tide pool area, incurring inevitable human contact and erosion. Some kind of interpretation, possibly combined with blocking off some of the fossils, has been proposed in the past. The continuous wave erosion makes protection unfeasible, but an interpretative sign or placard (that could be moved as erosion dictates) might be a way to enhance the visitor experience.
- The monument should consider future field inventories for paleontological resources to more fully document *in situ* occurrences of fossils. The monument may consider a formal site documentation and condition assessment on a regular schedule for significant fossil localities. A 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. 2009).
- Monument staff should be encouraged to observe exposed sedimentary rocks and associated eroded deposits for fossil material while conducting their usual duties. Staff should photodocument and monitor any occurrences of paleontological resources that may be observed *in situ*. Fossils and their associated geologic context (surrounding rock) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts. When opportunities arise to observe paleontological resources in the field and take part in paleontological field studies with trained paleontologists, monument staff should take advantage of them.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Geologic Resources

Division can coordinate additional documentation/research of such material.

- Future infrastructure developments or archeological excavations should consider scheduling site monitoring by a trained paleontologist in order to document and protect fossil resources.

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

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Data Sets

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

Cabrillo National Monument Collections
1913–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by CABR staff; status: Active.

Cabrillo National Monument Digital Geologic Map
2009–present. (geologic map data; electronic files; GIS metadata; associated report). Originated by NPS-Geologic Resources Inventory staff; status: Active. Online. <https://irma.nps.gov/App/Reference/Profile?Code=1047843>.

California Academy of Sciences
Pre-1894 (as old as 1850s and 1860s)–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by CAS staff; status: Active.

Natural History Museum of Los Angeles County
Pre-1976–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by LACM staff; status: Active.

Natural History Museum of Los Angeles County (University of California–Los Angeles collections)
Uncertain (would have to predate transfer to LACM during the 1980s/1990s)–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by UCLA staff; status: Active.

San Diego Natural History Museum
1928–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by SDNHM staff; status: Active.

San Diego State University
1928–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by SDSU staff; status: Active.

University of California Museum of Paleontology (USGS–Menlo Park collections)
Pre-1965–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by USGS staff; status: Active.

Channel Islands National Park

Channel Islands National Park (CHIS) protects five of California's eight Channel Islands and the surrounding ocean for a distance of one nautical mile (1.8 km). The northern four islands of CHIS are aligned east to west in a line about 100 km (60 miles) long, approximately 32 km (20 miles) south of the Santa Barbara coast. From west to east the northern Channel Islands are San Miguel Island, Santa Rosa Island (CHIS Figure 1), Santa Cruz Island, and Anacapa Island. Farther southeast, about 56 km (35 miles) southwest of Palos Verdes Point and 67 km (42 miles) southeast of Anacapa Island, is the fifth island, Santa Barbara Island. CHIS includes a variety of natural and cultural resources ranging from endemic organisms and rookeries of sea birds and sea lions to hundreds of archeological sites as old as the late Pleistocene. Paleontological resources are abundant and include marine invertebrate fossils and bones of the pygmy mammoth *Mammuthus exilis*. CHIS was originally proclaimed as a national monument on April 26, 1938, at which time it included Anacapa Island and Santa Barbara Island. It was designated a Biosphere Reserve in 1976, and redesignated a national park March 5, 1980. CHIS's boundaries changed June 10, 1949; May 15, 1978; and Oct. 25, 1978. Today, it encompasses 100,993.75 ha (249,561 acres) (CHIS Figure 2). The National Park Service (NPS) owns Anacapa Island, Santa Barbara Island, Santa Rosa Island, and the eastern 24% of Santa Cruz Island; it administers Santa Cruz Island in partnership with The Nature Conservancy, which owns the western 76% of the island, and administers San Miguel Island under an agreement with the U.S. Navy.

Geologic Background

The islands of CHIS are included in two of California's counties: San Miguel Island, Santa Barbara Island, Santa Cruz Island, and Santa Rosa Island are part of Santa Barbara County, and Anacapa Island is part of Ventura County. The four northern islands are separated from the mainland by the Santa Barbara Channel. The Oxnard–Ventura area is about 19 km (12 miles) northeast of Anacapa Island, and Santa Barbara is about 31 km (19 miles) north of the nearest part of Santa Cruz Island. The three Channel Islands not included in CHIS are San Clemente Island, San Nicolas Island, and Santa Catalina Island. All three, along with CHIS's Santa Barbara Island, are grouped as the southern Channel Islands. San Nicolas Island is about 44 km (27 miles) southeast of Santa Barbara Island and 67 km (42 miles) south of Santa Cruz Island. Santa Catalina Island is 34 km (21 miles) east of Santa Barbara Island, and San Clemente Island is 53 km (33 miles) southeast of Santa Barbara Island, due south of Santa Catalina Island.



CHIS Figure 1. Water Canyon Beach on Santa Rosa Island illustrates how dynamic coastal processes can reveal and destroy fossils. Photo by Derek Lohuis (CHIS), courtesy NPS.

A geologic resource evaluation scoping session, coordinated by the Geologic Resources Division of the NPS, was held for CHIS during May 2008 (KellerLynn 2008). The initial paleontological resource inventory and summary for CHIS was prepared by Koch and Santucci (2003).

The geology and paleontology of CHIS have been described in numerous documents. Relevant publications include those by Kew (1927), Hertlein (1928, 1933), Stock and Furlong (1928), Chaney and Mason (1930), Rand (1931), Bremner (1932, 1933), Loel and Corey (1932), Stock (1935), Wilson (1936), Cockerell (1938a, 1938b), Grant and Hertlein (1938), Orr (1956a, 1956b, 1960, 1962, 1968), Scholl (1959, 1960), Miller et al. (1961), Howard (1962, 1964a, 1964b), Valentine and Lipps (1963), Lipps (1964), White (1966), Johnson (1967, 1969, 1971, 1977, 1978, 1980), Weaver and Doerner (1967, 1969a, 1969b), Lipps et al. (1968), Avila and Weaver (1969), Bereskin and Edwards (1969), Doerner (1969), Nolf and Nolf (1969), Weaver (1969a, 1969b, 1969c, 1969d), Weaver and Meyer (1969), Weaver et al. (1969), Erickson (1975), Crowe et al. (1976), Fisher and Charlton (1976), Hill (1976), Howell and McLean (1976), Howell et al. (1976), Mattison and Hill (1976), McLean et al. (1976a, 1976b), Vedder and Howell (1976), Kamerling and Luyendyk (1979, 1985), Walker and Craig (1979), Guthrie (1980, 1992, 1993, 1998, 2005), Junger and Johnson (1980), Walker (1980), Wenner and Johnson (1980), Azzaroli (1981), Dibblee (1982a), Kies and Abbott (1982), Abbott et al. (1983), Bartling and Abbott (1983), Miller (1983), Cushing et al. (1984, 1986), McLean and Howell (1984), Roth (1984, 1990, 1993, 1996), Sorensen (1985), Champion et al. (1986), Morris et al. (1986), Norris (1991, 1995), Cushing (1993), Cole and Liu (1994), West and Erlandson (1994), Erlandson et al. (1996, 1999, 2005, 2007, 2008, 2011), Barnes and Aranda-Manteca (1997), Agenbroad (1998, 2001, 2002a, 2009, 2012), Atwater (1998), Dibblee and Ehrenspeek (1998), Gray and Harz (1998), Molesworth and Stone (1998), Nuccio and Woolley (1998), Pinter et al. (1998), Shapiro (1998), Thaler (1998), van

Roosendaal and Weigand (1998), Weigand et al. (1998), Woolley (1998a, 1998b), Agenbroad and Morris (1999), Guthrie et al. (1999), Weigand and Savage (1999), Gordon et al. (2001), Rick et al. (2001, 2008, 2009), Santucci et al. (2001), Rick (2002), Vellanoweth et al. (2003), Mead et al. (2004), Palmer (2004), Agenbroad et al. (2005), Braje et al. (2005), Hunt et al. (2006), Johnson et al. (2007), Anderson et al. (2008), Grayson (2008), Jones et al. (2008), Reeder et al. (2008), and Anderson et al. (2010). Geological mapping has been provided by Sonneman et al. (1969), Weaver and Doerner (1969c), Weaver and Nolf (1969), Dibblee and Minch (2001a, 2001b), Dibblee and Ehrenspeck (2001), and Dibblee et al. (1998). Dissertations and theses include those by Rand (1933), Kemnitzer (1933), Bereskin (1966), Edwards (1967), Meyer (1967), Avila (1968), Doerner (1968), Erickson (1972), Johnson (1972), Nuccio (1977), Kies (1982), Minck (1982), Roth (1982), Natenstedt (1983), Weaver (1985), and Kruk (1987).

The oldest exposed rocks of CHIS are found on Santa Cruz Island (Weaver 1969b), and consist of a combination of metamorphic and igneous rocks formed from the Middle Jurassic to the Early Cretaceous (see the appendix for a geologic time scale). Intrusive igneous rocks named the Willows Plutonic Complex formed about 162 Ma (million years ago) (Mattison and Hill 1976). At approximately the same time, a submarine volcanic pile was forming in the vicinity. This pile and its associated sediments and igneous intrusions later metamorphosed into the Santa Cruz Island Schist (Hill 1976). These two units probably represent fragments of one or more island arcs (Sorensen 1985). Another igneous body, the Alamos Tonalite, intrudes the schist (Weaver 1969b); this event occurred at approximately 141 Ma (Mattison and Hill 1976).

The northern Channel Islands are part of the Transverse Ranges terrane (distinct block of continental crust) or block (Atwater 1998), which underwent dramatic changes in location and orientation during the Cenozoic. Paleomagnetic data indicate that the block was attached to the North American craton during the Jurassic, Cretaceous, and early Cenozoic. The paleomagnetic tracks of the block and the rest of North America do not begin to diverge until the middle Cenozoic, when the block began moving north relative to the continent (Champion et al. 1986). For the Mesozoic–early Cenozoic period, the future northern Channel Islands were probably near San Diego (Bartling and Abbott 1983; Atwater 1998). Over this period, the Transverse Ranges block was located between the trench formed by subducting crust, and a volcanic arc (a forearc location) (Atwater 1998). During the Late Cretaceous, the islands would have been a short distance south of San Diego, with the two areas recording the deposition of similar submarine fans. Later, during the Eocene, the block moved north far enough to juxtapose the future site of the islands with the San Diego area, resulting in the accumulation of the same type of conglomerates (Bartling and Abbott [1983]; these are often known as Poway conglomerates).

The best record of the Paleocene and Eocene in CHIS is found on Santa Cruz Island. Rocks of this age are also found on San Miguel and Santa Rosa islands (Dibblee 1982a). During the Paleocene, what became San Miguel Island was located in a sediment-starved marine basin, while the Santa Cruz Island area was on the continental shelf. Both areas were covered by submarine sediment fans during the Eocene (Kies and Abbott 1982). Tropical marine conditions that began during the Late Cretaceous persisted into the Eocene, then gave way to cooler water (Doerner 1969). Depth fluctuated several times as a result of marine transgressions (advances) and regressions (retreats). The early and middle Paleocene were marked by regressions (Bartling and Abbott 1983), and a sea-level fall during the early Eocene is evidenced by the appearance of coarser sediments (Abbott et al. 1983). Depth increased to bathyal (broadly, continental slope) (Erickson 1975) and deeper (Doerner 1969) later in the Eocene. The increased depth was more than reversed during the Oligocene, and at least Santa Rosa Island was marked by terrestrial deposition as recorded in the Sespe Formation (Avila and Weaver 1969). The latter part of Sespe Formation deposition occurred at the beginning of another marine transgression that continued through the Vaqueros, Rincon, and Monterey formations, which were deposited in progressively deeper settings (Bandy and Kolpack 1963).

The Miocene of CHIS is marked by volcanism and movement that brought the northern Channel Islands close to their present location. These events were the result of long-term tectonic activity along the western margin of North America. For many millions of years, beginning in the Mesozoic, an oceanic plate known as the Farallon plate had been subducting beneath the North American plate. As more and more of the Farallon plate was subducted and destroyed beneath North America, portions fragmented off and became microplates. One such microplate, the Monterey microplate, was captured by the Pacific plate before it was completely subducted, at approximately 30 Ma. This set off a chain of events in the numerous small continental blocks along the southwestern margin of the North American plate. The Transverse Ranges block was wrenched out of position at about 19 Ma and rotated clockwise. This rotation and associated rifting allowed the underlying asthenosphere to well up, leading to widespread volcanism; the volcanism was the source of the volcanic rocks that make up a significant portion of the bedrock of the Channel Islands and Santa Monica Mountains (Weigand et al. 2002). Volcanism ended by about 16 Ma (Weigand et al. 2002) and rotation ceased by approximately 12 Ma (Weigand and Savage 1993). By the time motion stopped, the Transverse Ranges block had rotated roughly 90° clockwise (Bartling and Abbott 1983), and moved a few degrees north; there is some disagreement about the magnitude of northward movement between different measurement methods, but in relative terms the block has moved north from the vicinity of San Diego (Kamerling and Luyendyk 1985). Unlike the northern Channel Islands, the southern Channel Islands, including Santa Barbara Island, have not been rotated (Pinter and Sorlien 1991). In the area that would become CHIS,

volcanism was both subaerial and submarine (Weigand and Savage 1999). Following the volcanic activity, more marine sediments were deposited over the continental shelf and slope settings (Avila and Weaver 1969; Bereskin and Edwards 1969; Weaver and Doerner 1969b; Weaver and Meyer 1969).

The islands lack Pliocene rocks, and are thought to have been topographic highs during that time (Weaver and Doerner 1969b; Dibblee 1982a). Strontium isotope ratios indicate that the islands have been emergent for much of the Pleistocene: Santa Cruz Island and Santa Rosa Island have been emergent since at least 2 Ma, and Anacapa Island and Santa Barbara Island may have been emergent by around 1.6 Ma (D. Muhs, U.S. Geological Survey, pers. comm., February 2012). The islands have been gradually rising through the Pleistocene. Their maximum subaerial exposure was probably during the sea level lowstand at the end of the Pleistocene. At this time, the four northern Channel Islands were linked together into a larger landmass known as Santarosae, after Orr (1968) (sometimes written as Santa Rosae) (Johnson 1978). For many years, it was thought that the islands had been a peninsula of the mainland at some point during the Pleistocene, to account for the presence of mammoths (see for example Stock [1935] or Azzaroli [1981], which is one of the most recent defenses of the concept), but this hypothesis has been discredited based on the submarine geography of the area (Johnson 1978; Junger and Johnson 1980; Wenner and Johnson 1980) and the previously-unappreciated swimming capabilities of elephants (Johnson 1978, 1980). Sea level was as much as 90 to 100 m (300 to 330 ft) lower than present in the Channel Islands area at the last glacial maximum, about 20,000 years ago (Muhs et al. 2012). Because of rising sea levels during the Holocene, there are paleontological and archeological resources on now-submerged former coastal areas of the islands, and they occasionally wash up on them (Orr 1956b). The islands' dunes formed during glacial periods, when sand-sized carbonate debris (consisting of skeletal fragments of marine organisms) from the islands' shelves was made available by lower sea levels (Muhs et al. 2009). Coastal California may have been an ice-age refugium, with a stable long-term Mediterranean climate (Johnson 1977).

Recently, sediment from CHIS was part of a series of studies attempting to determine if there was an extraterrestrial impact that triggered the Younger Dryas cold period around 13,000 years ago (Kennett et al. 2008, 2009; Podoll and Pinter 2008; Scott et al. 2010). Various lines of evidence, including shock-synthesized diamonds and charcoal, were cited by Kennett et al. (2008, 2009) from the islands. The authors proposed that the effects of an impact could also account for the extinction of the islands' pygmy mammoths and a hiatus in the archeological record lasting for several hundred years. Podoll and Pinter (2008) and Scott et al. (2010) regarded the evidence as more mundane or even misidentified. Because of studies at CHIS and elsewhere, the Younger Dryas impact hypothesis is considered unlikely (Kerr 2010; Pinter et al. 2011). Regardless of whether there was an extraterrestrial event 13,000 years ago, that time

frame included a number of important events on the northern islands, such as charcoal deposition, increased aggradation, a rapid shift away from pine forests, mammoth extinction, and the appearance of humans (Pinter and Anderson 2006).

Humans were present on the Channel Islands by 13,000 calendar yr BP (years before present; calendar yr BP are radiocarbon dates that have been calibrated to calendar dates. In this document, radiocarbon dates that were not calibrated by the original authors have been calibrated using Calib 6.0 [<http://calib.qub.ac.uk/calib/>] where appropriate) (Johnson et al. 2007). Santa Rosa Island's archeological record goes back to around 13,000 calendar yr BP, and San Miguel Island's archeological record begins at least 11,500 calendar yr BP (Erlandson et al. 2007). Pollen indicates a pine and cypress forest was present when people first arrived on the islands (Johnson et al. 2007; Anderson et al. 2010). This forest was replaced at approximately 11,800 calendar yr BP by grassland and scrub as the climate warmed. The dry early Holocene was followed by increased moisture around 6,900 calendar yr BP (Anderson et al. 2010). Aridity increased again for the period 5,200 to 3,250 radiocarbon yr BP (Cole and Liu 1994).

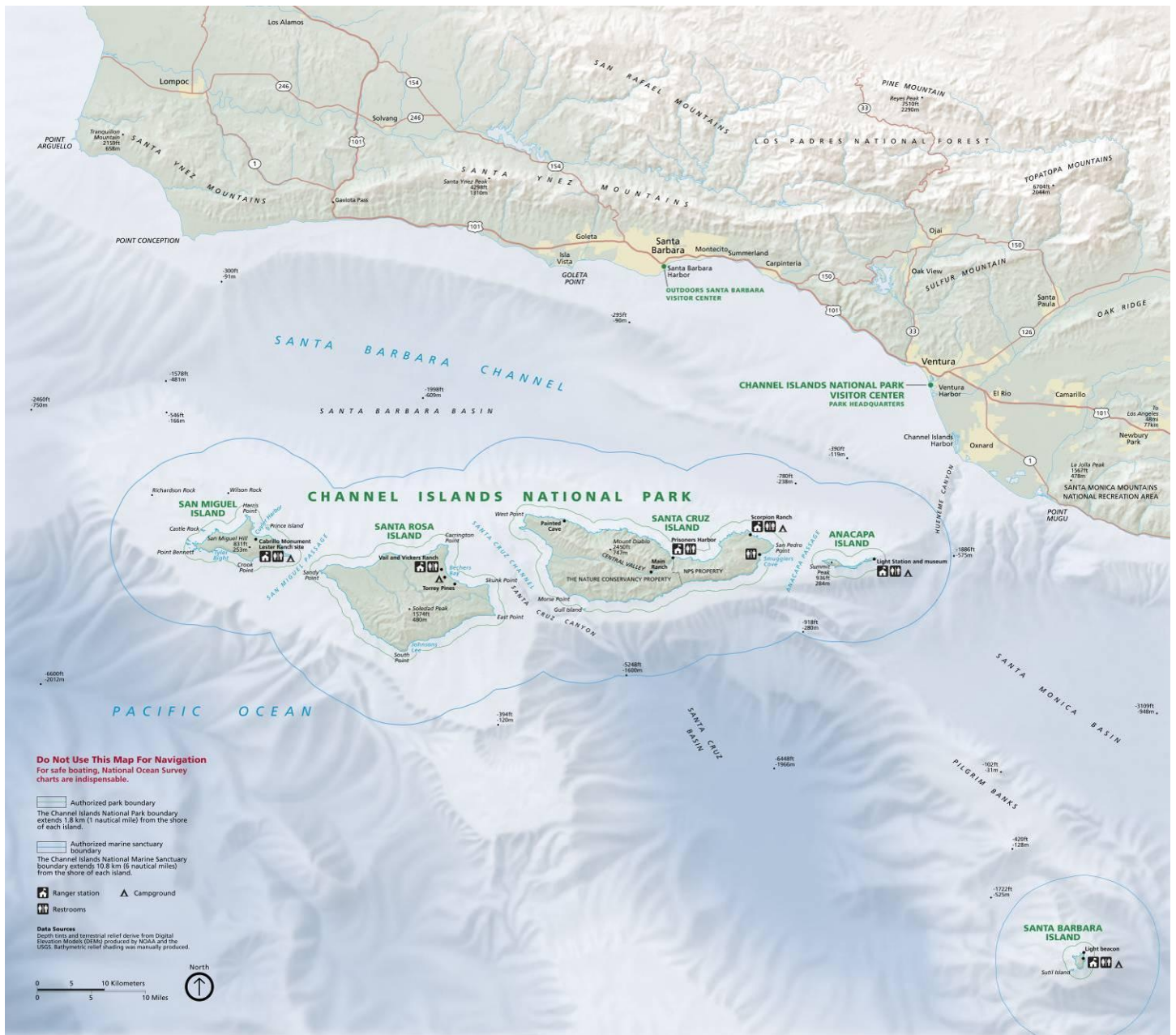
Each island in CHIS has distinct stratigraphy (CHIS Figure 3). Geologic units exposed on San Miguel Island include: Upper Cretaceous sedimentary rocks; the undifferentiated Pozo–Cañada Formation (Middle Paleocene–Middle Eocene); the South Point Formation (Middle–Upper Eocene); the Vaqueros Formation and/or Rincon Formation (Oligocene–Miocene); the San Miguel Island Volcanics (Lower Miocene); the Beechers Bay Formation (Lower–Middle Miocene); the Monterey Formation (Middle Miocene); and Quaternary sediments (Pleistocene–Holocene) (Weaver and Doerner 1969c; Dibblee and Ehrenspeck 2001) (CHIS Table 1). Units exposed on Santa Rosa Island include: the South Point Formation and Cozy Dell Formation (Middle–Upper Eocene); the Sespe Formation (Oligocene); the Vaqueros Formation and Rincon Formation (Lower Miocene); the Santa Rosa Island Volcanics (Middle Miocene); the Monterey Formation, San Onofre Breccia, and Beechers Bay Formation (Lower–Middle Miocene); and Quaternary rocks and sediments (Pleistocene–Holocene) (Sonneman et al. 1969; Dibblee et al. 1998) (CHIS Table 2). Units exposed on Santa Cruz Island include: the Santa Cruz Island Schist and Willows Plutonic Complex (Middle–Upper Jurassic); the Alamos Tonalite (Lower Cretaceous); the Pozo Formation (Upper Paleocene–Lower Eocene); the Cañada Formation (Upper Paleocene–Middle Eocene); the Jolla Vieja Formation and Cozy Dell Formation (Middle–Upper Eocene); the Vaqueros Formation (Oligocene–Lower Miocene); the Rincon Formation (Lower Miocene); the San Onofre Breccia, Santa Cruz Island Volcanics, Beechers Bay Formation, and Monterey Formation (Lower–Middle Miocene); the Blanca Formation (Middle Miocene); the Potato Harbor Formation and Middle Anchorage Alluvium (Pleistocene); and younger Quaternary rocks and sediments (Pleistocene–Holocene) (Weaver and Nolf 1969; Dibblee and Minch 2001a, 2001b)

(CHIS Table 3). Geologic units exposed on Anacapa Island include, from oldest to youngest, Early–Middle Miocene-age volcanics and associated sedimentary rocks, the interbedded San Onofre Breccia, and Quaternary rocks and sediments (Norris 1995) (CHIS Table 4). Units exposed on Santa Barbara Island include Early–Middle Miocene-age volcanics and associated sedimentary rocks, and Quaternary rocks and sediments (Vedder and Howell 1976; Norris 1991; Weigand and Savage 1999) (CHIS Table 5).

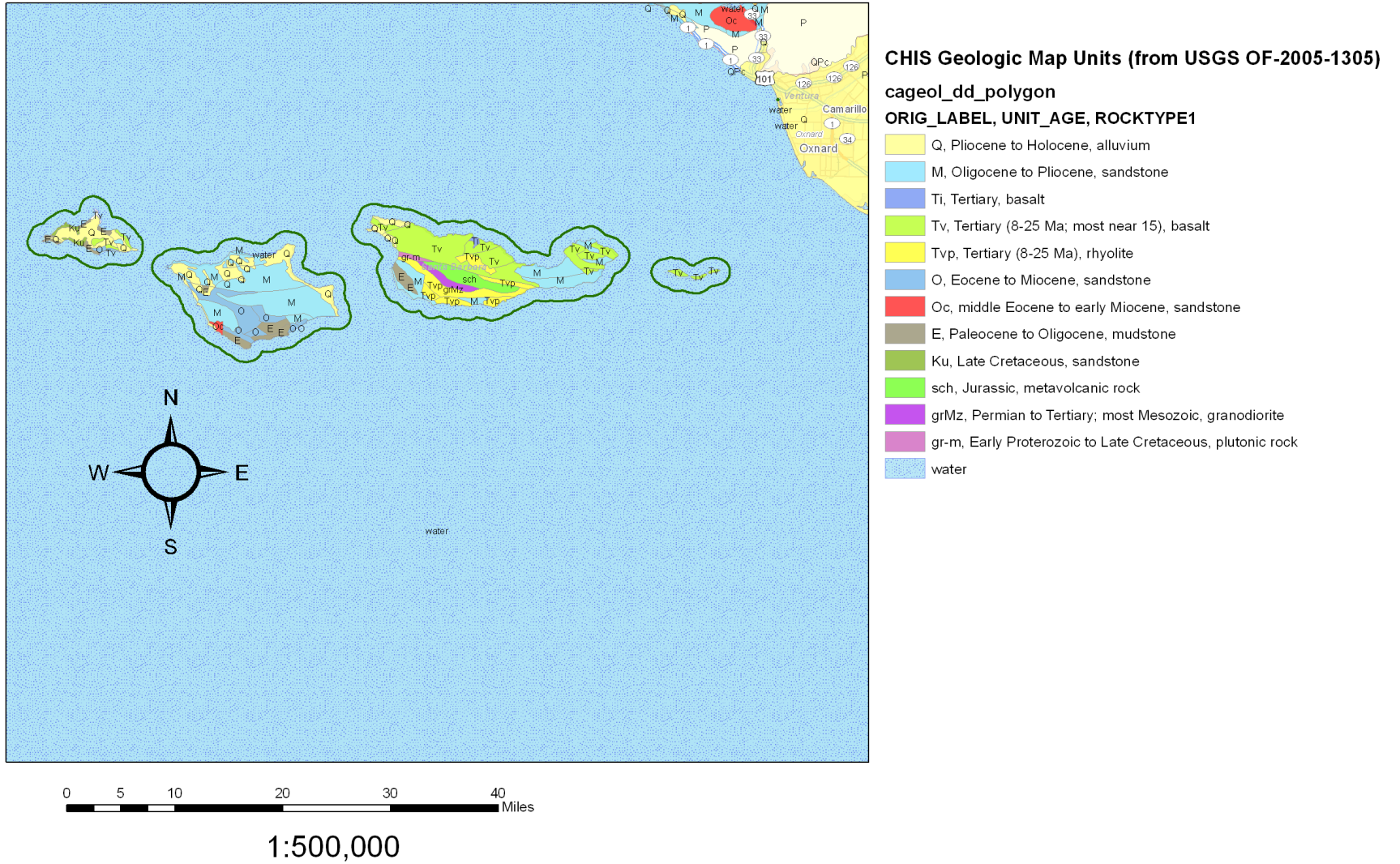
A number of these formations were named from rock exposures on the islands, including: the Santa Cruz Island Schist; the Willows Plutonic Complex; the Alamos Tonalite; the Mirounga and Point Bennett formations (two names for the Upper Cretaceous rocks of San Miguel Island); the Pozo Formation; the Cañada Formation; the Jolla Vieja Formation, the South Point Formation; the San Miguel Island Volcanics; the Santa Cruz Island Volcanics; the Santa Rosa Island Volcanics; the Beechers Bay Formation; the Blanca Formation; the Potato Harbor Formation; the Middle Anchorage Alluvium; the Santa

Cruz Island Formation (another name for the island’s young Quaternary sediments); and the Santa Rosa Island Formation (another name for the island’s Quaternary sediments). These units are often of limited extent, typically found only on one island.

The Mesozoic-age igneous rocks of Santa Cruz Island do not have fossils. The Santa Cruz Island Schist is unfossiliferous (Weaver 1969b) and, being mostly igneous in origin (Hill 1976), and metamorphosed to a high grade, is unlikely to have fossils. Almost all of the sedimentary formations of CHIS are known to be fossiliferous, and are sometimes abundantly fossiliferous. Unsurprisingly, the islands have rich marine fossil records (particularly of mollusks and microfossils), but they also have noteworthy Pleistocene and Holocene terrestrial fossil records, including “fossil forests” and pygmy mammoths. Many Holocene fossils have been found in cultural contexts, such as shell middens, and there are substantial museum collections of CHIS fossils.



CHIS Figure 2. Geography of CHIS (NPS).



CHIS Figure 3. Preliminary schematic geological map of CHIS (Santa Barbara Island is omitted, but has essentially the same bedrock as Anacapa Island). The large-scale source map (Ludington et al. 2005) does not have formal units; compare with CHIS tables 1-4 to estimate stratigraphic nomenclature.

Formation	Age	Fossils On San Miguel Island	Depositional Environment
Quaternary rocks and sediments	Pleistocene–Holocene	Foraminifera, pollen, charcoal, twigs, tree trunks and plant roots, bivalves, gastropods, barnacles, sharks, bony fish, lizards, snakes, diverse birds, shrews, voles, deer mice, vampire bats, foxes, dogs, skunks, pinnipeds, pygmy and Columbian mammoths, whales, deer, and bird eggshell	Shallow marine to terrestrial settings
Monterey Formation	Middle Miocene	Foraminifera, diatoms, and bivalves	Continental shelf
Beechers Bay Formation	Early–Middle Miocene	Brachiopods and bivalves	Submarine fan
San Miguel Island Volcanics	Early Miocene	Foraminifera	Subaqueous (probably submarine) volcanic flows
Vaqueros and/or Rincon Formation	Oligocene–Miocene	Foraminifera, bryozoans, bivalves, gastropods, barnacles, and echinoids	Open marine, continental shelf
South Point Formation	Middle–Late Eocene	Coccoliths and foraminifera	Submarine fan, bathyal depths
Undifferentiated Pozo–Cañada Formation	Middle Paleocene–Middle Eocene	Coccoliths and foraminifera	Marine basin and submarine fan settings
Upper Cretaceous rocks	Late Cretaceous	Coccoliths, foraminifera, and the bivalve <i>Inoceramus</i>	Submarine fan, continental shelf to continental slope

CHIS Table 1. Concise tabulation of San Miguel Island stratigraphy, fossils, and depositional setting; details and references can be found in the text.

Formation	Age	Fossils On Santa Rosa Island	Deposition Environment
Quaternary rocks and sediments	Pleistocene–Holocene	Diatoms, charcoal, plant spores and pollen, seeds, root and tree casts, reed casts, cypress, fungal spores and fragments, chitons, bivalves, gastropods, barnacles, crabs, echinoids, invertebrate trace fossils, sheephead and clupeiform fish, salamanders, lizards, snakes, a variety of birds (mostly raptors, shorebirds, and waterfowl), shrews, voles, deer mice, foxes, dogs, seals, sea lions, sea otters, Columbian and pygmy mammoths, whales, and owl pellets	Shallow marine to terrestrial settings
Beechers Bay Formation	Early–Middle Miocene	Foraminifera and bivalves	Submarine fan near volcanic source

Formation	Age	Fossils On Santa Rosa Island	Deposition Environment
San Onofre Breccia	Early–Middle Miocene	None to date; marine invertebrates are most likely	Shallow marine, associated with volcanics
Monterey Formation	Early–Middle Miocene	Foraminifera, diatoms, and bivalves	Outer shelf to upper slope
Santa Rosa Island Volcanics	Early Miocene	Foraminifera and bivalves	Volcanic flows and igneous intrusions
Rincon Formation	Early Miocene	Carbonaceous debris, foraminifera, corals, bivalves, gastropods, echinoids, fish scales, bone fragments, and reworked coccoliths	Continental shelf
Vaqueros Formation	Early Miocene	Foraminifera, corals, bivalves, gastropods, barnacles, echinoids, worm tubes, and reworked coccoliths	Shallow marine inner shelf, becoming deeper over time
Sespe Formation	Oligocene	Unspecified megafossils	Fluvial, floodplain, and coastal settings
Cozy Dell Formation	Middle–Late Eocene	Foraminifera, diatoms, and bivalves	Marine, beginning as continental slope and reaching abyssal depths as basin subsided
South Point Formation	Middle–Late Eocene	Foraminifera, diatoms, ostracodes, and fish teeth	Gravity-driven flow deposition on bathyal submarine fan
Possible Upper Cretaceous rocks	Late Cretaceous	None to date; foraminifera and marine invertebrates are most likely	Marine

CHIS Table 2. Concise tabulation of Santa Rosa Island stratigraphy, fossils, and depositional setting; details and references can be found in the text.

Formation	Age	Fossils On Santa Cruz Island	Depositional Environment
Unnamed Quaternary rocks and sediments	Pleistocene–Holocene	Nine identified taxa of trees, shrubs, and herbs, four types of unidentified seeds, corals, shells, foxes, dogs, and pygmy mammoths	Shallow marine to terrestrial settings
Middle Anchorage Alluvium	Pleistocene	Bivalve (<i>Pholad</i>) borings	Beach and coastal settings
Potato Harbor Formation	Pleistocene	Foraminifera, root casts, bryozoans, bivalves, gastropods, barnacles, and echinoids	Beginning as shallow marine, becoming eolian beach
Blanca Formation	Middle Miocene	Bivalves and barnacles	Nearshore marine volcanic and submarine fan complex

Formation	Age	Fossils On Santa Cruz Island	Depositional Environment
Monterey Formation	Early–Middle Miocene	Foraminifera, diatoms, bivalves, gastropods, and bones of fish, desmostylians, and whales	Outer shelf to slope, becoming deeper over time
Beechers Bay Formation	Early–Middle Miocene	Foraminifera, bivalves, and barnacles	Middle shelf to middle slope, with deposition by turbidity currents
Santa Cruz Island Volcanics	Early–Middle Miocene	Foraminifera and cetacean bones	Volcanic flows, beginning subaerially and becoming subaqueous over time
San Onofre Breccia	Early–Middle Miocene	Foraminifera, bivalves, and barnacles	Inner to middle continental shelf, with brackish and shallow marine fauna
Rincon Formation	Early Miocene	Foraminifera and fish scales	Middle to outer continental shelf
Vaqueros Formation	Oligocene–Early Miocene	Foraminifera, bryozoans, brachiopods, bivalves, gastropods, scaphopods, barnacles, echinoids, invertebrate burrows, shark and ray teeth, a possible whale bone, other bones, and reworked fossils	Continental shelf
Cozy Dell Formation	Middle–Late Eocene	Coccoliths, foraminifera, bivalves, gastropods, and a possible seed of a katsura tree	Marine, beginning as continental slope and reaching abyssal depths as basin subsided
Jolla Vieja Formation	Middle–Late Eocene	Gastropods, possibly foraminifera	Submarine fan
Cañada Formation	Late Paleocene–Middle Eocene	Coccoliths, foraminifera, wood casts, corals, bivalves, nautiloids, gastropods, echinoids, worm tubes, and ray teeth	Marine, outer shelf to inner slope depths with submarine fan settings
Pozo Formation	Late Paleocene–Early Eocene	Coccoliths, foraminifera, bivalves, gastropods, and worm tubes	Marine, beginning as continental shelf and becoming deeper
Upper Cretaceous rocks (subsurface)	Late Cretaceous	Foraminifera	Marine
Alamos Tonalite	Early Cretaceous	Unfossiliferous (intrusive igneous rocks)	Not applicable (igneous rocks that solidified at depth)
Willows Plutonic Complex	Middle–Late Jurassic	Unfossiliferous (intrusive igneous rocks)	Not applicable (igneous rocks that solidified at depth)

Formation	Age	Fossils On Santa Cruz Island	Depositional Environment
Santa Cruz Island Schist	Middle–Late Jurassic	None to date; fossils are unlikely because of metamorphism	A combination of sedimentary, volcanic, and intrusive rocks associated with a submarine volcanic complex (before metamorphism)

CHIS Table 3. Concise tabulation of Santa Cruz Island stratigraphy, fossils, and depositional setting; details and references can be found in the text. Metamorphic and intrusive igneous rocks are included here for completeness, but are not discussed in detail in the text because of the improbability of fossils.

Formation	Age	Fossils On Anacapa Island	Depositional Environment
Quaternary sediments	Pleistocene–Holocene	Foraminifera, chitons, bivalves, gastropods, scaphopods, barnacles, a beetle (possibly recent), echinoids, sheephead and other fish, 10 species of birds, and deer mice	Shallow marine to terrestrial settings
Anacapa Island volcanics and associated sedimentary rocks	Early–Middle Miocene	Marine gastropods	Submarine to subaerial volcanic flows

CHIS Table 4. Concise tabulation of Anacapa Island stratigraphy, fossils, and depositional setting; details and references can be found in the text.

Formation	Age	Fossils On Santa Barbara Island	Depositional Environment
Quaternary rocks and sediments	Pleistocene–Holocene	Foraminifera, corals, bivalves, gastropods, ostracodes, and single bones of a bald eagle and sea lion	Shallow marine
Santa Barbara Island volcanics and associated sedimentary rocks	Early–Middle Miocene	Foraminifera	Volcanic flows at upper bathyal depths

CHIS Table 5. Concise tabulation of Santa Barbara Island stratigraphy, fossils, and depositional setting; details and references can be found in the text.

Sources of Paleontological Resources

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

San Miguel Island

San Miguel Island may be divided by an unrecognized fault; bedrock on the east side of the island consists of Cretaceous and lower Cenozoic marine rocks, while the west side has Eocene and Miocene marine formations and Miocene basalt (Dibblee and Ehrenspeck 2001).

Upper Cretaceous rocks

Although Upper Cretaceous rocks are occasionally identified on Santa Cruz Island (Dibblee 1982a) and Santa Rosa Island (Kew 1927; Weaver 1969c), they are only known for certain on west-

central San Miguel Island (Weaver 1969c). The Upper Cretaceous rocks on San Miguel Island were first lumped with overlying strata as undivided Eocene strata (Bremner 1933). The Cretaceous strata include 1,928 m (6,325 ft) (Weaver 1969c) or

more (Dibblee and Ehrenspeck 2001) of gray, buff, and red rocks with grain sizes from mudstones to conglomerates (Weaver 1969c). These rocks represent submarine fan deposits, from the middle fan (Dibblee and Ehrenspeck 2001). Fossils indicate an outer continental shelf or upper continental slope location (Weaver 1969c). The upper contact with the undivided Pozo-Cañada Formation was reported as conformable by Weaver (1969c); however, in a turnabout compared to Bremner (1933)'s undivided Eocene, later mapping has shown that some rocks mapped as Lower Cenozoic are actually Upper Cretaceous (Bartling and Abbott 1983; Miller 1983, 1985), which may affect this, and the ages of the formations suggest a hiatus. Microfossil stratigraphy shows that the Cretaceous rocks of the island were deposited over much of the Late Cretaceous, from the early Turonian stage (approximately 93 Ma) to the early Maastrichtian stage (approximately 70 Ma), with a hiatus during the Santonian stage (approximately 85.8 to 83.5 Ma) (Miller 1985).

The Upper Cretaceous rocks of San Miguel Island have been known under several names, including the Jalama Formation, the Mirounga Formation, and the Point Bennett Formation. The Jalama Formation name, previously used in the Santa Ynez Mountains on the mainland, was introduced to the island by Weaver (1969c). Other authors have disagreed with the application of the mainland name to the island, and have proposed new names based on rocks found on the island itself: the Mirounga Formation (Bartling and Abbott 1983; Miller 1985) and the Point Bennett Formation (Dibblee and Ehrenspeck 2001). Based on nomenclatural priority, the Mirounga Formation should take precedence over the Point Bennett Formation.

The Upper Cretaceous rocks of San Miguel Island are “essentially devoid” of megafossils, but microfossils are locally abundant (Weaver 1969c). Weaver (1969c) described foraminifera (amoeba-like protists that form “shells”) from five localities on the island, Bartling and Abbott (1983) reported on samples of coccoliths (algal plates, also known as calcareous nanofossils) and foraminifera, and Miller (1985) described coccoliths from 69 localities on the northwest coast. Foraminifera are most abundant in the lower part of the formation (Weaver 1969c). The only megafossil reported is the distinctive giant Mesozoic bivalve *Inoceramus* (Bartling and Abbott 1983).

Undifferentiated Pozo–Cañada Formation (Middle Paleocene–Middle Eocene)

The undifferentiated Pozo–Cañada Formation is found only on the northwestern coast of San Miguel Island (Weaver and Doerner 1969a). It was initially described as a 685 m (2,250 ft)-thick sequence dominated by dark gray and rusty siltstone, with some sandstone and conglomerate (Weaver and Doerner 1969a); however, as noted above, later mapping has shown that some rocks mapped as this unit are actually Upper Cretaceous (Bartling and Abbott 1983; Miller 1983, 1985). Dibblee and

Ehrenspeck (2001) eliminated the “undifferentiated” terminology completely and replaced it with a 700 m (2,300 ft)-thick Paleocene-age Cañada Formation, with a conformable relationship to the island’s Cretaceous rocks. The unit includes some “Poway-style” conglomerates (Weaver and Doerner 1969a; Kamerling and Luyendyk 1985). The upper contact with the South Point Formation is conformable (Weaver and Doerner 1969a).

The undifferentiated Pozo–Cañada Formation is a marine unit including basinal and submarine fan deposition (Kies and Abbott 1982); conglomerates record the appearance of one fan amidst otherwise sediment-starved basin deposits (Abbott et al. 1983). The microfossils of the unit pertain to the Ynezian to Ulatisian foraminiferal stages (Weaver and Doerner 1969a), giving an age range including some period between 60.3 and 42.5 Ma (Middle Paleocene–Middle Eocene; foraminiferal stage dates are approximate, after McDougal [2007]).

The undifferentiated Pozo–Cañada Formation is fossiliferous on San Miguel Island. It has not yielded megafossils, but has abundant coccoliths and foraminifera. Weaver and Doerner (1969a) described seven coccolith and seven foraminifera collections from the island.

South Point Formation (Middle–Upper Eocene)

The South Point Formation can be found on San Miguel Island, where it was named, and southern Santa Rosa Island. It is a thick unit; 890 m (2,920 ft) are exposed at Crook Point on San Miguel Island. The formation is mostly composed of gray and buff-colored sandstone with interbedded shale and some siltstone. On San Miguel Island, it has a disconformable upper contact with the Rincon Formation (Weaver and Doerner 1969a) or Vaqueros Formation (Dibblee and Ehrenspeck 2001).

The South Point Formation is interpreted as sediment moved from the west by gravity-driven flows onto a submarine fan located at bathyal depths (Erickson 1975). It has foraminifera from the Ulatisian and Narizian stages (49.6 to 35.3 Ma), making it age-equivalent to the Jolla Vieja Formation and part of the underlying Cañada Formation on Santa Cruz Island. The oldest part of the formation is exposed on San Miguel Island (Weaver and Doerner 1969a).

The South Point Formation is fossiliferous on both San Miguel Island and Santa Rosa Island, having yielded coccoliths, foraminifera, diatoms (a type of algae with cell walls of silica), ostracodes (seed shrimp), a mollusk fragment, and ray teeth. Most fossils have been found in the finer-grained rocks; the sandstone facies has only yielded the mollusk fragment. Coccoliths (five localities) and foraminifera (25 localities) have been identified from San Miguel Island. Similar rocks on San Nicolas Island to the south have yielded foraminifera and gastropods (Weaver and Doerner 1969a).

Vaqueros and/or Rincon Formation (Oligocene–Miocene)

Historically, coastal California geology used a system of “formations” defined by fossil content instead of lithology. They were widely applied during the first few decades of the 20th century, until most were redefined to fit lithological units, limited to usage as biostratigraphic zones, or abandoned altogether (see Fritsche [1993] or Campbell et al. [2007] for some discussion of this phenomenon). Among these units were the Vaqueros and Temblor formations, which were applied to rocks with specific Middle Cenozoic mollusk assemblages, including on San Miguel Island (Arnold 1906; Hertlein 1928; Loel and Corey 1932; Bremner 1933). However, Weaver and Doerner (1969b) assigned the “Vaqueros” and “Lower Temblor” rocks in question to the Rincon Formation, and since that time usage of the Vaqueros Formation on San Miguel Island has been divided; some still use it or both it and the Rincon Formation (McLean et al. 1976a; Dibblee 1982a; Dibblee and Ehrenspeck 2001), and some use the Rincon Formation only (Miller 1983; Kamerling and Luyendyk 1985; Champion et al. 1986). See the Rincon Formation and Vaqueros Formation entries in the Santa Rosa Island section for more details specific to these formations.

The rocks in question are mostly limited to an area on the south coast of the island, north and east of Crook Point. The stratigraphic interval is up to 385 m (1,260 m) thick and can be divided into two informal members. The lower member is a gray, buff, and brown soft shale, with some sandstones and distinctive conglomerate beds. The upper member takes in the upper 76 m (250 ft) of the formation, and consists of light brown to dark brown shale with lenses of calcareous (lime-rich) beds that weather white. The upper contact with the overlying volcanics is conformable and interbedding (Weaver and Doerner 1969b).

The Vaqueros/Rincon rocks were deposited in much shallower water than the underlying South Point Formation, and includes shelf foraminifera in its upper member. The foraminifera and mollusk assemblages indicate a late Zemorrian–early Saucesian age (the Zemorrian–Saucesian boundary is 23.0 Ma) (Weaver and Doerner 1969b). A bivalve (*Pecten*) from this interval has been dated by strontium isotopes to 20.5 ± 1.5 Ma (Weaver 1985).

These rocks are fossiliferous on San Miguel Island. Foraminifera (Weaver and Doerner 1969b), bryozoans (Bremner 1933), bivalves, gastropods (Hertlein 1928; Loel and Corey 1932; Weaver and Doerner 1969b), barnacles, and echinoids (sea urchins) (Loel and Corey 1932) have been reported. In the lower member, foraminifera are found in the shale beds, and mollusks in the sandstone (Weaver and Doerner 1969b). Weaver and Doerner (1969b) provided lists of foraminifera found at four localities (two in each member). Several mollusk taxa have been named from these rocks, including the bivalves *Ostrea miguelsensis* (holotype California Academy of Sciences [CAS] 4121; Hertlein 1928) and *Pecten (Lyropecten) miguelsensis* (holotype University of California Museum of Paleontology

[UCMP] IP12943; Arnold 1906) and the gastropod *Fissurella rixfordi* (holotype CAS 4145; Hertlein 1928).

San Miguel Island Volcanics (Lower Miocene)

All five of the islands that make up CHIS have Lower–Middle Miocene volcanic rocks, formed as part of a spate of igneous activity between 19 and 13 Ma resulting from the tectonic activity that was rotating the Western Transverse Ranges continental block at the same time (Weigand and Savage 1999). Often, these rocks are either classified with the Conejo Volcanics of the mainland (for example Dibblee [1982a]) or assigned to formal or informal geologic formations named after the host island, i.e. the Santa Cruz Island Volcanics. The volcanics also have associated sedimentary rocks, which usually have sparse marine fossils. For the purposes of this report, each island’s Miocene volcanic/sedimentary interval will be considered a separate formation.

The San Miguel Island Volcanics are at least 460 m (1,520 ft) thick, and are composed of volcanic flows, breccia, sandstone, and siltstone. It can be divided into informal lower and upper members (Weaver and Doerner 1969b). The lower member is composed of basalt flows and volcanoclastic (volcanic rock fragments) sedimentary rocks, found in the southeastern part of the island, and the upper member is composed of dacitic intrusions and flows, found in the northern tip (Weigand and Savage 1999). Price Island, off the northeast coast of San Miguel Island, is also composed of rocks from the upper member (Palmer 2004). When the formation was first described, it was also used on Santa Rosa Island (Avila and Weaver 1969; Weaver and Doerner 1969b), where the lower member was thought to be present (Weaver and Doerner 1969b); since then, the Santa Rosa Island volcanics have been separated as their own formation. The upper contact with the Beechers Bay Formation is conformable (Weaver and Doerner 1969b). The flows were deposited subaqueously, probably in a submarine setting (Weaver and Doerner 1969b). They date to between 18.5 and 17.0 Ma (Weigand and Savage 1999). This formation is fossiliferous: Weaver and Doerner (1969b) described foraminifera from a locality in the lower member.

Beechers Bay Formation (Lower–Middle Miocene)

The Beechers Bay Formation was first formally designated as a member of the Monterey Formation, but is typically considered a formation in its own right (Chinn and Weigand 1994; Dibblee and Ehrenspeck 1998; Dibblee et al. 1998; Nuccio and Woolley 1998; Weigand and Savage 1999). The Beechers Bay Formation of San Miguel Island is composed of white tuffaceous sandstone and buff-colored volcanoclastic sandstone (Weaver and Doerner 1969b). It is marine in origin, with continental shelf fossils (Weaver and Doerner 1969b). Deposition occurred on a submarine fan (Weigand and Savage 1999). Fossils may be of Relizian age (17.5 to 15.0 Ma) (Weaver and Doerner 1969b). On San Miguel Island, the Beechers Bay Formation is below the Monterey Formation (Weaver and Doerner 1969b).

The Beechers Bay Formation of San Miguel Island has yielded brachiopods (lamp shells) and bivalves (Weaver and Doerner 1969b). Elsewhere in the islands, the Beechers Bay Formation assemblage also includes foraminifera and barnacles (Bereskin and Edwards 1969).

Monterey Formation (Middle Miocene)

The Monterey Formation was originally named from rock exposures on the California mainland. Like the Vaqueros Formation, the Monterey Formation was first used to describe a characteristic fossil assemblage and was later adapted to serve as a lithostratigraphic unit. It has been used to describe an interval of Lower–Middle Miocene rocks on the three large islands of CHIS, including two members: a shale member, and the coarser Beechers Bay Member, which was named from Santa Rosa Island (Avila and Weaver 1969). The use of the Monterey Formation name on the islands has been challenged (Avila and Weaver 1969; McLean et al. 1976a; Nuccio and Woolley 1998), and, as noted above, the Beechers Bay Member is often removed. The shale member of the Monterey Formation has yet to receive an alternate designation. Although it may be redundant to identify it as the shale member if it is considered the only member, it will be identified as such in this document when that name was used in the original source, to preserve authorial intent and avoid confusion with the Beecher Bay Formation in the event of future changes in nomenclature.

The Monterey Formation of the islands is interpreted as a silica-rich deposit on the continental shelf, under warm seas (Palmer 2004). On San Miguel Island, outcrops of this formation are limited to three areas: upper Willow Creek, Caldwell Point, and near the “San Miguel benchmark.” The shale member is composed of yellow-gray and brown shale, with a basal conglomerate. Foraminifera in the shale member are of Luisian age (15.0 to 13.6 Ma) (Weaver and Doerner 1969b).

The shale member of the Monterey Formation is fossiliferous on San Miguel Island, having yielded foraminifera, diatoms, and bivalves from a continental shelf setting. Foraminifera can be abundant, and the bivalve *Pecten crassicardo* forms local reefs in calcareous beds (Weaver and Doerner 1969b). Weaver and Doerner (1969b) listed taxa from two foraminifera localities. Elsewhere, the shale member has gastropods, fish, and whale bones (Weaver and Meyer 1969), and an unspecified part of the Monterey Formation on Santa Cruz Island has yielded bones of desmostylians, bizarre elephantine marine mammals (Barnes and Aranda-Manteca 1997).

Quaternary rocks and sediments (Pleistocene–Holocene)

San Miguel Island has an excellent late Pleistocene–Holocene fossil record, encompassing everything from the bones of pygmy mammoths (Stock 1935) to fragments of foraminifera and mollusks among sediment grains (Johnson 1969). The strong winds of San Miguel Island can erode and deflate loose sediment to a depth of 20 cm (8 in), concentrating Holocene bones (Rick 2002). Exploration of the island’s Quaternary

fossils increased during the late 1970s, particularly in Daisy Cave and the unconsolidated sediments on the northern end of the island (Guthrie 1998). A paleontological resource survey took place from 1984 to 1985 (Guthrie 1993).

One of the unusual geologic features of the Channel Islands is the caliche deposits, and how they form apparent “fossil forests” where plants were rooted. Although caliche deposits are well-developed on Santa Rosa Island, San Clemente Island, and San Nicolas Island (Johnson 1967), San Miguel Island is particularly noted for these deposits (Palmer 2004) (CHIS Figure 4). The carbonate cement developed around near-surface structures, including tree trunks and roots. It formed both from soil processes and in eolian settings; the latter is where the “fossil forest” examples were formed, although this term is something of a misnomer because most of the plant structures represented are roots and not trunks. In cases of eolian caliche, blowing sand with carbonate minerals periodically overwhelmed existing vegetation; at least five such episodes occurred during the Pleistocene on San Miguel Island. Carbonates were then able to either form around plant structures, leaving hollows, or to fill in casts of roots, stems, and trunks. One log on the island has a diameter of 0.76 m (2.5 ft) and is 9 m (30 ft) long (Johnson 1967). These carbonate fossil structures are also known as rhizoconcretions (Johnson 1977). They are also sometimes found in the island’s “beachrock” (or more accurately “water-table rock”) (Johnson 1969). Gastropods are occasionally discovered associated with the caliche as well (Cockerell 1937). Cockerell (1938b) interpreted the concretions as having formed around roots of lemonadeberry sumac, and Johnson (1977) used them to infer the presence of shrub vegetation during the latest Pleistocene. However, pollen from Daisy Cave (see below) indicates the presence of a pine forest for at least the northeast coast of the island near the end of the Pleistocene, transitioning into a coastal shrub assemblage near the Pleistocene–Holocene boundary (West and Erlandson 1994; Erlandson et al. 1996). Macroscopic plant fossils known from the late Quaternary of San Miguel Island include the tree *Pinus* (pines) and the shrubs *Rhus* (sumacs) and *Ribes* (currants) (Johnson 1977), and nonspecific charcoal and twigs (Rick et al. 2001).



CHIS Figure 4. An example of a calichified “fossil forest” on San Miguel Island. Photo courtesy NPS.

In addition to caliche, the Quaternary deposits of the Channels Islands often include areas of red sediments and carbonized vegetation. Historically, these locations were interpreted as burned areas, and were used as evidence for anthropogenic fires on the island tens of thousands of years ago, such as locations where humans prepared mammoth meat (Orr 1956a, 1956b, 1968). However, the identity of the “fire areas” has been challenged, and these features have been attributed to groundwater instead of fire. This extends to the bird and mammoth bones previously interpreted as burned (Cushing et al. 1986; Cushing 1993).

Pleistocene mollusks are extremely abundant on San Miguel Island: Johnson (1971) estimated that there were millions of specimens of the terrestrial gastropod *Helminthoglypta ayresiana* on the island. Mollusks as old as the early Pleistocene have been found (Valentine and Lipps 1963). Cockerell (1938a) named the gastropod subspecies *Helminthoglypta ayresiana lesteri* from a specimen from the island (Academy of Natural Sciences of Drexel University, formerly Academy of Natural Sciences of Philadelphia [ANSP] 170430). This subspecies has fallen out of use (Johnson 1971). Bivalves and gastropods are both represented (Cockerell 1939, 1940). Holocene bivalves and gastropods have been taken from archeological sites on the island for isotopic studies of climate (Robbins et al. 2006). Other invertebrates from the Quaternary deposits of the island include barnacles (Johnson 1977). Dated materials from the island include caliche root casts, charcoal, bivalves, and barnacles (Johnson 1977). A publication about the invertebrate fauna from the terrace cut during the last interglacial is in preparation (D. Muhs, pers. comm., February 2012).

The Quaternary vertebrate record of San Miguel Island includes sharks, bony fish (Rick et al. 2001), the alligator lizard *Gerrhonotus multicarinatus* (Guthrie 2005), the Pacific rattlesnake *Crotalus viridis* (Guthrie 1998), diverse birds (Guthrie 2005), the ornate shrew *Sorex ornatus*, the extinct vole *Microtus miguelensis*, the extinct giant deer mouse *Peromyscus nesodytes* and mainland relative *P. maniculatus*, the extinct vampire bat *Desmodus stocki*, the dwarf Channel Island fox *Urocyon littoralis* (Guthrie 1998), dogs (Rick et al. 2008), the spotted skunk *Spilogale* (Knowlton et al. 2007), several species of pinnipeds (Walker and Craig 1979), the pygmy mammoth *Mammuthus exilis* (Stock 1935), the Columbian mammoth *M. columbi* (Madden 1977), whales (Bremner 1933), and mainland deer (Vellanoweth et al. 2003). Approximately 95% of vertebrate specimens are from birds, dominated by alcids (puffins and auks) and the extinct flightless sea duck *Chendytes lawi* (Guthrie 1992). Extinct birds are represented by *Chendytes*, the gannet *Morus reyanus*, the puffin *Fratercula dowi*, and the owl *Asio priscus* (Guthrie 2005). Terrestrial animals seem to be divided into two assemblages: a coastal assemblage dominated by alcids, and an inland assemblage dominated by *Chendytes*. Gastropods and *Peromyscus nesodytes* are found in both assemblages (Guthrie 1993).

The island’s fish and sea mammal record is principally associated with human activities. Fish are represented by sharks, clupeids, sculpins, surfperch, greenling, wrasses, flatfish, scorpionfish, and pricklebacks (Rick et al. 2001). Pinnipeds were collected from an archeological site at Point Bennett (SMI-525). This site, dating to at least 1,100 radiocarbon yr BP, included bones of California sea lions (*Zalophus californianus*), Steller sea lions (*Eumetopias jubatus*), harbor seals (*Phoca vitulina*), northern elephant seals (*Mirounga angustirostris*), Guadalupe fur seals (*Arctocephalus townsendi*), northern fur seals (*Callorhinus ursinus*), and sea otters (*Enhydra lutris*) (Walker and Craig 1979). Sea otter bones have been found in other middens as well (Mitchell 1966).

The Quaternary avifauna of San Miguel Island is represented by dozens of species and thousands of bones. The most recent summary reported 61 species in 10 orders: loons, grebes, procellariiforms (albatrosses and petrels), pelecaniforms (large waterbirds), ciconiiforms (storks and vultures), anseriforms (ducks and geese), falconiforms (eagles, hawks, and falcons), charadriiforms (mostly shorebirds and sea birds), owls, and perching birds (Guthrie 2005). Over 17,000 bones as well as eggshells have been recovered from 19 sites, mostly from seabird nest colonies but also owl roost and eagle nest sites. Of these 17,000 bones, more than 16,000 of them are from four species. In order of abundance, they are the extinct puffin *Fratercula dowi*, Cassin’s auklet (*Ptychoramphus aleuticus*), ancient murrelet (*Synthioboramphus antiquus*), and *Chendytes lawi* (Guthrie 2005). Aside from *Chendytes* and *Fratercula dowi*, extinct taxa include the owl *Asio priscus* and three bird subspecies (Guthrie 1992).

The Pleistocene puffin *Fratercula dowi* is represented on the island by eggs and over seven thousand bones. It was common on the island between 40,000 and 25,000 radiocarbon yr BP, and was present as recently as 12,000 radiocarbon yr BP. Several paratypes (specimens of a type series that are not the holotype, or name-bearing specimen) of the species were designated from San Miguel Island specimens held at the Santa Barbara Museum of Natural History (SBMNH) (Guthrie et al. 1999). The flightless sea duck *Chendytes lawi* is one of the characteristic Pleistocene organisms of CHIS. The genus and species were named for a specimen found on the mainland, near Santa Monica (Miller 1925); since then, thousands of bones of this species have been found on CHIS islands, and a second, older species (*C. milleri*) with better flight capabilities has been named from San Nicolas Island (Howard 1955). *Chendytes lawi* is of interest for studies of the extinction of Pleistocene animals because although it was a flightless bird, it persisted alongside humans until about 2,500 years ago (Grayson 2008; Jones et al. 2008).

The terrestrial mammal assemblage of the late Pleistocene and Holocene of San Miguel Island is small, consisting of a handful of rodents, insectivores, and small carnivores, a bat, and mammoths. One of the constituents, the vole *Microtus*

miguelensis, is named from a San Miguel Island specimen (SBMNH 191, a mandible fragment), found at Cuyler Harbor (Guthrie 1998). Interestingly, over the past 20,000 years, three rodent species have been present on the island, all of which are larger than mainland forms (Guthrie 1987), in contrast to the island fox and pygmy mammoth. The pygmy mammoth (*M. exilis*, exiled mammoth) is one of the best-known fossil organisms of CHIS. It was first named *Elephas exilis* from a skull discovered on Santa Rosa Island (Stock and Furlong 1928); more details on its history and general characteristics can be found under the Quaternary heading of the Santa Rosa Island section. The first report of the pygmy mammoth on San Miguel Island is Stock (1935); at that time, the San Miguel Island specimens were the largest known. Other reports include Hooijer (1976), Roth (1996); Agenbroad (1998, 1999b, 2005), Gray and Harz (1998), and Agenbroad et al. (2005). Madden (1977) reported the presence of its probable ancestor, the Columbian mammoth (*M. columbi*), on the island as well. Another familiar Channel Island animal, the island fox, is historically considered to have arrived on the islands during the late Pleistocene (Orr 1968; Collins 1991). However, the oldest definite evidence of the fox only dates to 6,400 calendar yr BP, and it may have been distributed entirely by humans. If it indeed was introduced during the middle Holocene instead of arriving during the Pleistocene, its appearance may correlate with the extinction of *Chendytes lawi* and *Fratercula dowi* (Rick et al. 2009). Dogs were introduced to the island by the middle Holocene at least (Rick et al. 2008), and skunks were probably introduced by humans as well (Wenner and Johnson 1980). Deer bones, found at the 8,000-year old Cave of the Chimneys site, probably represent imported material (Vellanoweth et al. 2003).

The Pleistocene and early Holocene inhabitants of San Miguel Island went extinct over a period of several thousand years. The snake and bat species probably went extinct before the arrival of humans (Guthrie 1998). The pygmy mammoth went extinct around 11,030 years ago. *Microtus miguelsenis* followed at about 11,000 years ago (Knowlton et al. 2007). *Peromyscus nesodytes* went extinct around 8,000 years ago (Knowlton et al. 2007), perhaps replaced by the smaller *P. maniculatus*, which was probably accidentally introduced by humans (Guthrie 1998). As noted, *Chendytes lawi* persisted until about 2,500 years ago (Grayson 2008; Jones et al. 2008). Shrews and spotted

skunks were present on San Miguel Island during the Holocene until sometime in the past thousand years (Knowlton et al. 2007); shrews may have persisted until the recent period of overgrazing by introduced cattle and sheep (D. Guthrie, Claremont McKenna College, pers. comm., February 2012). Specimens of these two taxa may belong to isolated individuals, instead of representatives of island populations (Walker 1980).

Daisy Cave (SMI-261) is one of the best-known sites on San Miguel Island, with both paleontological and archeological resources dating as far back as the latest Pleistocene. Daisy Cave as a paleontological site dates to at least $15,780 \pm 120$ radiocarbon yr BP (19,350–18,680 calendar yr BP). Humans visited briefly around $11,600 \pm 150$ calendar yr BP, producing the oldest documented shell midden in North America, and began a more extensive occupation between 10,000 and 8,500 calendar yr BP. They left for most of the middle Holocene, then returned during the late Holocene. Toward the end of its human use, the Chumash people used it for burials (Erlandson et al. 1996). People engaged in fishing in the area between about 11,500 and 8,300 calendar yr BP, using bone gorges to catch a variety of taxa (Rick and Erlandson 2000; Rick et al. 2001). In terms of paleontological resources, Daisy Cave includes a 13,000-year-long pollen record, charcoal, twigs, body fossils of more than 150 species of invertebrates and vertebrates, and bird guano (Erlandson et al. 1996). Groups represented include bivalves, gastropods (Erlandson et al. 1996), sharks, bony fish (Rick et al. 2001), snakes (Guthrie 1993), birds (including *Chendytes*), shrews, *Peromyscus nesodytes*, vampire bats, skunks, and sea mammals (Erlandson et al. 1996). Non-archaeological materials in the cave are probably from owls (Guthrie 1980, 1998, 2005), with a possible component derived from foxes as well (Guthrie 1980). Santucci et al. (2001) presented an overview and cited selected examples of National Park Service fossils found in caves.

Elsewhere on the island, people were eating shellfish, fish, sea birds, and pinnipeds (Erlandson et al. 2007), which led to the production of shell middens. It should be noted that there is the potential to confuse bald eagle middens with human middens (Erlandson et al. 2007). Humans also fashioned bone and shell artifacts, and occasionally used Pleistocene fossils, one example being a bead made from a Pleistocene gastropod shell (Vellanoweth et al. 2003).

Santa Rosa Island

Like Santa Cruz Island, Santa Rosa Island is divided by a major east-west fault (Avila and Weaver 1969; Weigand and Savage 1999). The division in geology is not as stark as on Santa Cruz Island, although older rocks are only exposed in the south (Weigand and Savage 1999). There has been some recent movement on the fault (Kew 1927).

South Point Formation (Middle–Upper Eocene)

As discussed in the San Miguel Island section, the South Point Formation is a thick sandstone-dominated Eocene unit, deposited on a deep-water submarine fan. This formation occurs in southern Santa Rosa Island, where it attains a thickness of at

least 1,050 m (3,445 ft), as found through drilling. Unlike the situation on San Miguel Island, the upper contact is conformable, and with the Cozy Dell Formation (Weaver and Doerner 1969a). It may correlate to the Jolla Vieja Formation on Santa Cruz Island (Dibblee and Ehrenspeck 1998). The South

Point Formation of Santa Rosa Island has yielded foraminifera (nine localities studied), diatoms, ostracodes, and fish teeth (Weaver and Doerner 1969a).

Cozy Dell Formation (Middle–Upper Eocene)

Unlike many other units discussed here, the Cozy Dell Formation (or Cozy Dell Shale) is a name that has been extended from the mainland. It can be found on southern Santa Rosa Island (Weaver and Doerner 1969a) and southern Santa Cruz Island (Doerner 1969). On Santa Rosa Island, it can be found south of the Santa Rosa Island fault. A thickness of up to 125 m (410 ft) has been observed in outcrop, and up to 195 m (640 ft) in wells. The formation here is similar to outcrops on Santa Cruz Island, except for being somewhat more colorful (black, browns, and rust in addition to grays). The upper contact with the Sespe Formation is disconformable (Weaver and Doerner 1969a).

The Cozy Dell Formation of CHIS was deposited in deep water. Deposition began with the preexisting submarine fan complex on the continental slope (Kies and Abbott 1982), followed by deepening water through deposition (Doerner 1969). Foraminifera suggest lower bathyal to abyssal depths (Doerner 1969). The foraminifera also indicate cooling of the surface waters, to perhaps a warm temperate range (Weaver and Doerner 1969a). On what is now the mainland, the depth was not so great, and the depositional setting has been compared to the modern Mississippi River delta front (Slatt and Thompson 1985). Basin subsidence was rapid (Link and Welton 1982). Foraminifera of the Narizian stage (42.5 to 35.3 Ma) have been found on Santa Cruz Island (Doerner 1969).

The Cozy Dell Formation of Santa Rosa Island has yielded foraminifera (five localities studied), diatoms, and bivalves (Weaver and Doerner 1969a). Elsewhere, coccoliths (Kies and Abbott 1982), a seed resembling that of *Cercidiphyllum* (katsura trees) (Shapiro 1998), wood fragments (Fritsche 1994), gastropods (Shapiro 1998), scaphopods (tusk shells), crabs, asteroids (sea stars), ophiuroids (brittle stars), and trace fossils (Squires 1994) have also been reported from the formation.

Sespe Formation (Oligocene)

The Sespe Formation is well-known from the Santa Monica Mountains and Simi Valley on the California mainland, where it is part of a complex series of intertonguing terrestrial, shallow marine, and deep marine formations (Yerkes and Campbell 1979; Dibblee 1982b; Schwartz and Colburn 1987; Dibblee and Ehrenspeck 1993; Fritsche 1993). In the Channel Islands, the Sespe Formation has only been definitely identified on Santa Rosa Island, although there are suggestions that there are unrecognized outcrops elsewhere in CHIS. Examples of possible occurrences of the Sespe Formation elsewhere in CHIS include the uppermost meter or so (“a few feet”) of the Cozy Dell Formation on Santa Cruz Island, and the basal beds of the Rincon Formation on San Miguel Island; fossil fragments have been found in the questionable beds on San Miguel Island

(Weaver and Doerner 1969a). The Sespe Formation is found in a number of locations in southern and western Santa Rosa Island. It may be as much as 380 m (1,250 ft) thick on the island, although it can be difficult to distinguish from the overlying Vaqueros Formation. It is mostly composed of sandstone, with some siltstone, claystone, and conglomeratic beds. It is noted for its distinctive coloration, including layers of red, maroon, pink, and green (Weaver and Doerner 1969a). The upper contact with the Vaqueros Formation is conformable and in some places gradational (Avila and Weaver 1969).

The Sespe Formation is nonmarine in origin on the mainland, and is thought to be so on Santa Rosa Island as well (Avila and Weaver 1969). In the Santa Monica Mountains National Recreation Area (SAMO; see the SAMO summary in this report for more details), 25 km (16 miles) east-northeast of Anacapa Island, it is interpreted as a fluvial formation (Dibblee 1982b), with depositional settings including braided and meandering rivers, floodplain overbanks, salt marshes, and coastal environments (Bown 1994). Braided rivers are prominent low in the formation, and are replaced by meandering rivers and finally coastal settings (Bown 1994). Well cores from this formation taken beneath the Santa Barbara Channel include delta plain rocks (Miles and Rigsby 1990). Possible marine beds have been found in some locations (Fritsche and Shmitka 1978). Originally, the Sespe Formation was interpreted as representing an arid climate, but the discovery of mammal fossils indicated a more humid setting (Soper 1938). A savannah with a gallery forest is now thought to have been present, under a seasonal climate (Bown 1994).

Deposition occurred during a long period of time, with at least one substantial hiatus between approximately 36 and 29.5 Ma (Prothero et al. 1996). Two cycles of regional uplift and subsidence may have occurred during deposition (Bown 1994). Land mammals in the formation indicate an age range including at least the Uintan (45.4 to 40 Ma) to the Arikarean (30.5 to 19 Ma) North American land mammal ages for the main portion of the formation (Bown 1994), and a younger tongue of the formation is dated to the Hemingfordian (19 to 15.5 Ma) (Whistler and Lander 2003). The formation is thought to be Zemorrian in age (34.0 to 23.0 Ma) on Santa Rosa Island (Weaver and Doerner 1969a).

The Sespe Formation is reportedly fossiliferous on Santa Rosa Island. Unspecified megafossils of “Vaquerosian” age have been found in upper beds “near Cluster Point and in a canyon just west of Grouse Triangulation Station No. 2” (Weaver and Doerner 1969a).

The Sespe Formation has yielded a number of terrestrial fossils on the California mainland. Briefly, plants are represented by petrified wood and leaf impressions (Loel and Corey 1932). Invertebrates are represented by mollusks (Kelly et al. 1991) and trace fossils (Fritsche and Shmitka 1978). The non-mammalian vertebrate assemblage includes sharks, rays

(Whistler and Lander 2003), frogs (Kelly et al. 1991), tortoises (Brattstrom 1961), soft-shelled turtles (Golz and Lillegraven 1977), several types of lizards (Brattstrom 1955; Golz and Lillegraven 1977), snakes (Brattstrom 1955), crocodilians, and birds (Golz and Lillegraven 1977). More than 100 fossil mammal species from 35 families have been recognized in the Sespe Formation (Bown 1994). The following lists are not intended to be exhaustive for references, but to illustrate the breadth of mammal taxa. Sespe Formation mammals that are not carnivorans, perissodactyls (odd-toed ungulates), or artiodactyls (even-toed ungulates) include didelphid marsupials (opossums), several groups of insectivores, the extinct insectivore-like apatemyids and pantolestids, primates and their nearest relatives, several groups of rodents, rabbits and pikas, and extinct early carnivorous mammals (hyaenodont creodonts and miacids) (Golz 1976; Golz and Lillegraven 1977; Kelly 1990; Bown 1994; Whistler and Lander 2003). Carnivorans are represented by bears (Wang et al. 2009), amphicyonids (beardogs), true dogs (including the extinct “bone crusher” borophagines), mustelids (weasels and allies), indeterminate cats (Whistler and Lander 2003), and nimravids (false saber-toothed cats) (Lander 1983). Perissodactyls include early tapir relatives (helatids and isctolophids), rhinoceroses (semiaquatic amynodonts, swift hyracodonts, and true rhinocerotids), brontotheres, and horses (Golz 1976; Golz and Lillegraven 1977; Bown 1994). Finally, artiodactyls are represented by hippo-like anthracotheres (Bown 1994), peccaries, pig-like entelodonts (Whistler and Lander 2003), a variety of small extinct deer-like ungulates (Golz 1976; Golz and Lillegraven 1977; Lander 1983, 2011), moschids (musk deer) (Whistler and Lander 2003), oreodonts and related agriochoerids (sheep-like artiodactyls), and camels (Bown 1994).

Vaqueros Formation (Lower Miocene)

The Vaqueros Formation was originally described on the California mainland and has a complex history as a term. It was originally defined and used as a biostratigraphic term based on marine invertebrate fossils (Miles and Rigsby 1990). Defining formations by fossils is no longer accepted, and the Vaqueros Formation is now limited to a difficult-to-define section of strata in coastal southern California (Dibblee and Ehrenspeck 1993; Fritsche 1993). Thus, older references sometimes apply the term “Vaqueros Formation” to rocks that are no longer included in the formation, and there is still biostratigraphic use of the description “Vaquerosian” for the old “Vaqueros Formation” fossil assemblage. The Vaqueros Formation is regarded as present on Santa Rosa and Santa Cruz islands of CHIS (Avila and Weaver 1969; Bereskin and Edwards 1969); as noted above in the San Miguel Island section, it also may be present on that island.

The Vaqueros Formation of Santa Rosa Island is found mostly south of the Santa Rosa Island Fault, with one exposure north of it. It is up to 150 m (500 ft) thick in outcrop, and perhaps up to 300 m (1,000 ft) thick in total, according to well data (Avila and Weaver 1969). Avila and Weaver (1969) divided the formation

into a lower member of coarse sandstone and conglomerate, a middle member of brown shale and siltstone, and an upper member of sandstone and siltstone; Woolley (1998a) agreed with the lower and upper members, but found the middle member to be very limited in distribution and regarded it as part of the upper member. The upper contact with the Rincon Formation is conformable. Together, the Vaqueros and Rincon formations of the island are essentially different facies of one subtropical to tropical inner shelf setting, with the water becoming deeper and cooler over time (Avila and Weaver 1969). The invertebrates found in this unit on the island indicate an Early Miocene age (Dibblee and Ehrenspeck 1998).

Fossils are common in this formation on Santa Rosa Island, particularly in intervals of calcareous sandstone and mudstones (Avila and Weaver 1969). Fossils are locally abundant enough to form “reefs” (Kew 1927; Loel and Corey 1932; Avila and Weaver 1969). The island’s Vaqueros Formation assemblage includes foraminifera (Patet 1972), corals (Avila and Weaver 1969), bivalves, gastropods (Hertlein 1928; Loel and Corey 1932; Avila and Weaver 1969), barnacles (Loel and Corey 1932), echinoids (Grant and Hertlein 1938), invertebrate burrows (Dibblee and Ehrenspeck 1998), and worm tubes (Loel and Corey 1932). There are also reworked Eocene-age coccoliths (McLean et al. 1976a). Several species of mollusks have been named from this unit on the island. These include: the bivalves *Ostrea loeli* (holotype CAS 4117), *O. wiedeyi* (holotype CAS 4129), and *Placunanomia granti* (holotype CAS 4140); and the gastropods *Alectrion churchi* (holotype CAS 4149), *Calliostoma augustiniensis* (holotype CAS 4146), and *Turritella tritschi* (CAS 4150) (Hertlein 1928). Additionally, the bivalve variant *Pecten miguelensis submiguelensis* (holotype UCMP IP31737) was named from UCMP locality A311 (Loel and Corey 1932). Grant and Hertlein (1938) named the echinoid species *Brissus kewi* (UCLA 6326; UCLA collection are now at the LACM) and *Lytechinus coreyi* (UCLA 6805) for specimens from this unit on the island. Avila and Weaver (1969) listed megafossils from six localities.

Over its entire depositional area, the Vaqueros Formation marine single-celled and invertebrate assemblage includes foraminifera (Blake 1983), radiolarians (another type of “shelled” protist), diatoms (Cushman and LeRoy 1938), corals (Loel and Corey 1932), bryozoans (Loel and Corey 1932; Squires and Fritsche 1978), brachiopods (Loel and Corey 1932), bivalves, gastropods, scaphopods, barnacles, crabs (Loel and Corey 1932; Squires and Fritsche 1978), ostracodes (Cushman and LeRoy 1938), echinoids (Loel and Corey 1932; Squires and Fritsche 1978), and invertebrate trace fossils such as worm tubes (Loel and Corey 1932), burrows, and general bioturbation (Daniel-Lyle 1995). Marine vertebrates are represented by teeth of sharks and rays (Loel and Corey 1932; Squires and Fritsche 1978; Daniel-Lyle 1995), pinnipeds (Loel and Corey 1932), the marine mammal *Desmostylus* (Squires and Fritsche 1978), dolphins (Barnes et al. 2003), whales (Dooley et al. 2004), and indeterminate bones (Squires and Fritsche 1978; Daniel-Lyle

1995). Terrestrial environments are represented by petrified and carbonized wood (Loel and Corey 1932), logs, palm fronds (Lander 2011), root traces, turtles, rhinoceroses, horses, entelodonts, camels, and indeterminate artiodactyls (Daniel-Lyle 1995).

Rincon Formation (Lower Miocene)

The Rincon Formation is present on Santa Rosa Island (Bereskin and Edwards 1969) and Santa Cruz Island (Avila and Weaver 1969), and as noted may be present on San Miguel Island (Dibblee 1982a). This formation was often known as or included in the Temblor Formation in older publications on California geology (Patet 1972). On the California mainland, it is sometimes interpreted as the deep-water equivalent of the shallower-water Vaqueros Formation (Fritsche 1993). On Santa Cruz Island, the depositional setting is interpreted as middle to outer continental shelf, becoming shallower to the east or northeast (Bereskin and Edwards 1969). It represents a rapid deepening of depositional setting, due to subsidence (Isaacs 1983). Oxygen may have been limited (Finger 1983).

On Santa Rosa Island, it is found both north and south of the Santa Rosa Island Fault. It has a complex gradational relationship with the underlying Vaqueros Formation and the Santa Rosa Island Volcanics, which in some places grade laterally into the Rincon Formation, and in others overlie or are vertically sandwiched by the Rincon Formation. The Rincon Formation on the island consists of shale, mudstone, claystone, and siltstone, with some fine-grained sandstone in the upper part. Thickness differs from place to place, from less than 270 m (900 ft) to over 566 m (1,860 ft) (Avila and Weaver 1969). Avila and Weaver (1969) divided it into informal lower, middle, and upper members. Foraminifera indicate deposition spanned the late Zemorrian to early Relizian stages on the island (the boundary is 23.0 Ma) (Avila and Weaver 1969); the base is older and the upper part is younger than the strata on Santa Cruz Island (Avila and Weaver 1969). The associated volcanics on Santa Rosa Island date to 19.3 to 18.1 Ma (Weigand and Savage 1999).

The Rincon Formation is extensively fossiliferous on Santa Rosa Island. The fossil assemblage on the island includes carbonaceous debris, foraminifera, corals, bivalves, gastropods, echinoids, fish scales, and bone fragments. Mollusks can be abundant enough to form “reefs” (Avila and Weaver 1969). Hertlein (1928) named two species of bivalves from the “Temblor Formation” of Santa Rosa Island: *Ostrea englekyi* (holotype CAS 1416) and *Pteria rositae* (holotype CAS 4142). Avila and Weaver (1969) listed taxa from 27 megafossil localities and 24 foraminifera localities. Reworked Eocene-age coccoliths have also been found (McLean et al. 1976a).

Overall, the fossil assemblage of the Rincon Formation includes carbonaceous debris (Avila and Weaver 1969), acritarchs (a “wastebasket” classification for organic microfossils that cannot otherwise be classified) (Frederiksen 1995), coccoliths (Stanley

et al. 1994), foraminifera, dinoflagellate algae (Finger 1983), tasmantid algae, spores from pteridophytes (including clubmosses, spikemosses, and ferns), gymnosperm and angiosperm pollen (Frederiksen 1995), corals (Avila and Weaver 1969), brachiopods (Squires and Fritsche 1978), bivalves, gastropods (Avila and Weaver 1969), scolecodonts (worm jaws) (Frederiksen 1995), ostracodes (Finger 1983), echinoids (Avila and Weaver 1969), sharks (Squires and Fritsche 1978), fish scales, bone fragments (Avila and Weaver 1969), isolated cetacean bones (Squires and Fritsche 1978), and fecal pellets (Frederiksen 1995). Loel and Corey (1932) include a number of fossils in their Temblor Formation, but they are not necessarily all from the Rincon Formation.

Santa Rosa Island Volcanics (Lower Miocene)

The Santa Rosa Island Volcanics are composed of dark basalts, lighter-colored dacites, and sedimentary rocks. They can be divided into three members: a lower clastic member, a middle intrusive member, and an upper basaltic flow member. The clastic member is up to 273 m (895 ft) thick and includes brown sandstones, siltstones, and shales. This member is associated with conglomerate and breccia of the San Onofre Breccia (Avila and Weaver 1969). Originally, it was thought that all of the igneous rocks were intrusive. Later, the interval was included in the San Miguel Island Volcanics before eventually getting its own name. The igneous rocks date from 19.3 to 18.1 Ma (Weigand and Savage 1999).

The clastic member is fossiliferous, having yielded foraminifera and the bivalve *Spondylus perrini* (Avila and Weaver 1969). Avila and Weaver (1969) provided taxa lists for 13 foraminifera localities. The foraminifera indicate a slope setting under warm temperate waters; the sedimentary rocks may represent turbidites (Avila and Weaver 1969). Howell and McLean (1976) reported foraminifera and invertebrate burrows from a volcanoclastic unit they assigned to the Blanca Formation (see the Santa Cruz Island section); alternatively, this may represent some part of the Santa Rosa Island Volcanics or the Monterey Formation.

Monterey Formation (Lower–Middle Miocene)

The Monterey Formation of Santa Rosa Island, as represented by the shale member (see the San Miguel Island section for the Monterey Formation), has complex relationships with the Beechers Bay Formation and the Santa Rosa Island Volcanics. The two laterally interfinger (Nuccio and Woolley 1998), and either can be stratigraphically higher (Avila and Weaver 1969); for convenience, the Beecher Bay Formation is here depicted as higher, following Dibblee and Ehrenspeck (1998). The portion of the Monterey Formation lower than the Beechers Bay Formation may begin beneath the volcanics (Dibblee 1982a; Dibblee and Ehrenspeck 1998), although this may depend on definition; Dibblee and Ehrenspeck (1998), for example, included some shale mapped with the Rincon Formation by Sonneman et al. (1969) in the Monterey Formation, which makes the volcanics interrupt the Monterey Formation. The

shale member of Santa Rosa Island was originally assigned to the Modelo Formation (Kew 1927; Avila and Weaver 1969). It is a light-colored silica-rich shale, with outer shelf and upper slope foraminifera (Avila and Weaver 1969).

On Santa Rosa Island, the shale member has yielded foraminifera, diatoms, and bivalves (Avila and Weaver 1969). Avila and Weaver (1969) listed taxa from 12 foraminifera localities and two bivalve localities in the shale member. Howell and McLean (1977) reported middle Miocene-age diatomites on the island, which would probably best fit the shale member of the Monterey Formation.

Beechers Bay Formation (Lower–Middle Miocene)

The Beechers Bay Formation of Santa Rosa Island was first identified as the Santa Margarita Formation (Avila and Weaver 1969; Dibblee 1982a). It is heterogeneous, with three major facies: tuffaceous rocks, sandstone and shale, and conglomerate. The tuffaceous rocks are found low in the member, and the conglomeratic facies is found toward the top (Avila and Weaver 1969). The member can be divided into five informal subdivisions on the island, from A at the base to E at the top. The basal part is identified with the San Onofre Breccia (Weigand and Savage 1999). The subdivisions represent different settings on a deep-sea fan near an active volcanic source (Nuccio and Woolley 1998). The San Onofre Breccia and Beechers Bay Formation are thought to be lateral equivalents on Santa Rosa Island (Fisher and Charlton 1976), and the Beechers Bay Formation of Santa Rosa Island is the equivalent of the Blanca Formation on Santa Cruz Island (Dibblee 1982a). The San Onofre Breccia may be a facies of the Beechers Bay Formation (Weigand and Savage 1999); alternatively, the Beechers Bay Formation and the San Onofre Breccia of the island may actually be facies of the Blanca Formation (Kamerling and Luyendyk 1985). On Santa Rosa Island, the Beechers Bay Formation includes Relizian to middle Luisian foraminifera (approximately 17.5 to 14.0 Ma) (Weigand and Savage 1999).

The Beecher Bay Formation of Santa Rosa Island has yielded foraminifera from the C division (Weigand and Savage 1999), and the bivalve *Spondylus perrini* (Avila and Weaver 1969). Fossils are rare in the unit, and are limited to the middle portion; reworked bivalve fragments are also present (Avila and Weaver 1969).

Quaternary rocks and sediments (Pleistocene–Holocene)

The Quaternary sediments of Santa Rosa Island include a variety of fossiliferous marine and terrestrial sediments. Some of the sedimentary sequences, such as the island's dunes, include fossils as part of their basic lithological makeup. Many of the dune sediments include carbonate minerals derived from sand-sized fragments of older fossil invertebrates (Schumann et al. 2010). Santa Rosa Island, like San Miguel and Santa Cruz islands, has “fire areas” in its Quaternary deposits (Cushing et al. 1986); in the case of Santa Rosa Island, the “fire areas” were

often interpreted as the results of human fires (Cushing et al. 1986). Santa Rosa Island also has examples of the caliche (Johnson 1967) described in the San Miguel Island section.

Santa Rosa Island has a number of marine terraces (Orr and Broecker 1957; Orr 1960). Orr (1960) identified seven subaerial and five submarine terraces, with a vertical range of 400 m (1,300 ft). He named the Santa Rosa Formation for the sediments on the lowest subaerial terrace and the three wave-cut platforms below, and designated three members within the formation. From his original description, the oldest is the Garañon (or Garanon) Member, associated with the 8 m (25 ft) Garañon platform. A sea-level rise followed, cutting the 23 m (75 ft) Fox platform and depositing the sediments of the Fox Member. Finally, the Tecolote Member was deposited over both platforms and associated sediments during a lowstand, from some time before 30,000 radiocarbon yr BP to at least 10,400 ± 2,000 radiocarbon yr BP (17,260–7,430 calendar yr BP) (Orr 1960). More recent work indicates that the chronology is in need of revision; for example, the Garañon Member appears to be younger than the Fox Member, not older (D. Muhs, pers. comm., February 2012), and a date of 200,000 years for the Garañon Member (Roth 1996) is unlikely (D. Muhs, pers. comm., February 2012). Orr's names have not achieved wide usage, but are occasionally seen in publications.

The Garañon and Fox members both include lower marine facies and upper terrestrial facies. The marine facies of the Garañon Member has yielded chitons (sea cradles), bivalves, gastropods, echinoids, and bones of shore birds, sea lions, sea otters, pygmy mammoths, and whales. The terrestrial facies of the Garañon Member has bones of *Peromyscus* and pygmy mammoths, and weathered fragments of reworked Miocene-age bivalves (*Ostrea*) and gastropods (*Turritella*). The marine facies of the Fox Member has yielded chitons, bivalves, gastropods, barnacles, and echinoids, while the terrestrial facies of the member has yielded root casts, tree casts, gastropods, and pygmy mammoths. Higher and older Pleistocene marine sediments, at the 76 m (250 ft) level, also have yielded bivalves and gastropods (Orr 1960).

Most of the published Quaternary fossils from Santa Rosa Island represent animals. Other types of organisms are represented by diatoms, charcoal, plant spores and pollen (Anderson et al. 2010), seeds (Erlandson et al. 1999), root and tree casts (Orr 1960), reed casts (Orr 1962), the cypress *Cupressus goveniana* (Orr 1956b; Johnson 1977), fungal spores (Anderson et al. 2010), and fungal fragments (Scott et al. 2010). Many of the microfossils have been found at the Abalone Rocks Marsh and Soledad Pond pollen sites (Anderson et al. 2010). The palynomorphs (organic microfossils such as pollen and spores) show that the island had a coastal conifer forest at the end of the Pleistocene, replaced at approximately 11,800 calendar yr BP by grassland and scrub as the climate warmed (Anderson et al. 2010).

Santa Rosa Island has many Quaternary invertebrate fossils, from both marine and terrestrial settings. The assemblages include chitons, bivalves, gastropods, barnacles (Orr 1960), crabs (Erlandson et al. 2011), echinoids (Orr 1960), and trace fossils, such as rocks bored by mollusks (Kew 1927), worm tubes (Erlandson et al. 1999), and possible arthropod fecal material (Scott et al. 2010).

The Quaternary fossil vertebrate assemblage of Santa Rosa Island is best known from fluvial sediments on the northwestern side of the island (Guthrie 1998). It includes sheephead and clupeiform fish (Erlandson et al. 1999), the salamander *Batrachoseps* (Mead et al. 2004), alligator lizards (Erlandson et al. 1999), Pacific rattlesnakes, the extinct owl *Asio priscus* (Howard 1964b), the extinct caracara *Caracara prelutosa* (Howard 1962), the extinct gannet *Morus reyanus*, *Chendytes lawi* (Guthrie 1998), Canada geese, teals (Howard 1944), other extant waterfowl and raptor taxa (Guthrie 1998), the Island Scrub Jay (K. Faulkner, CHIS Chief of Natural Resources Management, pers. comm., January 2012), an unspecified small bird (Mead et al. 2004), ornate shrews (Guthrie 1998), the vole *Microtus* (Mead et al. 2004), the giant deer mouse *Peromyscus nesodytes* (Wilson 1936), island foxes (Orr 1968; Rick et al. 2009), dogs (Rick et al. 2008), seals, sea lions (Orr 1968), the sea otter *Enhydra lutris* (Mitchell 1966), the mammoths *M. columbi* and *M. exilis* (Guthrie 1998), and whales (Stock and Furlong 1928; Stock 1935; Orr 1968). Most of them lived between 37,000 and 12,000 years BP (Guthrie 1998). Among the island's sites is a long-term owl roost from the mouth of Arlington Canyon, used between $28,240 \pm 940$ radiocarbon yr BP ($34,620\text{--}31,160$ calendar yr BP) and $10,240 \pm 180$ radiocarbon yr BP ($12,450\text{--}11,330$ calendar yr BP), which has yielded bones of snakes, shrews, and mice from barn owl pellets (Guthrie 1998).

Peromyscus nesodytes was named from Santa Rosa Island, from a specimen originally in the California Institute of Technology (CIT) vertebrate paleontology collection (CIT specimen 1780, locality 106) (Wilson 1936); this specimen is now in the collections of the Natural History Museum of Los Angeles County (LACM). Thousands of bones of this rodent are known from the island, with thousands alone associated with the Arlington Canyon site that yielded the remains of Arlington Springs Man (see below) (CHIS Figure 5) (Orr 1962). The mice were initially interpreted as having been trapped in a bog at this site (Orr 1968), but represent the remains of owl pellets instead (CHIS Figure 6) (J. Johnson, Santa Barbara Museum of Natural History Curator of Anthropology, pers. comm., March 2012). Other vertebrates from Arlington Canyon include the extinct owl (Howard 1964b) and caracara (Howard 1962), both described from the Tecolote Member, and a single bone of the Island Scrub Jay, representing both the only fossil occurrence of this bird and the only report outside of Santa Cruz Island (K. Faulkner, pers. comm., January 2012). Approximately 120 bird bones, mostly from geese and ducks, had been recovered by 1968 from the Tecolote and Garañon members (Orr 1968). Orr

(1968) reported an island fox skull in the late Pleistocene-age upper Tecolote Member, but it was later found that the "Pleistocene" remains actually dated to the late Holocene (Shelley 2001; Rick et al. 2009). Most of the island fox remains on the island were found during excavation of cemetery sites (Collins 1991). A microvertebrate site found at Carrington Point yielded a handful of fish, salamander, bird, and vole bones, dating to around $12,480 \pm 140$ yr BP ($15,130\text{--}14,070$ calendar yr BP) (Mead et al. 2004). A single whale vertebra was found near the base of the Quaternary sediment (Stock and Furlong 1928; Stock 1935), and a scattered partial whale skeleton was uncovered from the marine sediments of the Garañon Member over a period of years beginning in 1946 (Orr 1968). Sea lion, seal, and sea otter bones are also associated with the Garañon Member (Orr 1968).



CHIS Figure 5. *Peromyscus nesodytes* bones from Arlington Canyon (photo courtesy John Johnson, Santa Barbara Museum of Natural History).



CHIS Figure 6. Part of an owl pellet (left) with visible bones, from Arlington Canyon (photo courtesy John Johnson, Santa Barbara Museum of Natural History).

Humans were present on Santa Rosa Island by the end of the Pleistocene, and significantly altered the types and distribution

of paleontological resources. The oldest human record is represented by the remains known as Arlington Springs Man (briefly Woman). Arlington Springs Man was found in Arlington Canyon in 1959. This individual is known from two femurs (Orr 1962). Bone collagen provides a date of $10,960 \pm 80$ radiocarbon yr BP ($13,080\text{--}12,660$ calendar yr BP) (Agenbroad et al. 2005), but the collagen is degraded, and the person is probably slightly older, being bracketed by charcoal dates of $11,580 \pm 45$ radiocarbon yr BP ($13,585\text{--}13,291$ calendar yr BP) and $11,250 \pm 40$ radiocarbon yr BP ($13,294\text{--}13,070$ calendar yr BP) (Dandridge 2006). Originally, the bones were identified as masculine in origin (Orr 1962). They were reevaluated as feminine (Agenbroad et al. 2005; Dandridge 2006), but it now appears that they were masculine after all (Chawkins 2006). People were fishing on the island by 9,300 years ago (Erlandson et al. 1999; Rick and Erlandson 2000). A midden and possible campsite found near the mouth of Arlington Canyon shows the inhabitants were overwhelmingly consuming mollusks, followed distantly by fish (Erlandson et al. 1999). Archeological evidence indicates that humans consumed chitons, bivalves, gastropods, and crabs, captured geese, albatross, cormorants, other birds, and sea mammals, and caught fish (Erlandson et al. 2011).

Santa Rosa Island mammoths

The pygmy mammoth (*M. exilis*) is the most famous example of paleontological resources from CHIS, and Santa Rosa Island has long been known as the most prolific source of pygmy mammoth fossils (Stock 1935). Mammoth remains are most abundant on Santa Rosa Island, followed by San Miguel Island, then Santa Cruz Island, and finally a single tooth on San Nicolas Island (Roth 1996). The San Nicolas Island occurrence may represent a specimen moved by people (Vedder and Norris 1963; Johnson 1978), and could come from a mainland mammoth instead of a pygmy island mammoth (Vedder and Norris 1963). Overall, more than 200 localities within CHIS have yielded fossils of pygmy or Columbian mammoths (Agenbroad et al. 2004).

Pygmy mammoth paleobiology and the history of study on Santa Rosa Island have been detailed in several reports published over the past twenty years (Roth 1996; Agenbroad and Morris 1999; Agenbroad 1999a, 2001, 2009, 2012; Agenbroad et al. 2005). The first report of mammoth bones on Santa Rosa Island was made by R. E. C. Stearns in 1873. The specimen in question was a tooth found by W. G. Blunt *in situ* near a degraded tusk (Stearns 1873). Stearns did not relate more of the context, but the specimen was discovered in 1856 during a geodetic survey of the island (Roth 1996; Agenbroad 1999a, 2001). Specimens were reported sporadically for the next few decades. During the late 1920s, D. Irma Cooke, part of a botanical expedition to Santa Rosa Island based out of the SBMNH, found a tusk. David Banks Rogers, a SBMNH archeologist, then notified Chester Stock of the CIT. Stock and Furlong collected additional fossils from northwestern Santa Rosa Island during 1927 and 1928. In 1928, they elected to

formally name and describe the material. Stock and Furlong (1928) selected a skull and mandible with tusks from the island to serve as the type specimen of their new species *Elephas exilis* (CIT 14). The CIT specimens are now at the LACM; unfortunately, Stock's field notes have been destroyed (Roth 1996). The LACM made some collections on the islands, ending by World War II (Agenbroad 2001).

Phil Orr of the SBMNH began annual expeditions to Santa Rosa Island in 1946, collecting mammoth fossils and archeological specimens (Orr 1956b). Orr was interested in the possible connection of the extinction of the pygmy mammoth and the appearance of humans. He proposed that the "fire areas" of the islands represented areas burned by people, and identified locations he interpreted as roasting hearths of butchered mammoths (Orr 1956a, 1956b, 1968), putting the appearance of humans on the island perhaps 40,000 years ago (Orr 1968). More recent study has proposed that many of his "fire areas" were actually the result of groundwater (Cushing et al. 1986; Reeder et al. 2008). However, recent finds and new dates have also shown that the last mammoths of the island went extinct at essentially the same time that people first arrived, raising the possibility of some interaction, as Orr proposed (Agenbroad 2001; Agenbroad et al. 2005).

Orr's work on the island ended during the 1960s. His efforts resulted in the collection of numerous specimens for the SBMNH (Roth 1996). The next two and a half decades saw island access restricted by the landowners, Vail and Vickers Company (Agenbroad and Morris 1999), resulting in temporary cessation of paleontological work with the exception of Boris Woolley's collecting. Woolley, a member of the Santa Rosa Island ranching family, made an avocational collection of mammoth fossils during the 1970s; this collection was donated to the SBMNH in 1995 (Agenbroad 1999a; Agenbroad and Morris 1999). Also during this lull, Louise Roth produced a dissertation using pygmy mammoth museum specimens (Roth 1982), and published on their growth (Roth 1984).

Interest in the pygmy mammoths, and paleontology in CHIS in general, was sparked again by the discovery of a nearly complete skeleton of *M. exilis* in June 1994 on Santa Rosa Island (CHIS Figure 7). This skeleton was found on Carrington Point by San Diego State University professor Tom Rockwell and graduate student Kevin Colson while investigating the geology of the island (Agenbroad and Morris 1999). When excavated, it proved to be an articulated and approximately 90% complete skeleton of an adult male individual (Agenbroad 1999a), perhaps 50 years old at the time of death, and dating to $12,840 \pm 410$ radiocarbon yr BP ($16,730\text{--}14,020$ calendar yr BP) (Agenbroad et al. 2005). This discovery led to the institution of a pedestrian GPS survey of San Miguel, Santa Cruz, and Santa Rosa islands to locate more specimens. Between the initiation of the survey in January 1996 and 2002, the survey found more than new 140 localities, and showed that

Santa Rosa Island pygmy mammoths were not concentrated in a small area of the northwestern coast (Agenbroad 1999a).



CHIS Figure 7. Bill Faulkner at the excavation of the 1994 pygmy mammoth specimen (photo courtesy CHIS).

Although other elephants have been called dwarf forms, *M. exilis* appears to be the only true dwarf mammoth (Agenbroad 2001). The average mass of *M. exilis* was a little over 750 kg (1,750 lb), with a typical range of 500 to 950 kg (1,100 to 2,100 lb). The average shoulder height was 1.72 m (5.6 ft), with a typical range of 1.37 to 1.93 m (4.49 to 6.33 ft) (Agenbroad 2009); the largest published estimate is 2.35 m (7.71 ft) (Roth 1984). Orr (1956a, 1956b) thought that there may have been two species of pygmy mammoths on the islands, one a little less than 2 m (6 ft) tall at the shoulder, and one a little more than 1 m (4 ft) tall at the shoulder (Orr 1956b). More recent work by Agenbroad (2009) has shown there to be only one species of pygmy mammoth.

M. columbi is probably the ancestor of *M. exilis* (Madden 1977; Johnson 1978; Agenbroad 2012). Madden (1981) proposed distinguishing the island variety of the Columbian mammoth as

M. columbi orri. Originally, it was thought that the Imperial mammoth (*M. imperator*) was the ancestral species, but this species is taxonomically problematic (Agenbroad 2009). Roth (1984) found no particular trends in mammoth size over time, and suggested that the nearness to the mainland allowed multiple immigrations of larger mainland mammoths. The small size does not appear to be due to retention of juvenile features (paedomorphism) (Roth 1984), but could involve a combination of stunting and genetic reduction of size (Roth 1984, 1996).

The timing of mammoth introduction to the islands is not known. *M. exilis* fossils have been found with basal sediments of the Santa Rosa Island Formation (Agenbroad 2009). The most recent dated pygmy mammoth remains on the island are from $11,030 \pm 50$ radiocarbon yr BP (13,093–12,715 calendar yr BP) (Agenbroad et al. 2005). *M. columbi* was also present but rare during this time span (Agenbroad 2009). This larger species appears to be confined to the island's marine terraces, which may be due to biomechanical differences between the two species (Agenbroad 2012). Pygmy mammoths had lower centers of gravity than Columbian mammoths (Agenbroad 2012), their hip joints were located farther down and back (Thaler 1999), and their limbs were more flexed (Roth 1996). These differences would have allowed *M. exilis* to traverse steeper grades (Agenbroad 2001; Agenbroad 2012) and provided better agility and stopping abilities (Roth 1996).

Unlike the other mammals found on the islands, mammoths would have had to arrive under their own power, being unlikely candidates for rafting or transportation by humans (Wenner and Johnson 1980). While previously it was assumed that the ancestral population must have arrived via a land connection, such a connection is very unlikely based on geography, and elephants are underrated swimmers that would have been capable of swimming the 6 km (4 mile) distance between the mainland and Santarosae during the Pleistocene sea level lowstands (Johnson 1978, 1980; Roth 1996). Mammoths may have had a significant impact on the island ecosystems (Roth 1996).

Santa Cruz Island

Santa Cruz Island is bisected by the east-west Santa Cruz Island Fault, and there are distinct stratigraphic sequences on either side of the fault. On the north, the geology is limited to Quaternary rocks, the Monterey Formation, and the Santa Cruz Island volcanics. The south side of the island has a much longer record, including all of the island's outcrops of pre-Miocene rocks, the Rincon Formation, the San Onofre Breccia, and the Blanca Formation (Dibblee 1982a; Weigand and Savage 1999). The fault has a history of large infrequent earthquakes, with the last documented earthquake around 5,000 years (Pinter et al. 1998).

Upper Cretaceous rocks

Cretaceous rocks are not exposed at the surface on Santa Cruz Island, but Late Cretaceous-age foraminifera have been found in well cores taken from the island (Doerner 1969; Weaver 1969c).

Pozo Formation (Upper Paleocene–Lower Eocene)

The Pozo Formation is only found in upper Well Canyon in southwestern Santa Cruz Island, west of the Christi Fault

(Doerner 1969), although the unit known informally as the undifferentiated Pozo–Cañada Formation on San Miguel Island is thought to correlate to part of it (Weaver and Doerner 1969a). The Pozo Formation may be up to 140 m (450 ft) thick (Dibblee 1982a), but only 70 m (225 ft) are exposed (Doerner 1969). It is a buff-colored unit mostly composed of arkosic sandstone and siltstone, with some shale. The upper contact with the Cañada Formation is disconformable, and includes some

shallow paleochannels less than a meter or yard in depth. The hiatus was probably not very long (Doerner 1969). Before it was named, the rocks now included in the Pozo Formation had been included in the Martinez Formation (Bremner 1932; Doerner 1969), one of several biostratigraphically-defined units that had wide usage in California for the first few decades of the 20th century.

The Pozo Formation was deposited during the Late Paleocene to Early Eocene. It has been dated to the Bulitian (56.7 to 54.7 Ma) and possibly latest Ynezian (60.3 to 56.7 Ma) stages (Doerner 1969). Fossils from this formation indicate a relatively shallow marine setting, perhaps on the inner continental shelf, under tropical to semitropical waters; depth increased near the end of deposition, putting the area in an outer shelf to inner slope location (Doerner 1969). Kies and Abbott (1982) interpreted the formation as storm-ebb deposits.

The Pozo Formation is fossiliferous on Santa Cruz Island, having yielded coccoliths (Kies and Abbott 1982), foraminifera, bivalves, gastropods (Doerner 1969), and worm tubes (Shapiro 1998). Fossils are locally abundant enough to form reefs (Bremner 1932; Doerner 1969). There is a bed less than a meter (1 to 2 ft) thick near the base of the exposed section with abundant mollusks, particularly the gastropod *Turritella*, which is found in such numbers that the bed is sometimes called a *Turritella* reef. The bivalve *Ostrea* is also sometime found in thin, reef-like accumulations. Mollusks can be found throughout the unit as well, and are often the nuclei of concretions in the sandstone beds (Doerner 1969). Near the top of the formation is a faunal interval with a distinct mollusk assemblage and common worm tubes. This interval continues upward into the basal Cañada Formation (Shapiro 1998). Sparse, poorly preserved foraminifera have been found in the formation's siltstone and shale; Doerner (1969) listed examples from six locations. Squires and Saul (2002) reported and figured a specimen of the gastropod *Corsania* (*Janucia*) *janus* from this formation on the island.

Cañada Formation (Upper Paleocene–Middle Eocene)

The Cañada Formation was named for a 430 m (1,400 ft)-thick unit of gray to blue-gray shale, siltstone, and less abundant thin beds of limestone and sandy limestone. The formation is found in southwestern Santa Cruz Island; related rocks on San Miguel Island are part of the Pozo-Cañada Formation (Weaver and Doerner [1969a], although see Dibblee and Ehrenspeck [2001] for a different interpretation). The formation is most coarse near the base. The lowest meter or yard includes basal conglomerates filling channels cut into the Pozo Formation, and the next 15 m (50 ft) is a sandstone-siltstone interval. The upper contact with the Jolla Vieja Formation is conformable (Doerner 1969). The Cañada Formation and following Eocene formations were formerly included in the Domengine Formation (Bremner 1932), another biostratigraphic formation.

The Cañada Formation is another marine unit, and its fossils show continuation of the deepening trend begun near the end of the underlying Pozo Formation. Deposition began in an outer shelf or upper slope setting, progressively deepening to possibly a lower slope setting by the close of the formation (Doerner 1969). The formation's foraminifera illustrate eight short-lived shallowing events (Molesworth and Sloan 1998). The foraminifera range in age from the Bulitian to the early Narizian stages (between 56.7 and about 42 Ma) (Doerner 1969). Submarine fan deposition also occurred during the marine transgression (Kies and Abbott 1982), and gravelly layers left by storm surges can be found in the basal part of the formation (Abbott et al. 1983).

The Cañada Formation is fossiliferous on Santa Cruz Island. It has yielded coccoliths (Doerner 1969), foraminifera (Doerner 1969; Molesworth and Stone 1998), wood casts, corals, bivalves, nautiloids, gastropods, echinoids, worm tubes, and ray teeth (Shapiro 1998). Doerner (1969) listed taxa from eight coccolith and 25 foraminifera localities, and Molesworth and Sloan (1998) provided additional data on the formation's foraminifera. Macrofossils are diverse, but not abundant (Shapiro 1998). Hertlein (1933) named the bivalve species *Ostrea haleyi* (holotype CAS 5526) from the Domengine Formation on the island; the site is now thought to pertain to the Cañada Formation, and the species is regarded as a synonym of *Acutostrea idriaensis idriaensis* (Moore 1987).

Jolla Vieja Formation (Middle–Upper Eocene)

The Jolla Vieja Formation is found only in southwestern Santa Cruz Island. This formation has great variation in thickness and lithology. In Alegria Canyon, it is 26 m (85 ft) thick and mostly sandstone, with a few meters or feet at the base of conglomerate, but a fault-truncated section exposed north of Cañada De Los Sauces is 270 m (880 ft) thick and almost entirely composed of conglomerate. Siltstone and shale beds are also present, but sandstone and conglomerate are the dominant lithologies (Doerner 1969).

The Jolla Vieja Formation is interpreted as representing inner and middle submarine fan deposition (Kies and Abbott 1982). Geochemistry of the rocks shows that at least some of the sediments are essentially identical to those in contemporaneous rocks of the San Diego area, demonstrating the movement of the western Transverse Ranges crustal block (Weigand et al. 1999, 2000). Although foraminifera have not been found in the Jolla Vieja Formation, both the underlying Cañada and overlying Cozy Dell formations have foraminifera from the Narizian stage (42.5 to 35.3 Ma), indicating a Narizian age for the Jolla Vieja Formation as well (Doerner 1969).

The Jolla Vieja Formation is sparsely fossiliferous. Shapiro (1998) reported on a few gastropods recovered from the head of Alegria Canyon, and Doerner (1969) reported that some localities found by Rand (1933) to have foraminifera and mollusks may be from this formation.

Cozy Dell Formation (Middle–Upper Eocene)

As discussed in the Santa Rosa Island section, the Cozy Dell Formation is a shale-dominated deep marine formation. On Santa Cruz Island, it is up to 279 m (915 ft) thick and composed of greenish gray to bluish gray shale and silty shale, with some arkosic sandstones and limestone nodules. Near the top of the unit is less than a meter (1 to 2 ft) of red shale similar to the Sespe Formation (see the Santa Rosa Island section). The upper contact with the Vaqueros Formation is disconformable (Doerner 1969).

The Cozy Dell Formation has abundant foraminifera on Santa Cruz Island; Doerner (1969) provided lists of taxa from eight localities. *Coccoliths* (Kies and Abbott 1982), a seed resembling that of *Cercidiphyllum*, bivalves, and gastropods (Shapiro 1998) are also known from the island; macrofossils are rare (Shapiro 1998).

Vaqueros Formation (Oligocene–Lower Miocene)

As discussed in the Santa Rosa Island section, the Vaqueros Formation is a heavily fossiliferous shallow marine formation. The Vaqueros Formation of Santa Cruz Island was included in the Temblor Formation (Temblor Formation conglomeratic member of Bremner [1932]), and later was briefly and informally called the “Kinton Point Formation” (Bereskin 1966). It is found in southwestern Santa Cruz Island, where it can be divided into two informal members. The lower member is 169 m (555 ft) thick and conglomeratic. It is mostly made up of fragments of igneous rocks. The upper member is a brown volcanic arenite (made up of sand-sized fragments, but not necessarily a sandstone) with occasional beds of gray siltstone. It is 73 m (240 ft) thick. The upper contact with the Rincon Formation is conformable to gradational. Although the Vaqueros Formation as a whole is usually regarded as marine, the conglomeratic member on Santa Cruz Island may be partially nonmarine, particularly at the base. The upper 15 m (50 ft) of this member and the volcanic arenite member above have marine fossils. The fossils of the conglomeratic member suggest an inner shelf depositional setting, under subtropical waters; the volcanic arenite member’s fossils indicate inner to middle shelf deposition in the early stages, becoming only inner shelf higher up. The waters also warmed, supporting a tropical assemblage. The age of the formation differs across its depositional area; on Santa Cruz Island, foraminifera are dated to the Zemorrian and early Saucian stages (34.0 Ma to after 23.0 Ma). There may be a local depositional hiatus within the formation, based on fossil content (Bereskin and Edwards 1969). In general, the deposition of the Vaqueros Formation ended when subsidence increased, moving the area out of the previous shallow-water setting (Miles and Rigsby 1990).

The Vaqueros Formation of Santa Cruz Island is fossiliferous (Loel and Corey 1932; Bereskin and Edwards 1969). The conglomeratic member has an invertebrate assemblage of bryozoans (moss animals), bivalves, gastropods, scaphopods, barnacles, and echinoids, and vertebrate fossils including shark

and ray teeth, and undescribed vertebrae. It also has reworked fossiliferous Eocene-age rock fragments (Bereskin and Edwards 1969). Howell et al. (1976) noted gastropod specimens possibly reworked from the Pozo Formation. The volcanic arenite member has yielded brachiopods, bivalves, gastropods, barnacles (Bereskin and Edwards 1969), invertebrate trace fossils including *Thalassinoides* (Shapiro 1998), and a possible whale bone (Bereskin and Edwards 1969). Mollusks are found in calcareous concretions in this member (Bereskin and Edwards 1969). Bereskin and Edwards (1969) described one foraminifera locality from the formation.

Rincon Formation (Lower Miocene)

As discussed in the Santa Rosa Island section, the Rincon Formation is a Miocene shaly unit deposited on the continental shelf. What is now known as the Rincon Formation on Santa Cruz Island was included as part of the Temblor Formation (Temblor basal siltstone member of Rand [1931, 1933]; middle shale member of Bremner [1932]) (Bereskin and Edwards 1969). This unit is found in the southwestern part of the island, where it is up to 76 m (250 ft) thick and composed of soft gray or brown calcareous shale and mudstone, with dolomitic interbeds. The upper contact with the San Onofre Breccia is gradational (Bereskin and Edwards 1969). The foraminifera found on Santa Cruz Island indicate a Saucian age (23.0 to 17.5 Ma) (Bereskin and Edwards 1969).

The Rincon Formation is fossiliferous on Santa Cruz Island. This formation has yielded abundant foraminifera on Santa Cruz Island; Bereskin and Edwards (1969) listed taxa from 11 localities. Ctenoid fish scales (a type of scale found on many ray-finned fish) have also been documented from the basal part of the formation (Shapiro 1998). Bremner (1932) listed bivalve and gastropod taxa from four localities in a basal sandstone layer, but this seems more like the underlying Vaqueros Formation than the Rincon Formation.

San Onofre Breccia (Lower–Middle Miocene)

The San Onofre Breccia is a distinctive blue conglomeratic unit, first mapped on the California mainland. On Santa Cruz Island, it was originally included in the Temblor Formation (Bereskin and Edwards 1969; Weaver et al. 1969). It is found south of the Santa Cruz Island Fault (Dibblee 1982a), and is sometimes reported north of the fault as well (Crowe et al. 1976). This formation reaches a maximum thickness of 475 m (1,560 ft) in the southwestern corner of the island (Weaver et al. 1969). Conglomerate and breccia are the dominant lithologies, but sandstone, siltstone, and mudstone beds are also present (Bereskin and Edwards 1969; Weaver et al. 1969). The upper contact with the Blanca Formation in the west and the Beechers Bay Formation in the east is conformable and essentially arbitrary (Bereskin and Edwards 1969; Weaver et al. 1969).

The formation’s mollusks indicate shallow marine to brackish conditions, with an inner to middle continental shelf setting (Bereskin and Edwards 1969), perhaps as part of a shallow

broad marine fanglomerate in a high energy system (Weaver et al. 1969). It was probably deposited very near the shore, and may be partially nonmarine (Bereskin and Edwards 1969). Differences between the outcrops on the northeastern and southwestern sections of the island suggest that deposition was shallower in the northeast and more offshore in the southwest (Boles 1998). The source of the distinctive sediment was a rock unit called the Catalina Schist, found to the north and northwest (Schwartz and Colburn 1987). Foraminifera in the San Onofre Breccia indicate a late Saucian to Relizian age (between approximately 17.5 and 15.0 Ma) (Bereskin and Edwards 1969).

The San Onofre Breccia is fossiliferous on the island, and has yielded foraminifera, bivalves, and barnacles (Bereskin and Edwards 1969; Shapiro 1998). Bereskin and Edwards (1969) listed foraminifera from four localities. Bivalves are occasionally found in growth position in the sandstone beds (Boles 1998). The formation has also yielded reworked Paleocene-age bivalves and gastropods (Stewart 1976). Elsewhere, outside of CHIS, the San Onofre Breccia has also preserved bones of pinnipeds and cetaceans (Woodford 1925).

Santa Cruz Island Volcanics (Lower–Middle Miocene)

The Santa Cruz Island Volcanics are present north of the Santa Cruz Island Fault (Crowe et al. 1976). They may be as much as 2,400 m (8,000 ft) thick (Weaver and Meyer 1969), and include sedimentary beds and numerous igneous intrusions with the volcanic flows (Nolf and Nolf 1969). Four informal members have been designated. From oldest to youngest, they are the Griffith Canyon Member, the Stanton Ranch Member, the Devil's Peak Member, and the Prisoners Harbor Member (Nolf and Nolf 1969; Weigand and Savage 1999). Together, they date from 17.12 to 16.1 Ma. Eruption began subaerially, and became subaqueous by the end (Weigand and Savage 1999). This is reflected in the sedimentary rocks, which include fluvial beds and beds with marine fossils (Nolf and Nolf 1969). The eruption center is thought to have been near Devil's Peak (Crowe et al. 1976; Weigand and Savage 1999). The composition of the volcanics is that of an island arc (Crowe et al. 1976).

The Griffith Canyon Member may be as much as 1,100 m (3,700 ft) thick, but less than a third of this thickness can be observed in outcrop. It consists of basaltic flows and volcanic breccia. The overlying Stanton Ranch Member is 140 to 400 m (450 to 1,300 ft) thick and composed of red andesitic flows and tuff breccias. Its contact with the overlying Devil's Peak Member is disconformable in some places. The Devil's Peak Member is up to 730 m (2,400 ft) thick and composed of a variety of andesitic flows, breccias, and pyroclastics (Nolf and Nolf 1969). The contact with the overlying Prisoners Harbor Member is disconformable (Crowe et al. 1976). Finally, the Prisoners Harbor Member is up to 180 m (600 ft) thick and composed of andesitic and dacitic flows, flow breccias, and tuff beds (Nolf and Nolf 1969).

Fossils are known from the Prisoners Harbor Member and an unspecified member. Foraminifera have been found at a site southwest of Prisoners Harbor in the Prisoners Harbor Member (Nolf and Nolf 1969). These specimens were found in a mudstone bed (McLean et al. 1976b). Weaver and Meyer (1969) reported that cetacean bones had been found in an unspecified member near the top of the formation.

Beechers Bay Formation (Lower–Middle Miocene)

On Santa Cruz Island, the Beecher Bay Formation is exposed in a small area at Near Point, south of the Santa Cruz Island Fault. It is at least 180 m (580 ft) thick and is mostly composed of siltstone and sandstone, with some conglomerate (Bereskin and Edwards 1969). The Beecher Bay Formation of the island appears to have been deposited as turbidites in middle shelf to middle slope settings. Its foraminifera indicate a Relizian to Luisian age (17.5 to 13.6 Ma), possibly as young as Mohnian (13.6 to between 8.7 and 7.4 Ma) (Bereskin and Edwards 1969).

The Beecher Bay Formation of Santa Cruz Island has yielded foraminifera, bivalves, and barnacles. The bivalves and barnacles appear to have been transported from shallower-water settings (Bereskin and Edwards 1969). Bereskin and Edwards (1969) listed taxa from five foraminifera localities. Howell and McLean (1976) reported bathyal foraminifera from a volcanoclastic unit at Near Point. Because the foraminifera are bathyal, the unit in question is probably the Beecher Bay Formation.

Monterey Formation (Lower–Middle Miocene)

As discussed in the San Miguel Island section, the Monterey Formation of CHIS is a marine unit that includes a shale member and formerly included the Beecher Bay Formation. On Santa Cruz Island, the shale member is found north of the Santa Cruz Island Fault (Bereskin and Edwards 1969). The shale member ranges considerably in thickness, from approximately 490 m (1,600 ft) thick in the saddle between Cañada del Puerto and El Montañon, to a discontinuous thin veneer. It is a light-colored, rhythmically-bedded unit, with a propensity to be involved in landslides. It is sometimes bituminous (Weaver and Meyer 1969). The foraminifera of the member mostly date to the Luisian; in some places they may be as old as the Relizian. The foraminiferal assemblage indicates outer shelf deposition in the lower part of the member, and slope deposition later (Weaver and Meyer 1969).

The shale member has an assemblage including foraminifera, diatoms, bivalves, gastropods, fish, and whale bones. Foraminifera are most common in the lower part of the member. The most abundant megafossils are the bivalve *Pecten peckhami*, and fish scales and bones (Weaver and Meyer 1969). Weaver and Meyer (1969) listed taxa from six foraminifera localities. Hornafius and Lagle (1984) noted the presence of diatoms at China Harbor. Finally, a partial skull and vertebrae found in an unspecified part of the Monterey Formation on the

island represent a new genus and species of desmostylian mammal (Barnes and Aranda-Manteca 1997).

Blanca Formation (Middle Miocene)

The Blanca Formation is a volcanoclastic unit found south of the Santa Cruz Island Fault (Fisher and Charlton 1976). It has occasionally been extended to San Miguel Island (McLean et al. 1976a; Dibblee 1982a) and Santa Rosa Island (Howell and McLean 1976; McLean et al. 1976a; Dibblee 1982a; McLean and Howell 1984; Savage et al. 1991); Santa Rosa Island in particular may have rocks from the same volcanic complex and submarine fan as the Blanca Formation of Santa Cruz Island (Savage et al. 1991).

The Blanca Formation can be divided into lower, middle, and upper members. The lower member is composed of conglomerate and sandstone, and is similar to the underlying San Onofre Breccia. The middle member is generally the thickest, and consists of tuff, tuff breccia, volcanoclastic conglomerate, and sandstone. The upper member is composed of tuff breccia and sandstone, conglomerate, and breccia (Weaver et al. 1969; Fisher and Charlton 1976). The upper member also includes an andesitic flow (Weaver et al. 1969). The lower and middle members have a conformable contact, while the middle and upper members have a mostly conformable contact (Fisher and Charlton 1976). The most complete section is 436 m (1,432 ft) thick (Weaver et al. 1969). The formation is noted for being resistant to erosion (Weaver et al. 1969). Most of CHIS's sea caves are in the Blanca Formation (Santucci et al. 2001).

The relationship with the Santa Cruz Island Volcanics is unclear, although it is known that the two formations did not have the same source (Fisher and Charlton 1976; McLean et al. 1976b; *contra* Weaver and Meyer 1969). The Beechers Bay Formation is thought to be a lateral equivalent of the Blanca Formation (Bereskin and Edwards 1969; Fisher and Charlton 1976), perhaps an offshore facies (Weaver and Meyer 1969). The Blanca and Monterey formations may interfinger in places (McLean et al. 1976a).

The Blanca Formation was deposited in a nearshore marine setting near an active volcanic source (Weigand and Savage 1999), which may have been located between Santa Cruz and Santa Rosa islands (McLean et al. 1976a). Part of the formation may have been deposited in an nonmarine alluvial fan (McLean and Howell 1984). Sediment burial was rapid (Fisher and Charlton 1976). Volcanic rock fragments in the formation date from 14.9 to 13.3 Ma (Weigand and Savage 1999), and the volcanic flow in the upper member dates to 14.5 ± 0.8 Ma (McLean et al. 1976a).

The Blanca Formation is fossiliferous on Santa Cruz Island (Fisher and Charlton 1976; Howell and McLean 1976), having yielded bivalves and barnacles (Fisher and Charlton 1976). The lower part of the lower member has fragmentary fossils (Fisher and Charlton 1976).

Potato Harbor Formation (Pleistocene)

The Potato Harbor Formation is a sandy limestone formation up to 26 m (85 ft) thick. It is an eolian formation, deposited in very shallow marine and beach settings (Weaver and Meyer 1969). It includes basal fossiliferous marine terrace sediments overlain by deposits from multiple eolian episodes (D. Muhs, pers. comm., February 2012). This formation is found only on Santa Cruz Island, although there are similar (albeit possibly younger) rocks on San Miguel Island (Weaver and Meyer 1969). The Potato Harbor rocks were previously known under other names, such as the Santa Barbara Formation (Weaver and Meyer 1969) and the San Pedro Formation (Bremner 1932). Weaver and Meyer (1969) reported its age as Pleistocene or late Pliocene, but given the expansion of the Pleistocene, it probably is entirely Pleistocene. It may correlate to the 180 m (600 ft) terrace seen elsewhere (Weaver and Meyer 1969). The Potato Harbor Formation is fossiliferous, having yielded foraminifera, root casts, bryozoans, bivalves, gastropods, barnacles, and echinoids. It also has rocks that may have been derived from algal activity, and many of its constituent grains are actually sand-sized fragments of algae, foraminifera, bryozoans, mollusks, and echinoids. Most of these fossils come from the base of the unit; terrestrial gastropods and the root casts were found elsewhere in the formation (Weaver and Meyer 1969). Weaver and Meyer (1969) reported six megafossil localities in this formation.

Middle Anchorage Alluvium (Pleistocene)

The Middle Anchorage Alluvium is a red and brown sandy conglomerate found covering the Potato Harbor Formation for an area of about 65 ha (160 acres). It is interpreted as representing beach to more firmly terrestrial deposition, and may correlate to the 76 m (250 ft) terrace seen elsewhere. Its fossils are limited to borings of the bivalve *Pholad* on some of its clasts (Weaver and Meyer 1969).

Other Quaternary rocks and sediments (Pleistocene–Holocene)

The relatively young Quaternary sediments of Santa Cruz Island have occasionally been called the Santa Cruz Island Formation (Chaney and Mason 1930; Fergusson and Libby 1963). Santa Cruz Island also has examples of the “fire areas” discussed in the San Miguel Island section (Cushing et al. 1986).

While San Miguel Island is noted for its diverse Quaternary avifauna and Santa Rosa Island is known for pygmy mammoth fossils, Santa Cruz Island's best known Quaternary fossils are plant fossils. First described by Chaney and Mason (1930), the Pleistocene floral assemblage of the island includes nine taxa: the trees *Cupressus goveniana* (cypress), *Myrica californica* (California bayberry), *Pinus remorata* (bishop island pine, sometimes synonymized with *P. muricata*), and *Pseudotsuga menziesii* (Douglas fir); the shrubs *Arctostaphylos* sp. (manzanita), *Ceanothus thyrsiflorus* (blueblossom), *Cornus californica* (dogwood), and *Garrya elliptica* (coast silk-tassel), and the herb *Arceuthobium campylopodum* (western dwarf mistletoe) (Chaney and Mason 1930; Johnson 1977). These taxa

are represented by material from seeds and cones to wood and logs (Chaney and Mason 1930; Cockerell 1938b). Four types of seeds from unknown plants have also been found (Chaney and Mason 1930). The plant fossils were found low in a deposit of clay, yellow and gray sand, and gravel up to 9 to 11 m (30 to 35 ft) thick in the valley of Willow Creek. Chaney and Mason (1930) named these deposits the Santa Cruz Island Formation. Douglas fir from the assemblage has been dated to $14,200 \pm 250$ radiocarbon yr BP (17,900–16,830 calendar yr BP) (Fergusson and Libby 1963) and $11,760 \pm 100$ radiocarbon yr BP (13,820–13,390 calendar yr BP), and charcoal has been dated to 33,400 $\pm$ 420 radiocarbon yr BP (39,010–36,860 calendar yr BP) (Pinter et al. 1998). The paleofloral assemblage suggests a woodland of trees and shrubs (Mead et al. 2004), comparable to the modern-day vegetation around Fort Bragg, 685 km (425 miles) to the north-northwest (Chaney and Mason 1930). The presence of Douglas fir is of interest, because Santa Cruz Island is 100 km (60 miles) south of their present range. Isotopes from island specimens indicate that these trees were acquiring moisture from fog. They died out after approximately 15,000 calendar yr BP, possibly from a combination of increased summer heat and insufficient precipitation (Anderson et al. 2008). Other publications that discuss the Pleistocene flora of Santa Cruz

Island include Stock (1935), Axelrod (1983), and Santucci et al. (2001).

The only Pleistocene vertebrate reported from Santa Cruz Island is the pygmy mammoth. It was first reported from the island by Chaney and Mason (1930). The first find consisted of two tooth plates, and Stock (1935) suggested that the fossils had been brought to Santa Cruz Island by the early human inhabitants. This idea has since been challenged (Cushing et al. 1984). By 1984, seven mammoth specimens had been found on the island. These finds consisted of six teeth and a partial femur (Cushing et al. 1984). Interestingly, the Santa Cruz Island specimens are not obviously dwarfed (Roth 1996). Other publications that mention Santa Cruz Island mammoth remains include Johnson (1978), Agenbroad (1998, 1999b) and Agenbroad et al. (2005). Holocene vertebrates include island foxes, which are sometimes found in burial contexts on the island (Collins 1991), and dogs (Rick et al. 2008).

Finally, invertebrates are known from the unnamed Quaternary sediments. Published reports include a middle Holocene shell, and a coral (*Balanophyllia elegans*) from the 125 ka terrace (Pinter et al. 1998).

Anacapa Island

Anacapa Island, with a bedrock consisting largely of Lower–Middle Miocene volcanics, is actually three islets in an east-west line (Norris 1995).

Anacapa Island volcanics and associated sedimentary rocks (Lower–Middle Miocene)

Lower–Middle Miocene volcanics make up most of the bedrock of Anacapa Island (Norris 1995). As noted, these rocks are sometimes identified as the Conejo Volcanics (Scholl 1959, 1960; Dibblee 1982a; Norris 1995). The volcanics are andesitic in composition, similar to the Santa Cruz Island volcanics (Weigand and Savage 1999), and are 520 m (1,700 ft) thick (Scholl 1960). The San Onofre Breccia is interbedded with the volcanics (Lipps 1964; Norris 1995; Weigand and Savage 1999), with two 9 to 12 m (30 to 40 ft) intervals of San Onofre Breccia separated by 30 to 43 m (100 to 140 ft) of volcanics (Scholl 1960). The Anacapa Island volcanics are submarine in origin, at least in part (Norris 1995), although the associated breccias and sandstones seem to be mostly alluvial (Scholl 1959). The volcanics date to between 16.28 and 15.8 Ma (Weigand and Savage 1999). There is one report of potential fossils from these volcanic and sedimentary rocks: Scholl (1959) reported that poorly preserved marine gastropods were present beneath the andesitic flows, although this may refer to the San Onofre Breccia and not to the unnamed, less-distinctive sedimentary rocks associated with the volcanics.

Quaternary sediments (Pleistocene–Holocene)

The Quaternary deposits of Anacapa Island include less than a meter (2 to 3 ft) of marine sand possibly from the early Pleistocene, and 8 to 9 m (25 to 30 ft) of alluvial sand deposited

during the late Pleistocene (Scholl 1960). The island has at least two marine terraces, at approximately 10 m (30 ft) and 80 m (260 ft) (Muhs et al. 2010). The lower terrace dates to the last interglacial period, possibly including fossils from approximately 100 and 120 ka (Muhs et al. 2010), and the higher terrace dates to around 1.7 to 1.6 Ma (D. Muhs, pers. comm., February 2012). These terraces and those in the immediate offshore area illustrate both changes in sea level and the influence of tectonics (Norris 1995).

There are several reports of fossils from the Pleistocene rocks of Anacapa Island, which can be grouped into three main categories: old Pleistocene marine fossils, Pleistocene marine fossils on the central Anacapa island collected by UCLA, and invertebrate and vertebrate fossils from the late Pleistocene of West Anacapa Island collected by the LACM. The early Pleistocene marine sands have yielded foraminifera and mollusks (Scholl 1960). The central Anacapa island fossils came from the upper terrace, at 76 m (250 ft). The assemblage includes approximately 120 species of chitons, bivalves, gastropods, scaphopods, barnacles, and echinoids, and rare fish and bird bones (Valentine and Lipps 1963). Finally, the LACM collected fossils from several sites on the lower, 9 m (28 ft) surf-cut terrace on West Anacapa Island (Lipps 1964), in the Frenchy's Cove area (Guthrie 1998). These sites include the invertebrate localities 330 and 331, and the vertebrate localities 1642, 1703, 1757, and 1764. Lipps (1964) correlated the

sediments to Orr's Garañon and Tecolote members of the Santa Rosa Island Formation. Marine fossils from lower deposits (Garañon correlative) include 12 species of chitons, bivalves, and gastropods. The coastal sediments above (Tecolote correlative) include fossils of terrestrial gastropods, barnacles, a beetle (possibly a modern contaminant), sheephead fish, 10 species of birds dominated by the flightless duck *Chendytes lawi* (also present are alcids, auklets, murrelets, condors, gulls, petrels, cormorants, and shearwaters), the deer mouse *Peromyscus*, and an indeterminate vertebrate. Shell and echinoid fragments have also been found on the island (Lipps 1964). The

deer mouse species *Peromyscus anyapahensis* was named from a specimen found at LACM locality 1764 (holotype [name-bearing specimen] LACM 9205) (White 1966); this species went extinct during the late Pleistocene (Knowlton et al. 2007). Miller et al. (1961) and Howard (1964a) also described fossils from the LACM sites. The vertebrate sites are thought to date to around 37,000 years ago (Lipps 1964). The NPS constructed a building where the fossils had been discovered; the building was removed by 1985, but no additional fossils were found (Guthrie 1998).

Santa Barbara Island

Santa Barbara Island volcanics and interbedded sedimentary rocks (Lower–Middle Miocene)

Santa Barbara Island's bedrock is mostly composed of volcanics, with some intercalated marine shale (Vedder and Howell 1976; Weigand and Savage 1999). From oldest to youngest, the sequence goes from a lower section of andesitic to basaltic flows, a middle section of volcanic flows, siltstone, claystone, and shale, and an upper section of volcanic breccia. The lower section is seen in the western half of the island, and the upper section is seen in the northeast. Although there are a great deal of volcanic rocks, the actual vent was somewhere else (Vedder and Howell 1976). The volcanics range in age from 16.8 to 14.8 Ma (Weigand and Savage 1999). This unit is fossiliferous: foraminifera have been found in the claystone and shale of the middle interval. They indicate deposition at upper bathyal depths (Vedder and Howell 1976).

Quaternary rocks and sediments (Pleistocene–Holocene)

The Quaternary of Santa Barbara Island includes at least four marine terraces (Muhs et al. 2010), to as many as six (Lipps et al. 1968), up to about 80 m (260 ft) above sea level. Fossils in the lowest terrace indicate formation during the last interglacial, with warm-water forms possibly from the approximately 120 ka marine highstand and cool-water forms from the 100 ka highstand (Muhs et al. 2010). Lipps et al. (1968) described fossils from the 9 to 10 m (25 to 30 ft) and 40 m (130 ft) terraces. The terraces are thought to pertain to two different marine highstands, and come from an open coastal setting under 3 to 6 m (10 to 20 ft) of water. The fossil assemblage of the lower terrace include foraminifera, stony corals, bivalves, gastropods, ostracodes, and a single bone each of a bald eagle and a sea lion. The fossil assemblage of the upper terrace is limited to foraminifera, bivalves, gastropods, and ostracodes. Like the Pleistocene fossils of Anacapa Island, these fossils were collected by the LACM (Lipps et al. 1968). Other documents to mention these fossils include Valentine and Lipps (1966), Delaca and Lipps (1972), and Santucci et al. (2001).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within CHIS. However, they are known to preserve fossils elsewhere, and future field investigations within the park may recover fossils from one or more of them.

Santa Rosa Island

Possible Upper Cretaceous rocks

Kew (1927) reported the presence of possible Cretaceous rocks on Santa Rosa Island, which he tentatively correlated with the Chico Formation. The section in question had coarse- to medium-grained sandstones in the lower part, and gray or maroon gypsum-rich shale with calcareous sandy beds in the upper part (Kew 1927). From the description, the rocks seem similar to the South Point and Cozy Dell formations. In any case, Kew (1927) reported that the rocks were not fossiliferous.

San Onofre Breccia (Lower–Middle Miocene)

The San Onofre Breccia is locally present on Santa Rosa Island (Avila and Weaver 1969; Dibblee et al. 1998). It is associated with the clastic member of the Santa Rosa Island Volcanics (Avila and Weaver 1969) and is sometimes included with the Beechers Bay Formation as its lowest subdivision (Nuccio 1977; Nuccio and Woolley 1998). A volcanic clast from the breccia has been dated to approximately 15.8 Ma (Chinn and

Weigand 1994). Although fossiliferous elsewhere, fossils have

not yet been reported from this unit on the island.

Park Collections

Most fossil specimens from CHIS are at either the SBMNH, which includes the Orr (Agenbroad 2012) and Woolley mammoth bone collections (Agenbroad and Morris 1999) and has been the repository for CHIS since 1994 (Agenbroad 2012), or at the LACM (Mitchell 1966). Marine fossils from all five CHIS islands can be found at the LACM (D. Muhs, pers. comm., February 2012), which also includes the collections formerly held by UCLA, such as the type specimens of *Brissus kawi* and *Lytechinus coreyi* (Grant and Hertlein 1938) and the material described in Valentine and Lipps (1963), and Cal Tech (CIT) (Roth 1996), such as the type specimens of *Mammuthus exilis* (Stock and Furlong 1928) and *Peromyscus nesodytes* (Wilson 1936).

A few other institutions also have CHIS fossils. Over 1,000 Pleistocene invertebrate fossils from Anacapa Island are at the San Diego Natural History Museum (Koch and Santucci 2003). The type specimen of the gastropod subspecies *Helminthoglypta ayresiana lesteri* is in the Academy of Natural Sciences of

Drexel University in Philadelphia, Pennsylvania (Cockerell 1938a). The type specimens of the bivalves *Ostrea englekyi*, *O. haleyi*, *O. loeli*, *O. miguelensis*, *O. wiedeyi*, *Placunanomia granti*, and *Pteria rositae*, and the gastropods *Alectrion churchi*, *Calliostoma augustiniensis*, *Fissurella rixfordi*, and *Turritella tritschi* are in the collections of the California Academy of Sciences in San Francisco (Hertlein 1928, 1933), as well as specimens figured by Bremner (1932) from Santa Cruz Island. The type specimen of the bivalve *Pecten (Lyropecten) miguelensis* is in the collection of the University of California Museum of Paleontology in Berkeley, California (Arnold 1906). Finally, a pygmy mammoth femur from Santa Cruz Island is in the collections of the University of California at Santa Barbara's Department of Geological Sciences (Cushing et al. 1984), as well as many of the fossils described in Shapiro (1998), which were collected from the Christi Anticline area of Santa Cruz Island in 1996 and 1997. A table of type specimens from CHIS is included below (CHIS Table 6).

Taxon	Publication	Catalog Number	Provenance	Notes
<i>Alectrion churchi</i>	Hertlein 1928	CAS 4149	Vaqueros Formation, Santa Rosa Island	gastropod
<i>Brissus kawi</i>	Grant and Hertlein 1938	UCLA 6326 (now LACMIP 9133)	Vaqueros Formation, Santa Rosa Island	echinoid
<i>Calliostoma augustiniensis</i>	Hertlein 1928	CAS 4146	Vaqueros Formation, Santa Rosa Island	gastropod
<i>Elephas exilis</i>	Stock and Furlong 1928	CIT 14 (now at LACM)	Pleistocene, Santa Rosa Island	mammoth, now <i>Mammuthus exilis</i>
<i>Fissurella rixfordi</i>	Hertlein 1928	CAS 4145	Vaqueros/Rincon Formation, San Miguel Island	gastropod
<i>Helminthoglypta ayresiana lesteri</i>	Cockerell 1938	ANSP 170430	Pleistocene, San Miguel Island	gastropod, subspecies generally not used
<i>Lytechinus coreyi</i>	Grant and Hertlein 1938	UCLA 6805 (now LACMIP 9120)	Vaqueros Formation, Santa Rosa Island	echinoid
<i>Ostrea englekyi</i>	Hertlein 1928	CAS 1416	Rincon Formation, Santa Rosa Island	bivalve
<i>Ostrea haleyi</i>	Hertlein 1928	CAS 5526	Cañada Formation, Santa Cruz Island	bivalve, now assigned to <i>Acutostrea idriaensis idriaensis</i> (Moore 1987)

Taxon	Publication	Catalog Number	Provenance	Notes
<i>Ostrea loeli</i>	Hertlein 1928	CAS 4117	Vaqueros Formation, Santa Rosa Island	bivalve
<i>Ostrea miguelsenis</i>	Hertlein 1928	CAS 4121	Vaqueros/Rincon Formation, San Miguel Island	bivalve
<i>Ostrea wiedeyi</i>	Hertlein 1928	CAS 4129	Vaqueros Formation, Santa Rosa Island	bivalve
<i>Pecten (Lyropecten) miguelsenis</i>	Arnold 1906	UCMP IP12943	Vaqueros/Rincon Formation, San Miguel Island	bivalve
<i>Pecten miguelsenis</i> var. <i>submiguelsenis</i>	Loel and Corey 1932	UCMP IP31737	Vaqueros Formation, Santa Rosa Island	bivalve
<i>Peromyscus anyapahensis</i>	White 1966	LACM 9205	Pleistocene, Anacapa Island	mouse
<i>Peromyscus nesodytes</i>	Wilson 1936	CIT 1780 (now at LACM)	Pleistocene, Santa Rosa Island	mouse
<i>Placunanomia granti</i>	Hertlein 1928	CAS 4140	Vaqueros Formation, Santa Rosa Island	bivalve
<i>Pteria rositae</i>	Hertlein 1928	CAS 4142	Rincon Formation, Santa Rosa Island	bivalve
<i>Turritella tritschi</i>	Hertlein 1928	CAS 4150	Vaqueros Formation, Santa Rosa Island	gastropod

CHIS Table 6. Type specimens from CHIS. The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column.

Cultural Resource Contexts

The Quaternary fossil resources of CHIS have a number of connections to cultural resources, because of the extensive utilization of the islands by humans for essentially the entire Holocene. There are more than 675 archeological sites on San Miguel Island alone, most of which are shell middens (Erlandson et al. 2007). The majority of human associations with fossil resources are connections that occurred between contemporaries, such as the many ancient shell middens. Shells, bones, and plant matter were used to make beads, tools, cords, and other artifacts (Fergusson and Libby 1963; Orr 1968; Guthrie 1980; Rick 2002; Vellanoweth et al. 2003; Reeder et al. 2008). Among these artifacts is a bead of the gastropod *Olivella* that is a reused Pleistocene fossil from 30,450 calendar yr BP

(Vellanoweth et al. 2003). There are intentional burials of island foxes by humans on several of the Channel Islands, including Santa Cruz Island and Santa Rosa Island (Collins 1991). People also brought organic materials from the mainland, which is how deer bones came to be present at an early Holocene site on San Miguel Island (Vellanoweth et al. 2003). While it is not known if people encountered live mammoths on the Channel Islands, there is evidence that the Chumash people attributed pygmy mammoth bones to an ancient people (Cushing et al. 1984). The archeology of CHIS was recently summarized in Braje et al. (2010). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Paleontological Resource Management, Preliminary Recommendations

- The park should consider future field inventories for paleontological resources to more fully document *in situ* occurrences of fossils, and to evaluate fossiliferous areas for vulnerability to landslides and coastal erosion. 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 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. 2009).
- Coastal erosion and landslides are important threats to paleontological resources at CHIS. Mammoth fossils on CHIS islands can be exposed on cliffs and lost to the sea in a single winter (Santucci and Koch 2003). Coastal action can also bring fossils to the islands. For example, offshore of Anacapa Island, Holocene bioclasts from foraminifera, algae, bryozoans, mollusks, and echinoids are present (Scholl 1960), and may wash onto the island; and artifacts and bones from drowned sites now wash up on Santa Rosa Island (Orr 1956b). Regular inspection of vulnerable areas, with periodic salvage (as described in Guthrie [2005]), should be employed to deal with these issues.
- CHIS has terrestrial caves and more than 380 sea caves. Caves can be important sources for paleontological resources, as discussed by Santucci et al. (2001); CHIS's caves should be surveyed for fossils.
- Continuation of periodic mammoth survey work on the islands should be supported; Dr. Larry Agenbroad has a staff member at the Mammoth Site who is interested in continuing this work (L. Agenbroad, the Mammoth Site [Hot Springs, SD] principal investigator and site director, pers. comm., January 2012). One area of potential future research is an improved chronology for Columbian and pygmy mammoths (L. Agenbroad, pers. comm., January 2012).
- CHIS has some fossil types in great quantities; Johnson (1971) tried to bring the snail sample to attention, and there is a large sample of *Peromyscus nesodytes* bones from the owl pellet deposits. These large sample sizes could be ideal for statistical projects.
- Park staff should be encouraged to observe exposed sedimentary rocks and associated eroded deposits for fossil material while conducting their usual duties. Staff should photodocument and monitor any occurrences of paleontological resources that may be observed *in situ*. Fossils and their associated geologic context (surrounding rock) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts. When opportunities arise to observe paleontological resources in the field and take part in paleontological field studies with trained paleontologists, park staff should take advantage of them.
- Fossils found in a cultural context should not be disturbed unless they are part of a professional archeological investigation. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Geologic Resources Division can coordinate additional documentation/research of such material.
- Future infrastructure developments or archeological excavations should consider scheduling site monitoring by a trained paleontologist in order to document and protect fossil resources.
- Contact the NPS Geologic Resources Division for technical assistance with paleontological resource management issues.

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Channel Islands National Park Collections
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Academy of Natural Sciences
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California Academy of Sciences
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Natural History Museum of Los Angeles County
1930s–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by LACM staff; status: Active.

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1927–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by CIT staff; status: Active.

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San Diego Natural History Museum
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Santa Monica Mountains National Recreation Area

Santa Monica Mountains National Recreation Area (SAMO) protects a portion of southern California's Santa Monica Mountains and Simi Hills. The mountains, canyons, and coastal areas in its boundaries are host to a Mediterranean ecosystem and extensive cultural resources, both ancient and modern, as well as abundant fossils (SAMO Figure 1). SAMO was established November 10, 1978, and its boundaries were changed October 9, 2002. It is administered in partnership with a number of landowners at national, state, local, and private levels, and it includes many state and local parks. SAMO currently encompasses 62,359.95 ha (154,094.78 acres), 9,263 ha (22,891.76 acres) of which are under federal administration (SAMO Figure 2).

Geologic Background

Most of SAMO is in southwestern Los Angeles County, California, with a small section in southeastern Ventura County. The recreation area is in the midst of a heavily populated and developed area: the city of Los Angeles abuts it on the southeast, and various municipalities are adjacent to it along its entire northern border. SAMO is centered on the Santa Monica Mountains, with the bulk of its land in an east-west strip between Point Mugu on the west and Pacific Palisades and Santa Monica on the east. The recreation area also has a narrow eastern extension reaching as far as Glendale and a northern extension in the Thousand Oaks area that takes in part of the Simi Hills. North of the Simi Hills is Simi Valley, which separates the hills from the Santa Susana Mountains to the north. Northeast of SAMO is the San Fernando Valley, which is between the recreation area and the San Gabriel Mountains. These ranges, several other ranges to the northwest, north, and northeast, and the northern Channel Islands offshore to the west (see the Channel Islands National Park [CHIS] summary in this report for more details) are part of the larger Transverse Ranges group of mountain ranges. The name refers to the ranges' unusual east-west trends. This characteristic is the result of tectonic activity during the past 20 million years.



SAMO Figure 1. A roadcut in the Topanga Group of SAMO. The Topanga Group of SAMO is among its most fossiliferous units, and is particularly known for its Miocene marine invertebrates. This photo also illustrates two important issues facing geologic and paleontologic resources in SAMO: abundant plant cover and human disturbance (VLS).

The geology and paleontology of SAMO have been described in numerous documents. Relevant publications include those by Arnold (1906, 1907), Dickerson (1914), Waring (1917), Kew (1924), Wiedey (1928), Hoots (1931), Woodring (1931), Loel and Corey (1932), Grant and Hertlein (1938), Soper (1938), David (1943), Reinhart (1943), Compton (1944), Susuki (1952), Durrell (1954), Popenoe (1954), Valentine (1956), Matsumoto (1960), Imlay (1963), Addicott (1964), Parker and Dawson (1965), Axelrod (1967, 1990), Almgren (1973, 1981), Colburn (1973, 1996), Popenoe (1973), Cornell (1974), Carey and Colburn (1978), Saul (1978, 1983a), Yerkes and Campbell (1979), Campbell and Yerkes (1980), Squires (1980, 1990, 1993, 1997, 2011), Saul and Alderson (1981, 2001), Schymiczek (1981a, 1981b), Squires et al. (1981), Bottjer et al. (1982), Dibblee (1982a), Fritsche et al. (1983, 1993), Sorensen (1985), Strathearn and Griffis (1986), Hutchison (1987), Alderson (1988, 2012), Colburn et al. (1988), Strathearn et al. (1988), Jefferson (1989), Prevost (1992), Dibblee and Ehrenspeck (1993a), Flack (1993), Fritsche (1993), Bown (1994), Groves (1994), Rumelhart and Ingersoll (1997), Squires and Kennedy (1998), Squires and Saul (1998, 2000, 2001, 2002, 2006, 2007, 2009), Stadum and Weigand (1999), Fritsche and Savage (2000), Fisk et al. (2001), Ingersoll (2001), Lander et al. (2001a, 2001b, 2003), Shapiro et al. (2001), McCulloh et al. (2002), Noriega et al. (2002), Koch and Santucci (2003), Nyborg et al. (2003, 2009), Whistler and Lander (2003), Koch et al. (2004), Abeja et al. (2005), Saul and Stadum (2005), Bocheński and Campbell (2006), Hunt et al. (2006), Stanton and Alderson (2006, 2010, in press), Campbell et al. (2007), Calvano et al. (2008), Groves and Alderson (2008), KellerLynn (2008), Saul and Squires (2008a, 2008b), and Lander (2011). Geological mapping has been provided by Hoots (1931), Castle (1960), Yerkes et al. (1971), Yerkes and Campbell (1980, 1993, 1994, 1997), Squires (1981a), McGill (1989), Dibblee and Ehrenspeck (1990a, 1990b, 1991a, 1991b, 1992a, 1992b, 1992c, 1993b, 1993c), Yerkes and Showalter (1991, 1993), Dibblee et al. (1993), Campbell et al. (1996), Yerkes (1996a, 1996b, 1997a, 1997b), Tan and Clahan (2003), Saucedo et al. (2003), and Tan et al. (2004). Dissertations and theses include those by Brockhouse (1932), Zebal (1943), Susuki (1951), Blackerby (1965), Osborne (1987), Flack (1990), Mack (1993), and Savage (1996). A geologic resource evaluation scoping session, coordinated by the Geologic Resources Division of the National Park Service (NPS), was held for SAMO during May 2008.

(KellerLynn 2008). The initial paleontological resource inventory and summary was prepared by Koch and Santucci (2003), and a paleontological survey was prepared by Koch et al. (2004).

Because of their proximity to Los Angeles, the Santa Monica Mountains have long been an area of geological research. They are also structurally complex, with dense chaparral cover (Fritsche 1993). One side effect of these factors is competing geologic nomenclatural systems (SAMO Table 1). At this time, there are two basic systems in wide use: the system used by Thomas Dibblee and used by the Dibblee Geological Foundation, and the system used by Russell Campbell and R. F. Yerkes of the U.S. Geological Survey. The two systems diverge the most in the Miocene section. The Dibblee system designates the Miocene rocks, from oldest to youngest, as the Lower Topanga Formation (Dibblee included the Vaqueros Formation, but this unit is usually considered distinct by other workers using this nomenclature; see for example Lander [2011]), the Conejo Volcanics and Middle Topanga Formation, the Upper Topanga Formation, and the Monterey Formation. The USGS identifies the same rocks as the Vaqueros Formation, the Topanga Canyon Formation, the Conejo Volcanics, the Calabasas Formation, and the Modelo Formation. When these differences are combined with the nomenclatural system(s) used before the 1970s, which had substantially different names for the Cretaceous, Paleocene, and Eocene rocks, it can be confusing to determine exactly what is being referred to by a given publication. Alternate names and usages will be described in the text. Another factor to consider with older publications is the topographic quadrangle system. Some maps use a different set of smaller quadrangles, for example Soper (1938). In more recent history, the Simi Valley East quadrangle used to be the Santa Susana quadrangle, and the Simi Valley West quadrangle was simply the Simi Valley quadrangle.

The geologic record exposed in SAMO extends from the Upper Jurassic to the present (see the appendix for a geologic time scale), with a relatively complete record since about 90 Ma (million years ago). The Santa Monica Mountains are part of the western Transverse Ranges terrane (distinct block of continental crust) or block (Atwater 1998), which underwent dramatic changes in location and orientation during the Cenozoic. Paleomagnetic data indicate that the block was attached to the North American craton during the Jurassic, Cretaceous, and early Cenozoic. The paleomagnetic tracks of the block and the rest of North America do not begin to diverge until the middle Cenozoic, when the block began moving north relative to the continent (Champion et al. 1986). The oldest rocks exposed in SAMO are part of the Santa Monica Slate, a metamorphosed Upper Jurassic sedimentary rock unit that formed in association with a volcanic arc (Sorensen 1985). The next few tens of millions of years are sparsely represented in the mountains. Lower Cretaceous rocks include the Catalina Schist, a metasedimentary rock unit metamorphosed around 115 Ma (Grove et al. 2008), and granitic intrusive rocks dating to $102 \pm$

10 Ma (Dibblee 1982a). Upper Cretaceous deposition began with subsidence and a marine transgression (advance) that produced several formations, first the terrestrial conglomerates of the Trabuco Formation (Dibblee 1982a), then the fan delta and shallow marine deposits of the Tuna Canyon Formation of the Santa Monica Mountains (Dibblee 1982a; Shapiro et al. 2001) and the submarine fan deposits of the Chatsworth Formation in the Simi Hills (Squires et al. 1981).

The transgression was followed by uplift and regression (retreat) that led to erosion for several million years. Following erosion, subsidence and transgression brought renewed deposition of terrestrial and shallow-marine formations in both the Santa Monica Mountains and the Simi Hills during the last part of the Paleocene, including the nonmarine to shallow-marine Simi Conglomerate (Dibblee 1982a; Parker 1983a), the nonmarine to shallow-marine Las Virgenes Sandstone (Parker 1983a, 1983b; Noriega et al. 2002), and the shallow-marine Coal Canyon Formation of the Santa Monica Mountains (Squires and Kennedy 1998; Squires and Saul 2001). The Paleocene and Eocene formations of the Simi Hills consist of a sedimentary succession from fluvial and alluvial, to lagoonal, to marine (Sage 1975; Parker 1983a), and are part of a transgression into the rapidly subsiding (sinking) Ventura Basin (Zinsmeister 1983a). Depths were greater in what are now the Santa Susana Mountains to the north, where bathyal (continental slope) depths were attained, than they were in the Santa Monica Mountains, where sublittoral (continental shelf) depths were still present during the late Paleocene (Saul 1983a). Uplift and regression during the Early and Middle Eocene are reflected by a period of erosion for several million years. Renewed subsidence in the latest Middle Eocene brought deposition of the alluvial to marine Lajas Formation throughout the region (Squires 1981b, 1983a).

Beginning in the early middle Eocene, sea level in the SAMO area dropped from a combination of local uplift and ice buildup on Antarctica. The western Transverse Ranges block was progressively uplifted because of the approaching East Pacific Rise spreading center (Lander 1983, 1994, 1997, 2011). For many millions of years, beginning in the Mesozoic, an oceanic plate known as the Farallon plate had been subducting beneath the North American plate along the latter's western margin. By the Middle Eocene, the Farallon plate had been mostly subducted, and the East Pacific Rise, which formed its western boundary with the Pacific plate, was approaching the North American plate. The East Pacific Rise was topographically a high part of the sea floor, due to high heat flow. Its approach and partial subduction lifted the western North American plate, bringing on a period of erosion during the Late Eocene and Early Oligocene. Increased friction between the subducting plate boundaries slowed the rate of subduction. Erosion and renewed subsidence reduced the elevation of the uplifted areas, allowing alluvial and fluvial redbed deposits of the Sespe Formation to be deposited throughout the area during the middle part of the Oligocene (Lander 1994, 1997, 2011; Fritsch 1998).

At the same time as the East Pacific Rise began to interact with western North America, increasing friction between plates and thinning of the subducting Farallon plate caused portions of the plate to fragment off, becoming microplates. The microplate under the Transverse Ranges is the Monterey microplate. It was too small to be subducted; instead, it became attached to (captured by) the Pacific plate at the East Pacific Rise at approximately 30 Ma. This event would eventually lead to the Transverse Ranges' transverse orientation, among other things (Weigand et al. 2002). The sea returned to the SAMO area toward the end of the Oligocene, as represented by a shallow-marine tongue of the Vaqueros Formation in the upper Sespe Formation (Lander 2011). For the next few million years, into the Early Miocene, terrestrial deposition of the Sespe Formation and marine deposition of the Vaqueros Formation and the Topanga Canyon Formation (or Lower Topanga Formation), which overlies the Sespe Formation, alternated as the sea transgressed and regressed. Three and a half transgressive-regressive cycles occurred between the Middle Eocene and the onset of volcanism in the Early Miocene (Lander et al. 2001b; Lander 2011). Deposition occurred in a north-south basin with the deepest part of the ocean to the west (Schwartz and Colburn 1987; Lander 2011).

The Miocene of SAMO is marked by volcanism and tectonic movements, mostly lateral. These events followed from the capture of the Monterey microplate by the Pacific plate during the Oligocene. The capture of the microplate caused a reorganization of the numerous small continental blocks along the southwestern margin of the North American plate. The Transverse Ranges block was wrenched out of position at about 19 Ma and rotated clockwise. This rotation and associated rifting allowed the underlying asthenosphere to well up, leading to decompression melting and widespread volcanism; the volcanism was the source of the volcanic rocks that make up a significant portion of the bedrock of the western Santa Monica Mountains and northern Channel Islands (Weigand et al. 2002). A large volcano grew from the sea floor in the area of the future western Santa Monica Mountains and eventually rose above sea level. The volcano formed an island that was of similar size to the Hawaiian volcanoes and had an elevation of over 1,500 m (4,900 ft) above sea level (Stadum and Weigand 1999). Small exposures of volcanic rocks also occur in the Simi Hills and Santa Susana Mountains (Weigand and Savage 1993). Volcanism ended by about 16 Ma (Weigand et al. 2002), and rotation ended by approximately 12 Ma (Weigand and Savage 1993). By the time motion stopped, the Transverse Ranges block had rotated roughly 90° clockwise (Bartling and Abbott 1983), and moved a few degrees north; there is some disagreement about the magnitude of northward movement between different measurement methods, but in relative terms the block has moved north from the vicinity of San Diego (Kamerling and Luyendyk 1985). The tectonic basin now known as the Los Angeles Basin formed during these events. It began subsiding around 18 Ma, and stopped subsiding only about 3 Ma (Rumelhart and Ingersoll 1997). The tectonic events

were rapid and dramatic enough that the brief hiatus between the deposition of the Topanga Canyon Formation and the Conejo Volcanics is marked by an angular unconformity (the lower rocks were tilted away from horizontal) (Dibblee and Ehrenspeck 1993a).

Marine deposition followed the eruptions, lasting for several million years with the exception of a brief period of exposure and erosion around 15 Ma (McCulloh et al. 2000) that produced the most profound unconformity in the area. Two primary depositional settings were common in the SAMO area following the unconformity: submarine fans, with turbidity currents and fine particles settling, represented by the Modelo Formation; and submarine basin plains with only fine particles, represented by the Monterey Formation (Fritsche 1993). Before the eruption of the Conejo Volcanics, the Santa Monica Mountains area was a depositional basin (Dibblee and Ehrenspeck 1993a). The mountains were uplifted during the Pliocene (Schwartz and Colburn 1987). Like the northern Channel Islands, the Santa Monica Mountains lack Pliocene rocks, which indicates they were elevated by that time (Dibblee 1982b).

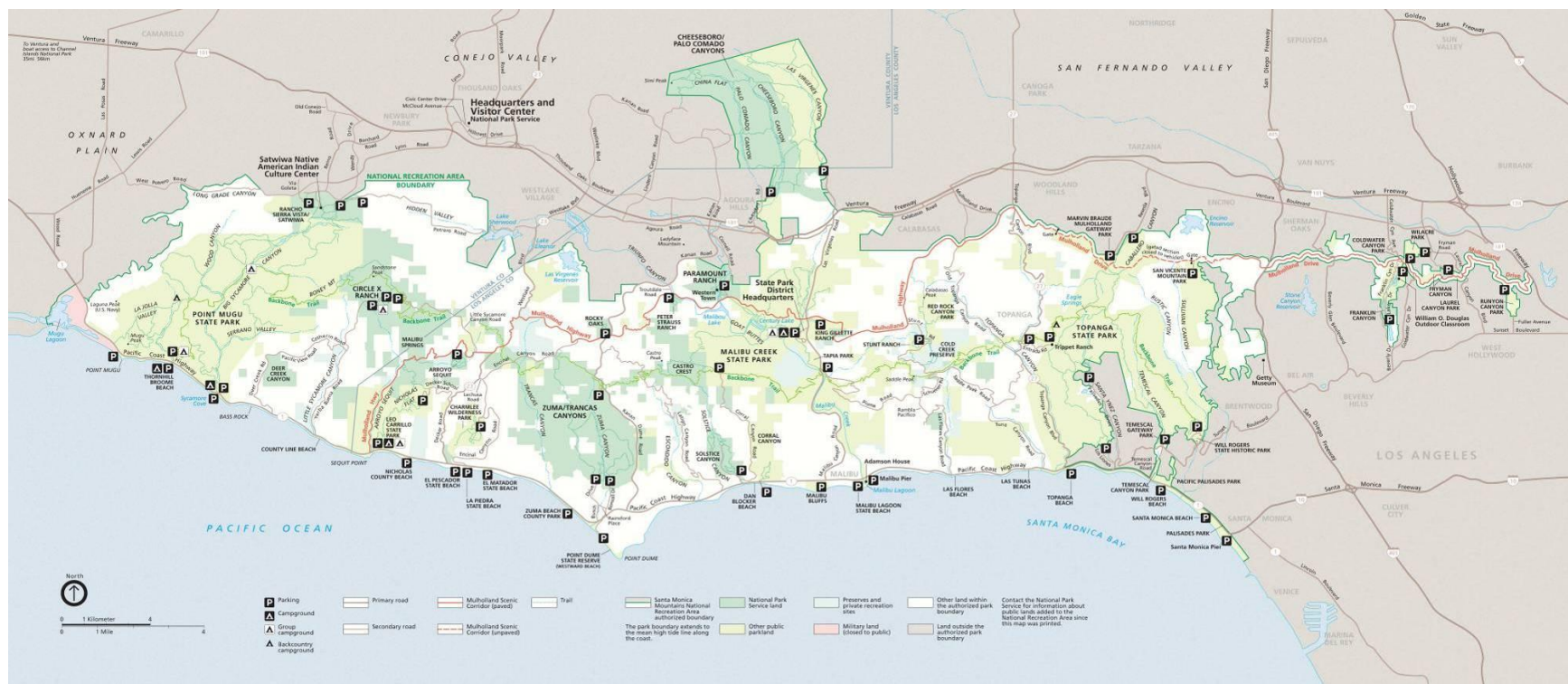
Quaternary deposition at SAMO is represented by both marine and nonmarine deposits. The alternation is the result of changing sea levels influenced by the growth and melting of ice sheets at a global scale, and tectonic uplift at a local scale. Sea level highstands are represented by marine terraces. There are two prominent marine terraces in the SAMO area: the higher, older Malibu Terrace and the lower, younger Point Dume (or Pacific Palisades) Terrace (Soper 1938; Shaller and Heron 2004). The Malibu Terrace formed about 320,000 years ago, when sea level was 4 m (13 ft) higher than present. The Point Dume Terrace formed about 125,000 years ago, at a sea level of 6 m (20 ft) above present (although the Point Dume Terrace formed under a higher highstand than the Malibu Terrace, the Malibu Terrace is higher today because of uplift that occurred between the two highstands). An intermediate terrace, the Corral Terrace, formed about 200,000 years ago when sea level was nearly the same as present (Shaller and Heron 2004). The terraces are not found at consistent elevations because of tilting and uplift over the past 320,000 years; for example, the Point Dume terrace is at sea level west of Point Dume and 90 m (300 ft) in the adjoining quadrangle to the east (Soper 1938).

Coastal California may have been an ice-age refugium, with a stable long-term Mediterranean climate (Johnson 1977a). The late Quaternary of the Los Angeles area is known for its assemblage of now-extinct large mammals. These animals may have gone extinct through a combination of a shift to a warmer, drier climate and overhunting by humans. For example, droughts would have induced animals to cluster around water sources, which would have made them easier to hunt (Johnson 1977b). Archeological evidence indicates that humans arrived in the nearby northern Channel Islands at least 13,000 years ago (Erlandson et al. 2007).

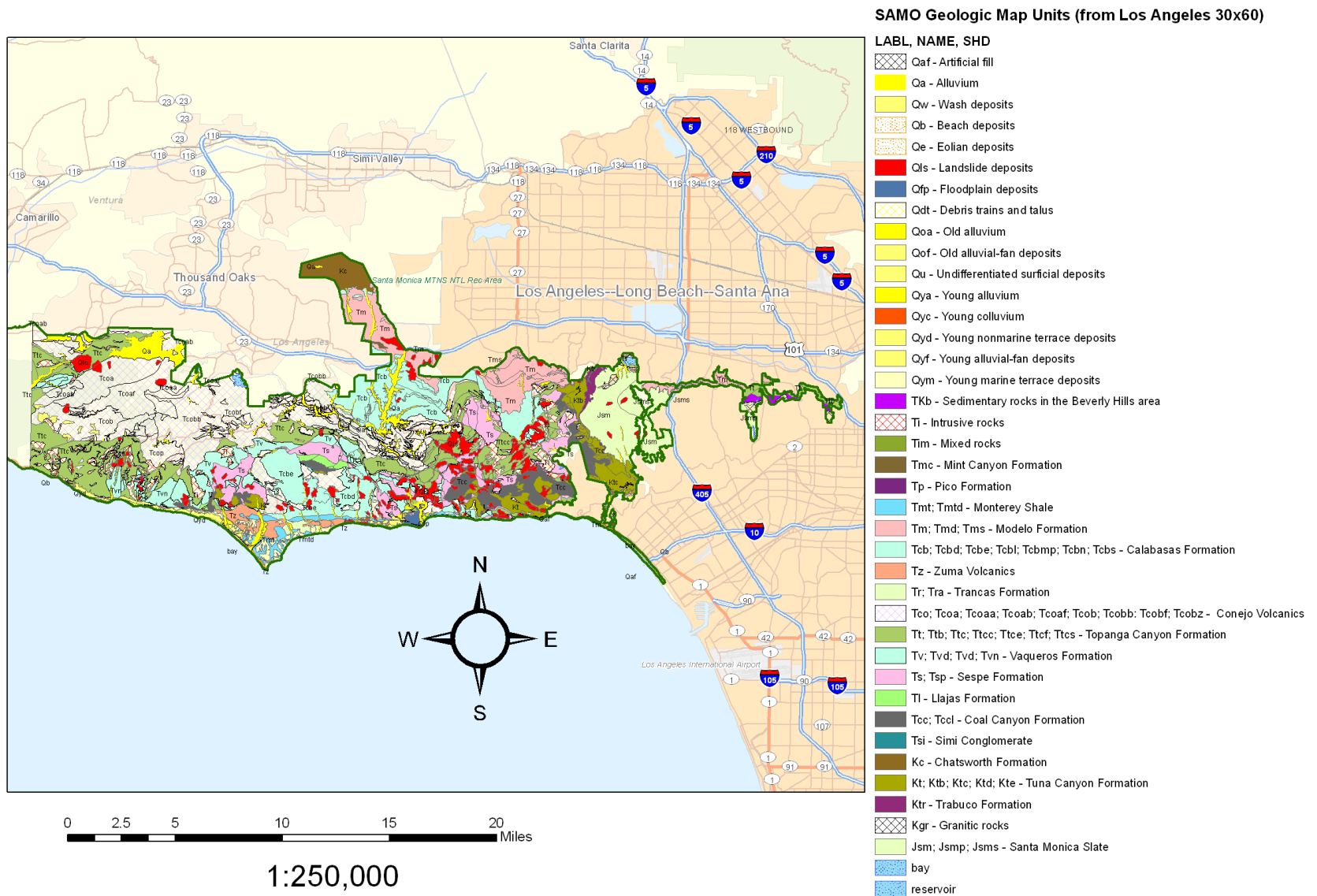
Geologic units exposed within SAMO include, from oldest to youngest, the following: the Santa Monica Slate (Upper Jurassic); possibly the Catalina Schist (Lower Cretaceous); upper Lower Cretaceous granites; the Trabuco Formation, Tuna Canyon Formation, and Chatsworth Formation (Upper Cretaceous); the Simi Conglomerate and Las Virgenes Sandstone (Paleocene); the Coal Canyon Formation (Middle–Upper Paleocene); the Santa Susana Formation (Upper Paleocene–Lower Eocene); the Llajas Formation (Lower–Middle Eocene); the Sespe Formation (Middle Eocene–Lower Miocene); the Vaqueros Formation (Upper Oligocene–Lower Miocene); the Topanga Canyon Formation/Lower Topanga Formation (Lower–Middle Miocene); the Conejo Volcanics (Lower Miocene); the Trancas Formation and Zuma Volcanics (Lower–Middle Miocene); the Calabasas Formation/Upper Topanga Formation (Middle Miocene); the Modelo Formation and Monterey Formation (Middle–Upper Miocene); unnamed Upper Pliocene–lower Pleistocene rocks and sediments; possibly the Saugus Formation (lower Pleistocene); and other Quaternary rocks and sediments (upper Pleistocene–Holocene) (Yerkes and Campbell 1979; Dibblee and Ehrenspeck 1993a; Fritsche 1993).

There are multiple distinct lithological areas within SAMO. The Simi Hills stratigraphic section, present in the Thousand Oaks quadrangle section of SAMO, includes the Chatsworth Formation, Simi Conglomerate, Las Virgenes Sandstone, and Santa Susana Formation as its Cretaceous–Eocene sequence (Yerkes and Showalter 1991). Most of the rest of SAMO has a sequence including the Trabuco Formation, Tuna Canyon Formation, Coal Canyon Formation (sometimes considered a synonym of the Santa Susana Formation), and possibly the Llajas Formation. In addition, the area south of the Malibu Coast Fault is the only part of SAMO with the Catalina Schist (possibly), Zuma Volcanics, and Trancas Formation (Yerkes and Campbell 1980; Campbell et al. 1996).

The Catalina Schist, Cretaceous granitic rocks, and Miocene intrusive igneous rocks associated with the volcanics are not fossiliferous, but all of the other units are fossiliferous or potentially fossiliferous within SAMO. Even the Miocene volcanic rocks include some fossils. Most fossils from SAMO are of marine invertebrates, but terrestrial fossils are known from some of the units, including the Sespe Formation, the Topanga Canyon Formation/Lower Topanga Formation, and the young Quaternary deposits (SAMO Table 2).



SAMO Figure 2. Geography of SAMO (NPS).



SAMO Figure 3. Schematic geological map of SAMO. Map graphic adapted from Yerkes et al. (2005).

Geologic Age (as of 2012)	Kew (1924)	Hoots (1931)	Yerkes and Campbell (1979)	Dibblee (various publications)	Fritsche (1993, pers. comm., March 2012)
Holocene	Terrace deposits	Terrace deposits	Terrace deposits	Surficial deposits	Terrace deposits
Pleistocene	Saugus Formation	Marine deposits	(not present)	Saugus Formation	Saugus Formation
Pliocene	Pico Formation	Upper and lower Pliocene	(not present)	Fernando or Pico Formation	Pico Formation
Miocene	Modelo Formation	Modelo Formation	Modelo Formation	Monterey Formation	Modelo Formation
	Topanga Formation	Topanga Formation	Calabasas Formation	Upper Topanga Formation	Calabasas Formation
			Conejo Volcanics and associated sedimentary rocks	Conejo Volcanics and Middle Topanga Formation	Conejo Volcanic Complex, associated sedimentary rocks
			Topanga Canyon Formation	Lower Topanga Formation	Topanga Canyon Formation
	Vaqueros Formation	Vaqueros(?) and Sespe(?) formations	Vaqueros Formation		
Oligocene	Sespe Formation		Sespe Formation	Sespe Formation	Sespe Formation
Eocene	Tejon Formation	(not present)	Llajas Formation(?)	Llajas Formation	Llajas Formation
	Martinez Formation	Martinez Formation	Coal Canyon Formation	Santa Susana Formation	Santa Susana Formation
Paleocene			Simi Conglomerate(?)	Simi Conglomerate	Simi Conglomerate
Cretaceous	Chico Formation	Chico Formation	Tuna Canyon Formation	Unnamed strata	Tuna Canyon Formation
					Trabuco Formation
Jurassic	Metamorphic rocks	Santa Monica Slate	Santa Monica Slate	Santa Monica Slate	Santa Monica Slate

SAMO Table 1. Schematic comparison of stratigraphic nomenclature employed for the Santa Monica Mountains over time (after Eugene Fritsche, California State University–Northridge; pers. comm., March 2012).

Formation	Age	Fossils Within SAMO	Depositional Environment
Unnamed Quaternary rocks and sediments	Pleistocene–Holocene	Corals, bryozoans, chitons, bivalves, gastropods, scaphopods, barnacles, decapod crustaceans, echinoids, rays, fish, frogs, lizards, snakes, 20 bird species, ground sloths, moles, rodents, mastodons, mammoths, tapirs, horses, bison, and camels	Nearshore marine to terrestrial
Saugus Formation	early Pleistocene	None to date; terrestrial mammals are most likely	Terrestrial
Unnamed Pliocene–Pleistocene rocks and sediments	Late Pliocene–early Pleistocene	Pine cones, manzanita seeds, brachiopods, bivalves, gastropods, and echinoids	Nearshore marine
Monterey Formation	Middle–Late Miocene	Foraminifera and diatoms	Submarine basin plain
Modelo Formation	Middle–Late Miocene	Foraminifera, radiolarians, diatoms, silicoflagellates, brown and red algae (seaweeds), petrified and lignitized wood, leaves of land plants, sponge spicules, bivalves, gastropods, echinoids, argonaut cephalopod egg cases, shark teeth, 20 genera of fish from 18 families, fish teeth and abundant scales, a sea lion metacarpal, a few whale bones, and horse bones	Submarine fans
Calabasas/Upper Topanga Formation	Middle Miocene	Foraminifera, diatoms, plant casts, fish scales, reworked wood, and reworked mollusks	Offshore marine, with deposition by turbidity currents
Zuma Volcanics	Early–Middle Miocene	Foraminifera	Submarine volcanics and marine sediments
Trancas Formation	Early–Middle Miocene	Foraminifera and gastropods	Marine
Conejo Volcanics	Early Miocene	Foraminifera, coralline (red) algae, vascular plant fragments, bryozoans, brachiopods, bivalves, gastropods, barnacles, crabs, echinoids, serpulid worm tubes, bioerosion of shells, shark teeth, and fish bones and scales	Mostly volcanic flows and associated sedimentary rocks; eruptions beginning as submarine, becoming subaerial over time

Formation	Age	Fossils Within SAMO	Depositional Environment
Topanga Canyon/Lower Topanga Formation	Early–Middle Miocene	Carbonaceous debris, stromatolites, possible microbial limestone, foraminifera, plant and wood fragments, leaves and leaf impressions, root traces, brachiopods, bivalves, gastropods, barnacles, crabs, echinoids, invertebrate burrows and borings, sharks and rays, fish scales and bones, lizards, snakes, insectivores, rodents, rabbits, sea lions, sea cows, horses, rhinoceroses, whales, and camels	Nearshore marine interrupted by a fluvial interval
Vaqueros Formation	Late Oligocene–Early Miocene	Carbonaceous debris, foraminifera, petrified wood, logs, palm fronds, root traces, bryozoans, brachiopods, bivalves, gastropods, barnacles, echinoids, burrows, worm tubes, rays, fish scales, and a lower jaw of a blastomerycine musk deer	Nearshore to offshore marine
Sespe Formation	Middle Eocene–Early Miocene	Logs, palm fronds, root casts, bivalves, invertebrate burrows, frogs, tortoises, opossums, rodents, pikas, and camels	Fluvial, floodplain, and coastal settings, with occasional marine incursions
Llajas Formation	Early–Middle Eocene	Possibly bivalves and gastropods	Coastal alluvial fans to marine over time
Santa Susana Formation	Late Paleocene–Early Eocene	None to date (unless the Coal Canyon Formation is synonymized with it); marine invertebrates and invertebrate trace fossils are most likely	Nearshore to bathyal marine
Coal Canyon Formation	Middle–Late Paleocene	Microbial limestone, bivalves, gastropods, crabs, and echinoids, possibly more (many sites are just within or just outside of SAMO)	Low-energy protected bay
Las Virgenes Sandstone	Paleocene	None to date; logs, brackish-water mollusks, and invertebrate burrows are most likely	Fluvial to nearshore marine
Simi Conglomerate	Paleocene	Carbonaceous debris and plant fragments	Fluvial to marine canyon or submarine fan
Chatsworth Formation	Late Cretaceous	Foraminifera, unspecific macrofossils, and trace fossils	Mostly sand-rich submarine fan deposition
Tuna Canyon Formation	Late Cretaceous	Foraminifera, leaves, bivalves, ammonites, gastropods, echinoids, and ophiuroids	A variety of marine settings, most deposition by turbidity currents

Formation	Age	Fossils Within SAMO	Depositional Environment
Trabuco Formation	Late Cretaceous	None to date; not known to be fossiliferous at this time	Alluvial fan settings
Lower Cretaceous intrusives	Early Cretaceous	Unfossiliferous (intrusive igneous rocks)	Not applicable (igneous rocks that solidified at depth)
Catalina Schist	Early Cretaceous	None to date; fossils are unlikely because of metamorphism	Sedimentary rocks (before metamorphism)
Santa Monica Slate	Late Jurassic	Bivalves (possibly)	Sedimentary rocks probably associated with a volcanic arc or arcs (before metamorphism)

SAMO Table 2. Concise tabulation of SAMO stratigraphy, fossils, and depositional setting; details and references can be found in the text. Metamorphic and intrusive igneous rocks are included here for completeness, but are not discussed in detail in the text because of the improbability of fossils.

Sources of Paleontological Resources

The fossils of SAMO present opportunities for education, interpretation, and continued or future scientific research in the park. Over 2,300 fossil localities were known from the Santa Monica Mountains as of 2004 (Koch et al. 2004).

Santa Monica Slate (Upper Jurassic)

The Santa Monica Slate (or Formation) is one of the basement rock units of the Los Angeles area (Sorensen 1985). It is found in eastern SAMO (Yerkes and Campbell 1993, 1994; Yerkes 1996a, 1997a). Generally, it is a dark slate unit with local schist zones, and is at least 1,500 to 2,100 m (5,000 to 7,000 ft) thick (Hoots 1931). This unit is composed of metamorphosed sedimentary rocks, primarily metamorphosed graywacke (poorly sorted sandstone with a matrix of clay-sized grains), siltstone, and shale and other mudrocks, with some metamorphosed sandstone, carbonates, conglomerates, and volcanic sediments (Sorensen 1985). It probably began as a sedimentary deposit associated with the volcanic island arc or arcs that also produced the Willows Plutonic Complex and Santa Cruz Island Schist of Santa Cruz Island in CHIS (see the CHIS summary in this report for more details) (Sorensen 1985). The contact with the overlying Trabuco Formation is an example of an angular unconformity (an unconformity where there is not only a depositional hiatus, but also tilting of the underlying rock) (Shapiro et al. 2001). The Santa Monica Slate was first thought to possibly be Triassic in age (Hoots 1931; Durrell 1954), but is now known to date to the late Oxfordian and early Kimmeridgian stages of the Late Jurassic (roughly 157 to 155 Ma), based on its fossils (Imlay 1963).

The Santa Monica Slate is sparsely fossiliferous (Yerkes 1996a), with fossils including the bivalve *Buchia* (Imlay 1963) and ammonites (Sorensen 1985). It may be fossiliferous within SAMO: *Buchia* fossils have been found at 34.08667° N, 118.50583° W, in the Topanga quadrangle. This location, off of

Mandeville Canyon Road just outside of Mandeville Canyon Park (Imlay 1963), is just within or just outside of SAMO.

Tuna Canyon Formation (Upper Cretaceous)

The Tuna Canyon Formation is found in eastern SAMO (Yerkes and Campbell 1980, 1993, 1994; Campbell et al. 1996; Yerkes 1996a). Like many Upper Cretaceous units of coastal California, its rocks were first identified as part of the Chico Formation (see for example Hoots 1931). The Chico Formation is one of a group of units defined during the early days of California geology on the basis of fossil content, and then widely applied throughout the state. Most of these units have been redefined as lithological units, limited to usage as biostratigraphic (fossil) zones, or abandoned altogether (see Fritsche [1993] or Campbell et al. [2007] for some discussion of this phenomenon). Hoots's (1931) green-brown upper part of the Chico Formation corresponds to the Tuna Canyon Formation, and the lower red portion corresponds to the Trabuco Formation (see below). Yerkes and Campbell (1979) named the Tuna Canyon Formation from exposures in SAMO's Tuna Canyon.

The Tuna Canyon Formation is a marine sedimentary unit over 2,100 m (7,000 ft) thick (Dibblee 1982a). The dominant lithologies are sandstone, siltstone, and conglomerate (Yerkes and Campbell 1979), with conglomerate common in the middle of the formation (Matsumoto 1960; Dibblee 1982a). It also includes some shale and limestone (Hoots 1931). The upper contact with the Coal Canyon Formation is unconformable (Yerkes and Campbell 1979; Colburn et al. 1988).

The Tuna Canyon Formation was deposited during a marine transgression (Colburn 1973). Deposition occurred on fan deltas, shallow-marine environments, and submarine fans (Dibblee 1982a; Squires and Saul 2000; Shapiro et al. 2001), at continental shelf and slope depths (Almgren 1973; Carey and

Colburn 1978). Much of the deposition was accomplished by turbidity currents (Colburn 1973; Yerkes and Campbell 1979). Transport direction and sediment sources changed over time (Colburn 1973). The surrounding geography has been interpreted as a steep, Andean-like coast (Shapiro et al. 2001). The formation has been dated biostratigraphically to between the late Turonian stage (Carey and Colburn 1978; Dibblee 1982a), approximately 90 Ma, and the early Maastrichtian stage (Carey and Colburn 1978; Yerkes and Campbell 1979), approximately 70 Ma.

The fossil assemblage of the Tuna Canyon Formation includes foraminifera (amoeba-like protists that form “shells”) (Yerkes and Campbell 1979), plant fragments (Saul and Alderson 2001), leaves (Popenoe 1973), bivalves, ammonites, and gastropods (Waring 1917; Hoots 1931; Squires and Saul 2000). Many of the mollusk fossils represent shallow water forms, which were probably transported to the deeper water settings where they were preserved (Squires and Saul 2000). Dark shale beds with plant fragments and a low-diversity mollusk assemblage composed mostly of hook-shaped scaphitid ammonites have been found in the lower beds (Saul and Alderson 2001). Siltstone beds in the uppermost Tuna Canyon Formation have foraminifera (Yerkes and Campbell 1979).

The Tuna Canyon Formation has long been known as fossiliferous, with a number of sites within or very near SAMO. A partial list of discoveries in chronological order includes the following reports. Waring (1917) reported on fossils collected by a 1910 expedition from Stanford University, from what would now be recognized as the Chatsworth Formation in the Simi Hills (localities 1 and 2) and the Tuna Canyon Formation in the Santa Ynez Canyon area (locality 3). The collectors found bivalves, ammonites, and gastropods at locality 3. Waring designated four new species from among these specimens: the bivalves *Crassatellites triangulatus* (holotype [name-bearing specimen] now curated at the California Academy of Sciences as CASG 61944.02) and *Inoceramus pambertoni* (type now CASG 69909.00), the ammonite *Placenticerus sanctaemonicae* (syntypes [name-bearing series] now CASG 61626.01 and 61944.01), and the gastropod *Pugnella rotundus* (type now CASG 61959.01). In addition, Saul and Alderson (1981) reported that Waring’s ammonite *Hauericeras transitionale*, which he described from Locality 2 in the Simi Hills (Waring 1917; type now CASG 61946.01) was probably from the Tuna Canyon Formation of Temescal Canyon in SAMO.

Kew (1924), describing the geology of parts of Los Angeles and Ventura counties, reported that fossils were abundant in the Chico Formation, including bivalves, ammonites, gastropods, echinoids (sea urchins), and ophiuroids (brittle stars); this description may not be limited to the modern Tuna Canyon Formation, but could apply to a combined Tuna Canyon Formation–Chatsworth Formation interval, given the area and historical use of the “Chico Formation” name. Hoots (1931) listed bivalves, ammonites, and gastropods from 12 localities in

the eastern Santa Monica Mountains. Soper (1938) reported a specimen of the giant bivalve *Inoceramus* from an embankment on the east side of Tuna Canyon. Popenoe (1954) reported Cretaceous bivalves, gastropods, and ammonites from the Santa Monica Mountains. Matsumoto (1960) reported the presence of ammonites from two sites in or near SAMO in a 90 m (300 ft)-thick sandstone bed near the top of what is now known as the Tuna Canyon Formation. One location, just inside or just outside of SAMO in Santa Ynez Canyon, yielded *Metaplacenticerus pacificum*, and the other, at the “Los Rosas” site in the Santa Monica Mountains, yielded *Pachydiscus* cf. *subcompressus* (Matsumoto 1960). LouElla Saul (Natural History Museum of Los Angeles County, pers. comm., April 2012) noted that the latter would be the youngest ammonite from the Santa Monica Mountains, and suggested that perhaps the locality is inaccurate.

Almgren (1973) reported late Campanian foraminifera in the Santa Monica Mountains, and Turonian foraminifera and ammonites from a locality on Mulholland Drive. Popenoe (1973) reported leaf fossils and late Turonian bivalves and ammonites from the ridge between Sullivan Canyon and Mandeville Canyon, possibly representing a stagnant lagoon, and ammonites and gastropods from Santa Ynez Canyon. Foraminifera and Late Turonian ammonites were reported by Carey and Colburn (1978) from the Hollywood Hills area, possibly within SAMO, from a conglomeratic inner fan setting. Saul (1978) reported bivalves from a locality at the mouth of Topanga Canyon either just within or just outside of SAMO; the specimens include paratypes (specimens from a type series that are not the holotype) of the bivalve *Yaadia robusta* (University of California–Los Angeles collections [UCLA] 38756 to 38758, now curated at the Natural History Museum of Los Angeles County [LACM]) (SAMO Figure 4). Yerkes and Campbell (1979) found exposures on the east wall of Las Flores Canyon and the east fork of Trancas Canyon with foraminifera.



SAMO Figure 4. *Yaadia robusta* from SAMO (all fossil invertebrate photographs in this chapter are courtesy of the Natural History Museum of Los Angeles County [LACM], and were taken by Caitlin De La Cruz).

Popenoe and Saul (1987) reported gastropods from a location on the north site of Garapito Creek. Squires and Saul (2000) reported an assemblage of bivalves, ammonites, and gastropods from the south fork of Garapito Creek. Fossils found here include the holotype and paratype specimen of the gastropod species *Deussenia californiana* (holotype LACMIP 12718, paratype 12719) (SAMO Figure 5). A similar assemblage is found elsewhere on Garapito Creek (Groves and Alderson 2008). Fossils have been found west of Rustic Canyon, including the straight ammonite *Baculites* in the uppermost part of the formation (Saul and Alderson 2001) and late Turonian gastropods (Squires and Saul 2006). Squires and Saul (2009) reported middle Campanian bivalves from a site on Santa Ynez Canyon, and late Campanian bivalves from a site on Rivas Canyon, both either just within or just outside of SAMO. Most recently, Squires (2011) named the gastropod species *Pyropsis aldersoni* (holotype LACMIP 13721) from the lower part of the formation, on the upper tributary to Garapito Creek near the divide between Garapito Canyon and Rustic Canyon.



SAMO Figure 5. *Deussenia californiana* (holotype LACMIP 12718).

Chatsworth Formation (Upper Cretaceous)

The Chatsworth Formation of the Simi Hills is another unit formerly known under the Chico Formation name. It is mostly composed of sandstone and mudstone beds (Colburn et al. 1981). In Palo Comado Canyon within SAMO it is 670 m (2,200 ft) thick and can be divided into informal lower, middle, and upper members. The lower member is composed of coarse sandstone, with minor amounts of shale and siltstone. The middle member begins as fine sandstone and coarsens upward; there are interbedded layers of shale and siltstone as well. The upper member is composed of thick bedded sandstone with shale and siltstone (Schymiczek 1981b). The upper contact with

the overlying Simi Conglomerate may or may not be conformable (Colburn et al. 1981).

The Chatsworth Formation mostly represents sand-rich submarine fan deposition (Link 1981). Most of it is from the middle part of the fan, but the Palo Comado Canyon area includes rare outer fan lobes (Schymiczek 1981a). Sand was transported by turbidity currents, and fine particles fell out of suspension (Colburn et al. 1981). The submarine fan complex prograded northward over the continental shelf and slope, and extended upslope to the south to equivalent rocks in the Santa Monica Mountains (Squires et al. 1981). At the time, the area was in a forearc basin (a basin between a volcanic arc and ocean trench) south of the present location of the future Sierra Nevada Mountains (Link et al. 1984). Foraminifera indicate low oxygen and at least middle bathyal depths for deposition (Almgren 1981). The fossils of the formation indicate it dates from the late middle Campanian stage to the early Maastrichtian stage (Saul and Alderson 1981), approximately 75 to 70 Ma.

The fossil assemblage of the Chatsworth Formation includes a variety of organisms. Terrestrial organisms are represented by wood (Squires et al. 1981), leaves, twigs, and other plant fragments (Colburn et al. 1981). Plant fossils are sometimes found compressed, in thin layers (Colburn et al. 1981). The marine assemblage includes coccoliths (algal plates, also known as calcareous nannofossils) (Filewicz 1981), foraminifera (Almgren 1981), corals, bryozoans (moss animals) (Welton and Alderson 1981), bivalves, ammonites (Popenoe 1954; Saul and Alderson 1981; Squires 1981c), nautiloids (Squires 1981c), gastropods (Popenoe 1954; Saul and Alderson 1981; Squires 1981c), scaphopods (tusk shells) (Saul and Alderson 1981; Squires 1981c), crustaceans (Welton and Alderson 1981), echinoids (Waring 1917; Welton and Alderson 1981), ophiuroids (Waring 1917), invertebrate trace fossils (Bottjer 1981) and general bioturbation (Link et al. 1984), and several shark taxa known from teeth (Welton and Alderson 1981).

Macrofossils are scarce, and typically represent transported animals (Squires 1981c). Many specimens were transported from shallow shelf settings to deeper areas by turbidity currents (Colburn et al. 1981; Squires et al. 1981). Microfossils are locally common, and are usually found in submarine interchannel areas (Squires 1981c). Trace fossils are locally fairly common (Squires 1981c). Fossil localities are most common in the lower part of the unit in canyons in the southeastern Simi Hills, and near the top of the section in the western Simi Hills (Stecheson 2001), and in general are rare in the upper part of the unit (Colburn et al. 1981). In contrast, mollusks are sometimes abundant enough in the lower part of the formation to form “reefs” (Sage 1975).

The Chatsworth Formation is fossiliferous within SAMO. Fossils have been found at Palo Comado Canyon (Almgren 1981; Schymiczek 1981a, 1981b; Squires 1981a) and Las Virgenes Canyon (Squires 1981a). Foraminifera (Almgren

1981) and trace fossils (Schymiczek 1981a, 1981b) have been reported from Palo Comado Canyon, and macrofossils are known from the Las Virgenes drainage (Squires 1981a).

Several fossiliferous areas are known from the immediate vicinity of SAMO as well. Waring (1917) reported bivalves, ammonites, gastropods, echinoids, and ophiuroids from the Simi Hills east of SAMO, and named several taxa. Popenoe (1973) reported bivalves and ammonites from the Lang Ranch area, just west of the Simi Hills extension of SAMO. Saul and Popenoe (1992) reported bivalves from a number of localities in Bell Canyon and Dayton Canyon, just east of the Simi Hills extension. Shell beds have been found in the lower part of the formation in Bell Canyon and Dayton Canyon (Saul and Alderson 2001). Ammonites, nautiloids, gastropods, and shark teeth have also been found in Dayton Canyon; most are fragmentary, but are not worn or abraded (Squires and Saul 1981).

Simi Conglomerate (Paleocene)

The Simi Conglomerate is best known from the Simi Hills, but appears to be locally present in the Santa Monica Mountains (Yerkes and Campbell 1979; Colburn et al. 1988). The Simi Conglomerate of the Simi Hills can reach thicknesses of more than 560 m (1,830 ft), and is composed of sandstone, conglomeratic sandstone, and mudstone (Squires and Filewicz 1983). The possible Simi Conglomerate of the Santa Monica Mountains is a cobble and boulder conglomerate with some sandstone, and is much thinner than the Simi Hills section, ranging from 6 m (20 ft) thick in Solstice Canyon to 90 m (300 ft) thick at Runyon Canyon (Colburn et al. 1988). The contact with the overlying Las Virgenes Sandstone is gradational (Zinsmeister 1983a), and the latter formation may represent a finer facies of the Simi Conglomerate depositional system (Zinsmeister 1983a, 1983b).

The Simi Conglomerate includes both nonmarine and marine deposition (Dibblee 1982a; Parker 1983a). Depositional setting differs by location and vertical position in the section. Fluvial deposition is found in the west, while in the east deposition occurred in a deep marine canyon or channels on a submarine fan (Parker 1983a). Marine deposition became more extensive at the top (Zinsmeister 1983b). In the Santa Monica Mountains, it appears to be a fluvial formation, perhaps deposited near alluvial fans (Colburn et al. 1988). The Simi Conglomerate is thought to date to some part of the Paleocene (Yerkes and Campbell 1979; Dibblee 1982a).

The Simi Conglomerate is not extensively fossiliferous, but is fossiliferous within SAMO: Colburn et al. (1988) found thin beds (30 cm to 1 m [12 in to 3 ft]) with abundant carbonaceous debris and plant fragments at several locations in the Santa Monica Mountains, including Runyon Canyon and Solstice Canyon. Overall, its fossil assemblage includes plant fragments (Colburn et al. 1988), wood (Parker 1983a), bivalves (Zinsmeister 1983a), gastropods, and invertebrate burrows

(Parker 1983a). Brackish-water (Sage 1975) and marine fossils (Zinsmeister 1983a) are known from the upper part of the formation. This unit also has reworked gastropods (Yerkes and Campbell 1979).

Coal Canyon Formation (Middle–Upper Paleocene)

The Coal Canyon Formation name is not universally accepted, its usage being intertwined with the Santa Susana Formation of the Simi Hills (see below). Outside of USGS maps, most recent publications have chosen to use the Santa Susana Formation name in the Santa Monica Mountains, in areas that have been mapped as the Coal Canyon Formation (Colburn et al. 1988; Dibblee and Ehrenspeck 1992a; Squires 1993, 1997; Colburn 1996; Squires and Kennedy 1998; Squires and Saul 1998, 2001, 2002, 2007). Current opinion on the Coal Canyon–Santa Susana question is mixed; Eugene Fritsche (pers. comm., March 2012) interpreted the two as synonyms, while Louella Saul (pers. comm., April 2012) considered the fossil assemblages to be distinct, and suggested that the Coal Canyon Formation represents shallower deposition under more brackish water. Because of the Coal Canyon Formation’s relevance to SAMO, and because it is easier for a reader to mentally synonymize the two formations than it is to separate them from a combined description, the two will be described separately here.

The Coal Canyon Formation was named in 1979 for rocks in the Santa Monica Mountains formerly classified with the Martinez Formation, another of the old biostratigraphic formations. It was named from Carbon Canyon, formerly Coal Canyon (Yerkes and Campbell 1979). This formation is found in central (Yerkes and Campbell 1980; Campbell et al. 1996) and western SAMO (Yerkes and Campbell 1994). It is a heterogeneous formation, composed of sandstone, pebble conglomerate, siltstone, limestone, and shale (Hoots 1931; Yerkes and Campbell 1979), up to 300 m (1,000 ft) thick (Dibblee 1982a). Limestone is found east of Topanga Canyon, as lenses and pods (Yerkes and Campbell 1979), and includes fossiliferous limestone concretions and white microbial limestone (often called “algal limestone”) reefs (Hoots 1931). The upper contact with the Sespe Formation is unconformable (Hoots 1931; Durrell 1954). Colburn et al. (1988) considered the Simi Conglomerate?–Coal Canyon Formation interval of Yerkes and Campbell (1979) to be divisible into the Simi Conglomerate, Las Virgenes Sandstone, and Santa Susana Formations. The Las Virgenes Sandstone and Santa Susana Formation of Colburn et al. (1988) are interfingering formations composed primarily of white coarse-grained arkosic (feldspar-rich) sandstone and fine-grained gray-green sandstone, respectively.

The Coal Canyon Formation is a marine unit (Yerkes and Campbell 1979). The well-described Coal Canyon Formation (=Santa Susana Formation) of the Palisades Highlands/Santa Ynez Canyon area is interpreted as a low-energy protected bay setting, with warm water and water depths of 40 to 70 m (130 to 230 ft). These conditions promoted the growth of microbial

shoals (Squires and Kennedy 1998; Squires and Saul 2001). Depth became shallower near the end of deposition (Strathearn et al. 1988; Squires and Saul 1998). On land, there was a pine forest with an understory of ferns and lycopods, under a warm and moist climate (Strathearn and Griffis 1986; Strathearn et al. 1988). The Coal Canyon Formation dates to the Paleocene, with microfossils dating to approximately 59 Ma (Carey and Colburn 1978), and Late Paleocene (Thanetian stage) gastropods (Colburn et al. 1988; Strathearn et al. 1988). Unlike the Santa Susana Formation of the Simi Hills, there is no evidence for Early Eocene deposition of the Coal Canyon Formation (Squires and Kennedy 1998).

The Coal Canyon Formation is fossiliferous, with mostly marine fossils. Its fossil assemblage includes microbial limestone (Squires and Kennedy 1998; Yerkes and Campbell 1979), organic-walled microfossils, foraminifera, dinoflagellate algae, coralline red algae, fern and lycopod spores, gymnosperm and angiosperm pollen, wood, fungal spores and hyphae (Strathearn and Griffis 1986; Strathearn et al. 1988), corals (Waring 1917), brachiopods (Strathearn et al. 1988), bivalves, gastropods (Squires 1980; Strathearn et al. 1988), scaphopods (Strathearn et al. 1988), crabs, echinoids (Squires 1980), worm tubes, clam burrows (Strathearn et al. 1988), other burrows and general bioturbation (Colburn et al. 1988), and shark teeth (Colburn et al. 1988). There are locally abundant gastropods in sandstone beds, and foraminifera, microbial structures, and sparse mollusks in limestone (Yerkes and Campbell 1979).

The Coal Canyon Formation is fossiliferous within SAMO. Hoots (1931) listed bivalves, gastropods, and echinoids from 11 “Martinez Formation” localities in the eastern Santa Monica Mountains, and reported the presence of microbial reefs. Soper (1938) reported microbial reefs in the Santa Ynez and Temescal canyon areas, and listed bivalves and gastropods from 11 localities in the central Santa Monica Mountains. Yerkes and Campbell (1979) noted the presence of mollusks in the Tuna and Topanga canyon areas. Squires (1980) named the crab species *Cyclocorystes aldersoni* (holotype LACMIP 5863) (SAMO Figure 6) from a locality on the east bank of the south fork of Garapito Creek. Saul (1983a) reported gastropods from several Santa Monica Mountains localities, including the Quarry Canyon and Garapito Creek areas, and noted the presence of reworked Cretaceous gastropods as well. Colburn et al. (1988) reported fossils from several localities within or just outside of SAMO. They found bivalves and gastropods at Fryman Canyon Overlook and Pacoima Road, algae and gastropods at Las Flores Canyon, and algae, brachiopods, bivalves, possible gastropods, and shark teeth at Solstice Canyon. Squires (1990) named the gastropod species *Tenagodus californiensis* (holotype LACMIP 8086) (SAMO Figure 6) from a specimen collected in the Garapito Creek area. Mack (1993) and Mack and Colburn (1993) described microbial limestones in the western Santa Monica Mountains, in rocks they assigned to the Santa Susana Formation. Nyborg et al. (2003) briefly discussed the crab assemblage of the Coal Canyon Formation; several years later,

Nyborg et al. (2009) named the crab species *Costacopluma squiresi* (holotype LACMIP 13560) from the head of Quarry Canyon. At this time they were using the Santa Susana Formation name for these rocks.



SAMO Figure 6. Left: *Cyclocorystes aldersoni* (holotype LACMIP 5863). Right: *Tenagodus californiensis* (LACMIP 8087) from SAMO.

A number of fossils, particularly of mollusks, have been described from the Pacific Palisades–Santa Ynez Canyon area that is surrounded by SAMO. Compton (1944) named the gastropod species *Serratocerithium usanium* (holotype Leland Stanford Junior University [LSJU] 7756, now in the California Academy of Sciences geological collections) from a ridge east of Santa Ynez Canyon, where it was found with other gastropods and bivalves. Strathearn and Griffis (1986) and Strathearn et al. (1988) described microfossils from the Trailer Canyon area, including organic-walled microfossils, foraminifera, dinoflagellate and coralline algae, fern and lycopod spores, and gymnosperm and angiosperm pollen. Squires (1993) reported gastropods from the Trailer Canyon area. Squires (1997) reported gastropods from several sites in the Canoga Park and Topanga quadrangles, and noted the presence of microbial limestone in Quarry Canyon. Squires and Kennedy (1998) named the gastropod species *Terebralia susana* (holotype LACMIP 7942) (SAMO Figure 7) from a locality on Quarry Canyon either just within or just outside of SAMO, and noted the presence of bivalves from localities just outside of the recreation area. They also discussed the microbial limestone of the area, but reported that important outcrops had been destroyed during construction projects. Squires and Saul (1998) named two species of the bivalve *Plicatula* from localities probably just outside of SAMO: *P. lapidicina* (holotype LACMIP 11278) from Quarry Canyon; and *P. trailerensis* (holotype LACMIP 11280) from the Trailer Canyon–Quarry Canyon divide. Squires and Saul (2001) named the gastropod genus and species *Spinigeropsis calafia* (holotype LACMIP 12873) from the Palisades Highlands, just outside of SAMO. Squires and Saul (2002) described gastropods from Trailer Canyon. Squires and Saul (2007) described gastropod specimens from locations in the Palisades Highlands, Quarry Canyon, and Trailer Canyon, all just outside of SAMO; these specimens were associated with the microbial limestone zone.

Finally, there are reports of interest for SAMO of fossils from the Coal Canyon Formation interval without specific localities. Dickerson (1914) reported that a Stanford University geology class collected fossils from the “Martinez Formation” of the Santa Monica Mountains in the Calabasas quadrangle, which could be either the Coal Canyon Formation or Santa Susana Formation. Waring (1917) reported corals, bivalves, and gastropods were present south of the Santa Monica Mountains in the “Martinez Formation”.



SAMO Figure 7. *Terebralia susana* (holotype LACMIP 7942).

Llajas Formation (Lower–Middle Eocene)

The Llajas Formation interval used to be identified as the Tejon Formation (Squires 1983a). It is principally known from the Simi Hills area (Dibblee 1982a), and is present locally in the Santa Monica Mountains (Yerkes and Campbell 1979). The SAMO rocks that may belong to this formation are found in Solstice Canyon and Steep Hill Canyon. They are mostly sandstone and siltstone, with some conglomerate and mudstone (Yerkes and Campbell 1979). The section in the Simi Hills and Simi Valley is 545 m (1,790 ft) thick, and includes a basal nonmarine conglomerate beneath marine sandstone and siltstone (Squires and Filewicz 1983). The Santa Monica Mountains section is 400 m (1,300 ft) thick, and has no basal conglomerate (Dibblee 1982a). In the Simi Hills area, the middle part of the formation is sometimes identified as the “Stewart Bed” (Squires 1983b). The upper contact with the Sespe Formation is disconformable (Squires and Filewicz 1983).

Deposition of the Llajas Formation occurred during a marine transgression and part of the following regression, leading depositional settings to change from nonmarine coastal alluvial fans, to shallow marine, to offshore, and back to shallow marine (Squires 1981b, 1983a, 1984; Squires and Demetron 1995). The water was tropical (at least 20 °C [68 °F]; Squires 2001) and less than 80 m (260 ft) deep (Squires 1984). Fossils indicate the formation was deposited from the middle Early Eocene to the

early Middle Eocene (Squires and Demetron 1995), and include representatives of the Ulatisian foraminiferal stage (49.6–42.5 Ma; foraminiferal stage dates are approximate, after McDougal [2007]) (Mason 1989).

The Llajas Formation has a diverse fossil assemblage, mostly made up of marine invertebrates. The possible Llajas Formation of SAMO appears to be fossiliferous, but has not attracted much attention. Waring (1917) reported bivalves and gastropods in the “Tejon Formation” south of the Santa Monica Mountains. Yerkes and Campbell (1979) mentioned the presence of gastropods in the possible Llajas Formation of the mountains, and Dibblee (1982a) noted that shallow-marine fossils were locally abundant. Overall, the Llajas Formation fossil assemblage includes coccoliths, foraminifera (Filewicz and Hill 1983), radiolarians (another type of “shelled” protist), diatoms (a type of algae with cell walls of silica) (Schymiczek 1983), plant fragments including petrified wood (sometimes bored by invertebrates) (Squires 1983a, 1984), corals, bryozoans, brachiopods (lamp shells), bivalves, nautiloid and sepiidan (cuttlefish) cephalopods, gastropods, scaphopods, crabs (Squires 1983b, 1984, 2001), lobsters (Squires 2001), ostracodes (seed shrimp) (Schymiczek 1983), echinoids, worm tubes (Squires 1983b, 1984, 2001), other burrows, general bioturbation (Squires 1983a), and shark and ray teeth (Squires 1984, 2001). The gastropod *Turritella* is abundant enough in some horizons to form “reefs” (Cushman and McMasters 1936). Fossils are mostly found in channel fill in shallow-marine deposits (Squires 1984). They were often transported from shallower areas (Squires 1979).

Sespe Formation and Carbon Canyon Tongue of the Vaqueros Formation (Middle Eocene–Lower Miocene)

The Sespe Formation is well known from the Santa Monica Mountains and Simi Valley, where it is part of a complex series of intertonguing terrestrial, nearshore shallow-water marine, and offshore deep-water marine formations. In brief, in the area of interest, it is a terrestrial formation that was affected by a large marine transgression near the end of its deposition; the lower part of this transgression is represented by the Carbon Canyon Tongue of the Vaqueros Formation, which occurs in the upper part of the Sespe Formation, and the upper part is represented by the Saddle Peak Member of the Topanga Canyon Formation/Lower Topanga Formation. Marine sedimentation eventually spread over the entire depositional area. In those areas where the intervening Sespe Formation is not present, the two marine formations are difficult to distinguish, except by fossils, and so are sometimes described together as the Lower Topanga Formation or an unnamed marine sandstone (Yerkes and Campbell 1979; Dibblee 1982a; Schwartz and Colburn 1987; Dibblee and Ehrenspeck 1993a; Fritsche 1993). In the Santa Monica Mountains, the Sespe Formation is primarily a nonmarine redbed sequence of sandstone, pebbly sandstone, and mudstone beds (Yerkes and Campbell 1979). It is 490 to 1,000 m (1,600 to 3,275 ft) thick in the mountains (Soper 1938), but

reaches a thickness of 1,650 m (5,410 ft) in the Simi Valley (Squires and Filewicz 1983). Because the Carbon Canyon Tongue of the Vaqueros Formation is sandwiched by rocks of the Sespe Formation, it is included in this section as well.

The Sespe Formation is locally divisible into members (Yerkes and Campbell 1979). Soper (1938) divided the Sespe Formation of the Santa Monica Mountains into lower, middle, and upper members, and the main body of the formation is sometimes divided into three members in the Simi Valley (Kelly 1990; Kelly et al. 1991; Bown 1994; Prothero et al. 1996; Lander 1997). The Sespe Formation along Piuma Road on Saddle Peak is divided into an unnamed lower portion and an upper part named the Piuma Member (Yerkes and Campbell 1979; Lander 2011). The Piuma Member (named after rocks on Piuma Road in the recreation area) is composed of rocks that intertongue westward into and bracket the nearshore shallow marine Vaqueros Formation and the unconformably overlying lower part of the Topanga Canyon Formation (Yerkes and Campbell 1979; Lander 2011). Yerkes and Campbell (1979) originally gave the Piuma Member an arbitrary base, distinguishing the member by its thinner beds, finer-grained sandstone, absence of pebble and cobble conglomerate, and more interbedded lacustrine siltstone compared to the unnamed lower member, which was diagnosed by its thicker bedded and coarser-grained sandstone and conglomerate. A tongue of the Vaqueros Formation divided the Piuma Member into lower and upper parts (Yerkes and Campbell 1979). This tongue of marine rocks is now known as the Carbon Canyon Tongue of the Vaqueros Formation, after Carbon Canyon in SAMO (Lander et al. 2001b; Whistler and Lander 2003; Lander 2011); some older references call it the Saddle Peak Tongue (Fisk et al. 2001; Lander et al. 2001a), but there was already a Saddle Peak Member at the base of the overlying Topanga Canyon Formation. The interposed Carbon Canyon Tongue is composed of sandstone, mudstone, and shale (Schwartz and Colburn 1987). Fritsche (1993) made several proposals regarding the members and tongues of the Sespe/Vaqueros/Topanga interval, including limiting the Piuma Member to the rocks above the Carbon Canyon Tongue of the Vaqueros Formation, designating it as the Piuma Tongue, and moving the terrestrial Fernwood Member of the Topanga Canyon Formation to the Sespe Formation as its upper tongue, but these proposals have not been widely adopted.

The Sespe Formation was deposited during a time of low sea level, which was falling partly in response to the development of ice on Antarctica. Sea level might have fallen by 400 m (1,300 ft), making it perhaps 200 m (660 ft) lower than present (Lander 1983). Some of what appears to be a decrease in sea level is actually the result of regional uplift of the western Transverse Ranges block, which occurred as the western edge of the North American continent overrode the progressively shallower floor of the Pacific Ocean and approached the East Pacific Rise (Lander 1994, 1997, 2011). In the SAMO area, the Sespe Formation is an interval of fluvial deposition (Dibblee 1982a), with depositional settings including braided and meandering

ivers, floodplain overbanks, salt marshes, and coastal environments (Bown 1994). Braided rivers are prominent low in the formation, and are replaced by meandering rivers and finally coastal settings (Bown 1994). Well cores from this formation taken beneath the Santa Barbara Channel northwest of SAMO include delta plain rocks (Miles and Rigsby 1990). Possible marine beds have been found in some locations (Fritsche and Shmitka 1978). The Carbon Canyon Tongue of the Vaqueros Formation was deposited in lagoonal to shallow marine settings (Schwartz and Colburn 1987). Originally, the Sespe Formation was interpreted as representing an arid climate, but the discovery of mammal fossils indicated a more humid setting (Soper 1938). A savannah with a gallery forest is now thought to have been present, under a seasonal climate (Bown 1994). The intertonguing contact with marine units represents the shoreline (Campbell and Yerkes 1976).

Deposition occurred during a long period of time, with at least one substantial hiatus between approximately 36 and 29.5 Ma (Prothero et al. 1996). Two cycles of regional uplift and subsidence may have occurred during deposition (Howard 1988, 1989; Bown 1994). Land mammals in the formation indicate an age range including at least the early Uintan to Arikareean North American land mammal ages (approximately 45.3 to 27.6 Ma) for the main portion of the formation (Bown 1994; Lander 2011), and an early Hemingfordian age (approximately 21.4 to 20.0 Ma) for the upper part of the Piuma Member (Whistler and Lander 2003; Lander 2011). Early and possibly late Arikareean land mammals are known from the lower part of the Piuma Member, whereas early Hemingfordian mammals are known from the upper part in SAMO (Fisk et al. 2001; Lander et al. 2001; Whistler and Lander 2003; Calvano et al. 2008; Lander 2011). Air-fall tuffs (rocks made of consolidated volcanic ash) called the Lower and Upper Saddle Peak tuffs occur in the lower and upper parts of the Piuma Member, bracketing the Carbon Canyon Tongue of the Vaqueros Formation. The tuffs date to 27.2 ± 0.2 and 21.2 ± 0.2 Ma, respectively (Lander et al. 2003; Calvano et al. 2008; Lander 2011).

The Piuma Member of the Sespe Formation is fossiliferous within SAMO, and includes both plants and animals (Fisk et al. 2001; Lander et al. 2001a, 2001b; Whistler and Lander 2003; Calvano et al. 2008; Lander 2011) (some occurrences in these documents have since been reassigned to the Carbon Canyon Tongue; see Lander [2011] for the most recent assignment) The recreation area's fossil assemblage includes root casts (Lander 2011), burrows (Lander 2011), frogs (Lander et al. 2001a; Lander 2011), tortoises (Lander 2011), didelphid marsupials (opossums), rodents, pikas (Fisk et al. 2001; Lander et al. 2001a, 2001b; Whistler and Lander 2003; Calvano et al. 2008; Lander 2011), and camels (Whistler and Lander 2003; Lander 2011). Most fossils have been found in road cuts along Piuma Road that expose 440 m (1,440 ft) of the Piuma Member, with a thin interval of the Carbon Canyon Tongue of the Vaqueros Formation at 98 m (320 ft) up (Whistler and Lander 2003; Lander 2011). The lower part of the member includes the Lower

Piuma Road Local Fauna at 4.3 to 19.9 m (14 to 65 ft) above the base. Fossils of frogs, the didelphid *Herpetotherium*, and the cricetid or murid mouse *Leidymys nematodon* have been found in this interval (Fisk et al. 2001; Lander et al. 2001a, 2001b; Calvano et al. 2008; Lander 2011). D. P. Whistler and E. H. Lindsay regard the rodent as a new species of *Leidymys* (B. Lander, Paleo Environmental Associates, pers. comm., January 2012).

Above the lower Piuma Member, the Carbon Canyon Tongue of the Vaqueros Formation within SAMO contains a molluscan assemblage and two florules. The sandstone bed at the base of the tongue contains the middle Vaquerosian turret snail *Turritella inezana bicarina* (Lander et al. 2001a, 2001b; Calvano et al. 2008; Alderson 2011; Lander 2011). The florules and land mammal local fauna were mistakenly assigned to the upper Piuma Road Member of the Sespe Formation in the past (Lander 2011). The Lower Piuma Road Florule is based on compressions of logs up to 2 m (7 ft) long (Fisk et al. 2001; Lander et al. 2001b; Lander 2011). Myliobatid ray pavement teeth and mammal bones, including a lower jaw possibly representing a late Arikareean blastomerycine moschid (musk deer), are associated with the florule (Fisk et al. 2001; Whistler and Lander 2003; Calvano et al. 2008; Lander 2011). The Upper Piuma Road Florule is based on fronds of the palm *Sabalites* (Fisk et al. 2001; Calvano et al. 2008; Lander 2011). Palm fronds from the Carbon Canyon Tongue in SAMO are probably the same as the reed casts of Yerkes and Campbell (1979) (Lander 2011).

Finally, the upper Piuma Member of the Sespe Formation includes the Upper Piuma Road Local Fauna, 5.2 to 9.1 m (17 to 30 ft) below the base of the overlying Saddle Peak Member of the Topanga Canyon Formation (Lander et al. 2001a; Calvano et al. 2008; Lander 2011). It has yielded fossils of the pika *Cuyamalagus* and the mice *Trogomys* and *Yatkolamys* (Fisk et al. 2001; Lander et al. 2001a, 2001b; Whistler and Lander 2003; Calvano et al. 2008; Lander 2011). D. P. Whistler and E. H. Lindsay regard the putative *Yatkolamys* material as belonging to a new species that is not referable to *Yatkolamys* (B. Lander, pers. comm., January 2012). Another possible Piuma Member mammal locality has been found along Malibu Canyon Road, southwest of Saddle Peak. This site has yielded camel remains (Whistler and Lander 2003; Lander 2011). Root casts, burrows, and a tortoise bone have also been found in the upper part of the member in the recreation area (Lander 2011).

As a whole, including areas outside of SAMO such as the Simi Valley area, South Mountain–Oak Ridge, and the Santa Ana and Santa Ynez Mountains, the Sespe Formation has yielded a number of terrestrial fossils. Briefly, plants are represented by petrified wood and leaf impressions (Loel and Corey 1932). Invertebrates are represented by mollusks (Kelly et al. 1991) and trace fossils (Fritsche and Shmitka 1978). The non-mammalian vertebrate assemblage includes sharks, rays (Whistler and Lander 2003), frogs (Kelly et al. 1991), tortoises

(Brattstrom 1961), soft-shelled turtles (Golz and Lillegraven 1977), several types of lizards (Brattstrom 1955; Golz and Lillegraven 1977), boid snakes (Brattstrom 1955), crocodilians, and birds (Golz and Lillegraven 1977). More than 100 fossil mammal species from 35 families have been recognized in the Sespe Formation (Bown 1994; Lander 1997). The following lists are not intended to be exhaustive for references, but to illustrate the breadth of mammal taxa. Sespe Formation mammals that are not carnivorans, perissodactyls (odd-toed ungulates), or artiodactyls (even-toed ungulates) include didelphid marsupials, several groups of insectivores, the extinct insectivore-like apatemyids and pantolestids, primates and their nearest relatives, several groups of rodents, rabbits and pikas, and extinct early carnivorous mammals (hyaenodont creodonts and miacids) (Golz 1976; Golz and Lillegraven 1977; Kelly 1990; Bown 1994; Whistler and Lander 2003). Carnivorans are represented by bears (Wang et al. 2009), amphicyonids (beardogs) (Hunt 2011), true dogs (including the extinct “bone crusher” borophagines), mustelids (weasels and allies), indeterminate cats (Whistler and Lander 2003), and nimravids (false saber-toothed cats) (Lander 1983). Perissodactyls include early tapir relatives (helatids and isctolophids), rhinoceroses (semiaquatic amynodonts, swift hyracodonts, and true rhinocerotids), brontotheres, and horses (Golz 1976; Golz and Lillegraven 1977; Bown 1994). Finally, artiodactyls are represented by hippo-like anthracotheres (Bown 1994), peccaries, pig-like entelodonts (Whistler and Lander 2003), a variety of small extinct deer-like ungulates (Golz 1976; Golz and Lillegraven 1977; Lander 1983, 2011), moschids (Whistler and Lander 2003), oreodonts and related agriochoerids (sheep-like artiodactyls), and camels (Bown 1994). Many of the fossils recovered since the 1980s are microfossils such as rodent teeth, found through sieving. Construction projects have yielded many specimens (Whistler and Lander 2003). A number of local faunas have been designated, like those on Piuma Road (Golz 1976; Mason 1989; Kelly 1990; Bown 1994; Whistler and Lander 2003).

Vaqueros Formation (exclusive of the Carbon Canyon Tongue) (Upper Oligocene–Lower Miocene)

The Vaqueros Formation has a complex history as a term. It was originally defined and used as a biostratigraphic term based on marine invertebrate fossils (Miles and Rigsby 1990). Defining formations by fossils is no longer accepted, and the Vaqueros Formation is now limited to a difficult-to-define section of strata in coastal southern California (Dibblee and Ehrenspeck 1993a; Fritsche 1993). Thus, older references sometimes apply the term “Vaqueros Formation” to rocks that are no longer included in the formation, and there is still biostratigraphic use of the description “Vaquerosian” for the old “Vaqueros Formation” fossil assemblage. Technically, the Vaqueros and overlying Topanga (or Topanga Canyon) formations can only be distinguished by fossil content, which is an invalid metric for separating formations. To address this, some authors have proposed merging the two into a greater “Lower Topanga

Formation,” in which the old Vaqueros Formation section is the lower “Lower Topanga Formation” (Dibblee and Ehrenspeck 1993a), or an unnamed sandstone with informal “Vaqueros” and “Topanga Canyon” portions (Fritsche 1993).

In the Santa Monica Mountains, the Vaqueros Formation is a gray to brown unit (Soper 1938), up to 760 m (2,500 ft) thick (Dibblee 1982a). It is mostly composed of sandstone, with some interbedded reddish or greenish mudstone. West of the Malibu Beach quadrangle, the lower part of the formation is a dark siltstone unit called the Danielson Member, named for Danielson Ranch on Big Sycamore Canyon in western SAMO. The upper part of the formation west of the Malibu Beach quadrangle is the more typical sandy San Nicholas Member, named for San Nicholas Canyon in SAMO (Yerkes and Campbell 1979). The Danielson Member and Encinal Member of the overlying Topanga Canyon Formation share some lithological characteristics with the Rincon Formation (see the CHIS summary in this report for more details on the Rincon Formation), and Fritsche (1993) proposed assigning them to that formation. Yerkes and Campbell (1979) described but did not name a basal eastern tongue that divides the Piuma Member of the Sespe Formation into lower and upper parts. This tongue is now known as the Carbon Canyon Tongue (discussed above) (Whistler and Lander 2003; Lander 2011).

Deposition occurred during a large-scale transgression, with smaller transgressions and regressions within the larger cycle (Blake 1983; Rigsby 1994), although in the Santa Monica Mountains, apparent regression was actually the result of rapid sedimentation permitting a delta to prograde (Oborne 1993). The Danielson Tongue represents offshore marine deposition (Fritsche 1993). The rest of the formation was deposited in marginal marine settings (Fritsche 1993). Osborne (1993) includes a detailed description of various depositional settings and associated fossils in the central Santa Monica Mountains. The age of the formation differs somewhat by location, but it can be considered as an upper Oligocene–lower Miocene formation. There are Zemorrian-age (34.0–23.0 Ma) foraminifera in the Danielson Member and Saucian-age (23.0–17.5 Ma) foraminifera in the San Nicholas Member (Yerkes and Campbell 1979).

The Vaqueros Formation of the Santa Monica Mountains has a variety of fossils, such as bivalves, gastropods, abundant fragments of barnacles, echinoids, burrows, and general bioturbation. Many voids in the rocks represent places where plant material decomposed, and shells can be abundant enough to form coquinoid layers (layers essentially made of fossils) (Fritsche et al. 1993). Loel and Corey (1932) reported on Vaqueros Formation fossils from seven localities in SAMO. Bivalves and gastropods were the most widely-distributed fossils, followed by barnacles and echinoids. One site also had bryozoans, brachiopods, and worm tubes (Loel and Corey 1932). Soper (1938) reported eight fossil localities in the central Santa Monica Mountains; among the types of fossils found was

the biostratigraphically-useful gastropod *Turritella inezana*. Osborne (1993) reported carbonaceous debris, petrified wood, root traces, bivalves, gastropods, barnacles, burrows, worm tubes, and general bioturbation from a variety of sites in the central Santa Monica Mountains. Shelly fossils are often found as fragments, and in some cases pits have been found where barnacles had eroded (Osborne 1993). The Danielson Member in the recreation area has yielded foraminifera, gastropods, and fish scales (Yerkes and Campbell 1979). Finally, the San Nicholas Member has yielded foraminifera, bivalves, gastropods (Yerkes and Campbell 1979), and invertebrate burrows (Fritsche et al. 1993).

Over its entire depositional area, the Vaqueros Formation’s marine single-celled and invertebrate assemblage includes foraminifera (Blake 1983), radiolarians, diatoms (Cushman and LeRoy 1938), corals (Loel and Corey 1932), bryozoans (Loel and Corey 1932; Squires and Fritsche 1978), brachiopods (Loel and Corey 1932), bivalves, gastropods, scaphopods, barnacles, crabs (Loel and Corey 1932; Squires and Fritsche 1978), ostracodes (Cushman and LeRoy 1938), echinoids (Loel and Corey 1932; Squires and Fritsche 1978), and invertebrate trace fossils such as worm tubes (Loel and Corey 1932), burrows, and general bioturbation (Daniel-Lyle 1995). Marine vertebrates are represented by teeth of sharks and rays (Loel and Corey 1932; Squires and Fritsche 1978; Daniel-Lyle 1995), pinnipeds (Loel and Corey 1932), the elephantine sea mammal *Desmostylus* (Squires and Fritsche 1978), dolphins (Barnes et al. 2003), whales (Dooley et al. 2004), and indeterminate bones (Squires and Fritsche 1978; Daniel-Lyle 1995). Terrestrial fossils, typically washed into the marine environment, are represented by petrified and carbonized wood (Loel and Corey 1932), root traces, turtles, rhinoceroses, horses, entelodonts, camels, and indeterminate artiodactyls (Daniel-Lyle 1995).

Topanga Canyon Formation/Lower Topanga Formation (Lower–Middle Miocene)

Early works on the Santa Monica Mountains distinguished a Topanga Formation, which Yerkes and Campbell (1979) raised to a group and divided into three formations. In ascending order, they are the Topanga Canyon Formation (named from Topanga Canyon in SAMO), Conejo Volcanics, and Calabasas Formation. They further subdivided the Topanga Canyon Formation into several members in SAMO. They designated a dark siltstone unit of deep-water origin as the Encinal Member in the western part of the range, west of Trancas Canyon. In the central part of the range, east of Malibu Canyon, they split the formation into three members, in ascending order the nearshore shallow-water Saddle Peak Member, the terrestrial Fernwood Member, and the nearshore shallow-water Cold Creek Member. The Saddle Peak and Cold Creek members are composed of sandstone, pebbly sandstone, silty sandstone, and sandy siltstone, and the Fernwood Member is composed of pebbly sandstone with some mudstone and limestone. The undivided Topanga Canyon Formation between the two areas is lithologically similar to the Saddle Peak and Cold Creek

members above its basal conglomerate (Yerkes and Campbell 1979). As noted above, the nomenclature employed by Dibblee and coworkers (see for example Dibblee and Ehrenspeck 1993a) includes the Vaqueros and Topanga Canyon formations together as the Lower Topanga Formation. The Topanga Canyon Formation becomes the upper Lower Topanga Formation in this system; as noted above, the Vaqueros Formation is often considered distinct by other workers using the Lower Topanga nomenclature. The Topanga Canyon Formation is 670 m (2,200 ft) thick (Dibblee 1982a), and the upper contact with the Conejo Volcanics and/or Middle Topanga Formation is unconformable in places (Durrell 1954; Fritsche 1993). In the past, the Topanga Canyon/Lower Topanga Formation interval had also been called the Temblor Formation, after a biostratigraphic formation, but this usage is no longer accepted (Dibblee 1982a).

The Topanga Canyon Formation is interpreted as including two major marine advances separated in time by a prograding delta. The shoreline is thought to have passed through what is now SAMO, with a delta in the Malibu Beach quadrangle (Flack 1993). The Encinal Member is a deep marine unit (Yerkes and Campbell 1979). The Saddle Peak and Cold Creek members are nearshore marine in origin (Yerkes and Campbell 1979); Flack (1993) interpreted the Cold Creek Member to show evidence of accelerated subsidence during deposition. Both the Saddle Peak and Cold Creek members have deltaic influences (Fritsche et al. 1993). The Fernwood Member was deposited under fluvial to brackish conditions (Yerkes and Campbell 1979), perhaps on a delta plain (Flack 1993). The undivided section has a fluvial base and becomes nearshore marine higher in section (Yerkes and Campbell 1979). Deposition of the Topanga Canyon Formation occurred during the Early Miocene. The Encinal Member includes foraminifera from the Saucian (23.0–17.5 Ma) and Relizian (17.5–15.0 Ma) stages (Yerkes and Campbell 1979), and there are mammals of the Late Hemingfordian stage (around 15.5 Ma) in the Fernwood Member (Lander et al. 2001a).

The Topanga Canyon/Lower Topanga Formation is extensively fossiliferous in SAMO. The Encinal Member has foraminifera (Yerkes and Campbell 1979; Campbell and Yerkes 1980; Flack 1993), plant and wood fragments, and fish scales and bones (Flack 1993). The Saddle Peak Member has bivalves and gastropods near its base (Yerkes and Campbell 1979; Lander 2011). Near the base of the formation in the area east of the junction of Schueren Road, Stunt Road, and Saddle Peak Road is a bed with abundant pectinid bivalves that is a local stratigraphic marker (Campbell and Yerkes 1980); a shell from this bed has been dated by strontium isotopes to 20.0 Ma (Lander 2011), and the Saddle Peak Member is implied by location and stratigraphy. The Fernwood Member has possible microbial limestone (Yerkes and Campbell 1979), leaves of land plants, petrified wood (Fisk et al. 2001; Lander 2011), root traces (Flack 1993), gastropods, invertebrate borings (Yerkes and Campbell 1979), lizards, snakes, insectivores, rodents, rabbits, horses, rhinoceroses, and camels (Lander 2011). The

Calabasas Peak Motorway Florule in the upper half of the member has plants including *Platanoxylon* (like a plane tree or sycamore); rodent fossils have been found low in this plant interval (Fisk et al. 2001; Lander 2011). The Stunt Road Local Fauna near the middle of the member has lizards, snakes, shrews, the mice *Mookomys* and *Trogomys*, rabbits, a possible rhinoceros, the horse *Parapliohippus*, and a camel. Higher in the member is the Calabasas Peak Motorway Local Fauna, with fossils of a squirrel, a mouse, and a camel (Whistler and Lander 2003; Lander 2011).

The Cold Creek Member of SAMO has a locally abundant mollusk fauna (Yerkes and Campbell 1979). This fauna was originally described by Arnold (1907) (Yerkes and Campbell 1979; Campbell and Yerkes 1980). Fossils have long been collected from Topanga Canyon and Old Topanga Canyon (Campbell et al. 2007). The assemblage from the canyons includes more than 130 species (Koch et al. 2004). The well-known Amphitheater locality in Old Topanga Canyon is under private ownership, and was closed to collecting as of 2004 (Koch et al. 2004). Arnold (1907) named 11 species and subspecific variations of bivalves and gastropods from what he described as the lower Miocene “yellow sandstone” at the head of Topanga Canyon. These included the bivalve *Mytilus mathewsonii* var. *expansus* (holotype USNM [National Museum of Natural History] 164968) (SAMO Figure 8) and the gastropods *Cerithium topangensis* (holotype USNM 164976), *Chlorostoma (Omphalius) dalli* (holotype USNM 164984), *C. (O.) dalli* var. *inornatus* (holotype USNM 164986), *C. (O.) dalli* var. *subnodosus* (holotype USNM 164985), *Macron merriami* (holotype USNM 164982), *Ocenebra* (more properly *Ocenebra*) *topangensis* (holotype USNM 164995) (SAMO Figure 9), *Pleurotoma (Bathytoma) keepi* (holotype USNM 164993), *Purpura edmondi* (holotype USNM 164983), *Sigaretus perrini* (holotype USNM 164979), and *Turbo topangensis* (holotype USNM 164980). Other animals from the Old Topanga Canyon–Topanga Canyon fossil sites include barnacles, crabs, echinoids, mako sharks, basking sharks, eagle rays, fish, sea lions, and whales, such as the pygmy baleen whale *Nannocetus* (Lander 2011). The gastropod species *Zonaria (Zonaria) emmakingae* (holotype LACMIP 12277) (SAMO Figure 10) was named from a fossil found 30 m (100 ft) below the *Turritella* gastropod bed in the Cold Creek Member on the south side of Old Topanga Road, roughly 5.3 km (3.3 miles) south of Ventura Freeway (Groves 1994; J. Alderson, pers. comm., January 2012). Brachiopods have also been found in the Cold Creek Member in the central Santa Monica Mountains (Bottjer et al. 1982), and fossiliferous lags, bioturbation, and fish scales have been found in this unit on Stunt Road (Fritsche et al. 1993). Sparse remains of sea cows have also been found in this member in SAMO (Lander 2011). Beds lying at and very near the base of the Cold Creek Member, and sometimes exposed in the roadbed of and in roadcuts along Calabasas Peak Motorway, have yielded a number of marine invertebrate taxa, including the bivalves *Diplodonta*, *Mytilus*, and *Tagelus*, the gastropods *Calyptraea* and the very rare *Melongena californica*, the echinoid

Vaquerosella coreyi, and an indeterminate sea cow (Alderson 2011; Lander 2011).



SAMO Figure 8. *Mytilus mathewsonii* from SAMO (LACM, formerly UCLA).



SAMO Figure 9. *Ocenebra topangensis* from SAMO (LACMIP 2236).



SAMO Figure 10. *Zonaria (Zonaria) emmakingae* (holotype LACMIP 12277).

Finally, there are reports of fossils within SAMO from the Topanga Canyon Formation where the member is not specified or the formation is undivided. A variety of marine and nonmarine fossils have been found, including carbonaceous debris, stromatolites (layered sedimentary structures formed by microorganisms), foraminifera, plant and wood fragments, leaf impressions, root traces, bivalves, gastropods, barnacles, invertebrate burrows, fish scales and bones, and cetacean bones (Flack 1993). Mollusks are locally abundant in the undivided Topanga Canyon Formation (Yerkes and Campbell 1979). Soper (1938) reported a fossiliferous horizon with bivalve reefs near the base of the formation, 15 m (50 ft) above the Sespe Formation.



SAMO Figure 11. *Anadara (Anadara) topangensis* (holotype UCLA 3258, now LACMIP 10095).

Some early reports on the geology of the Santa Monica Mountains include references to fossils from the Topanga Formation where the subdivision is not specified, and thus could be referring to the Topanga Canyon, Conejo Volcanics, or Calabasas formations. Wiedey (1928) named the bivalve species *Pterina jordani* (holotype San Diego Natural History Museum [SDNHM] 25) and *Tellina oldroydi* (holotype SDNHM 36) from rocks near the head of Dry Canyon in the “Temblor Formation”. The stratigraphic position is probably in the lower Cold Creek Member of the Topanga Canyon Formation (J. Alderson, pers. comm., January 2012). Hoots (1931) reported foraminifera, plant fragments, bivalves, gastropods, barnacles, echinoids, and vertebrate ribs from the Topanga Formation of the eastern Santa Monica Mountains, which includes the Topanga Canyon Formation. Soper (1938) reported a warm-water assemblage including bivalves, gastropods, and echinoids from a number of localities in the Topanga Formation of the central Santa Monica Mountains, at least 33 of which are from SAMO and most of which are from what would now be called the Topanga Canyon Formation or the Lower Topanga

Formation. Reinhart (1943) named the bivalve species *Anadara* (*Anadara*) *topangaensis* (holotype UCLA 3258, now LACMIP 10095) (SAMO Figure 11) from a site in the Topanga Formation less than 1 km east of Upper Franklin Canyon Reservoir. Susuki (1951) reported four fossiliferous zones in the Topanga Formation; using modern nomenclature, the lowest zone is in the Saddle Peak Member, the next highest is in the Cold Creek Member, and the upper two zones are in the Calabasas Formation (Yerkes and Campbell 1979; Campbell et al. 2007).

Conejo Volcanics (Lower Miocene)

The Conejo Volcanics are similar to the Miocene volcanics of the Channel Islands (see the CHIS summary in this document for more details) (Weigand and Savage 1993). Found throughout the Santa Monica Mountains, they are primarily composed of volcanic rocks, with some interbedded sandstone, siltstone, limestone, and tuff (Yerkes and Campbell 1979). This formation is up to 2,970 m (9,750 ft) thick (Dibblee 1982a). Basalt is the most common extrusive igneous rock; basaltic andesite and volcanic mudflows (lahars) are also common. Intrusive rocks of the same age include diabase and dacite. The greatest accumulations were in what is now the western and central areas of the mountains (Dibblee and Ehrenspeck 1993a). The Conejo Volcanics have a complex, intertonguing relationship with the partially-lateral and partially-overlying Calabasas Formation (Yerkes and Campbell 1979; Schwartz and Colburn 1987). Dibblee and Ehrenspeck (1993a) designated the interbedded sedimentary rocks as the Middle Topanga Formation, which would include the lower part of Yerkes and Campbell's Calabasas Formation. Fritsche (1993) suggested a similar but distinct separation, putting all of the Middle Miocene sedimentary rocks in the Calabasas Formation. Yerkes and Campbell (1979) named three tongues in the formation in the Point Dume and Malibu Beach quadrangles. From oldest to youngest, they are the Ramera Canyon, Solstice Canyon, and Malibu Bowl tongues, and they have a complex relationship with several subunits of the Calabasas Formation. The Zuma Volcanics found south of the Malibu Coast Fault may be a phase of the Conejo Volcanics (Weigand 1982).

The Conejo Volcanics erupted from near what is now Newbury Park (Schwartz and Colburn 1987). The lower part of the volcanics are submarine, but the middle and upper portions are subaerial in part (Williams 1983); subaerial or submarine deposition differs by location (J. Alderson, pers. comm., January 2012). A low montane subtropical forest grew in this volcanic highland. The elevation of the volcano may have been greater than 1,300 m (4,300 ft) (Stadum and Weigand 1999). The oldest volcanics, found in the eastern Santa Monica Mountains, erupted about 17.4 Ma (McCulloh et al. 2002). Most erupted between 17.1 and 16.3 Ma (Weigand et al. 2002). Bivalves from a number of sites in the interbedded limestones both within and just outside of SAMO were dated by strontium isotopes to between 17.6 ± 0.3 and 16.0 ± 0.5 Ma (McCulloh et al. 2002).

Eruption appears to have ceased by 16 Ma (Weigand et al. 2002).

Although it is primarily igneous in origin, the Conejo Volcanics are fossiliferous, unless restricted to only the igneous flows and intrusions. The fossil assemblage of the formation includes foraminifera (Yerkes and Campbell 1979), wood (Stadum and Weigand 1999), brachiopods, bivalves, gastropods, barnacles, echinoids, worm tubes (Stanton and Alderson 2006, 2010), and fish scales (Yerkes and Campbell 1979). The formation is fossiliferous in SAMO and the Santa Monica Mountains as a whole. McCulloh et al. (2002) found bivalves and gastropods in limestone in the eastern Santa Monica Mountains, including sites in SAMO. Stanton and Alderson (in press) described fossils from limestone in the Conejo Volcanics north of Malibu Canyon in SAMO. They found an assemblage including 70 taxa of brachiopods, bivalves (some with bioerosion), gastropods, barnacles, and serpulid worm tubes, and rarer coralline algae, vascular plants, bryozoans, crabs, echinoids, shark teeth, and fish bones; these fossils are of note because of the rarity of limestone in the Cenozoic of the Pacific coast, and because of the rarity of carbonate rocks being associated with submarine volcanism. The assemblage is dominated by hard-substrate epifaunal (dwelling on the seafloor surface) forms, and indicates a warm temperate environment and neritic depth. The sediment was transported to greater depths by gravity flows (Stanton and Alderson in press). Other fossils in the mountains include foraminifera and fish scales (Yerkes and Campbell 1979). Bivalve molds are sometimes found in sandstone (Campbell and Yerkes 1980). Black marine siltstone found locally at the base has abundant fish scales (Yerkes and Campbell 1979). Thin lenses of bivalve debris are also found low in the formation, in shallow-marine beds (Dibblee and Ehrenspeck 1993a). Several tree taxa are known from wood found in a 13.5 Ma tuff breccia located in the Westlake Village area adjacent to SAMO to the north. They include ponderosa pine, Douglas fir, incense cedar, and members of the Fagaceae (evergreen and live oaks), Rosaceae (mountain mahogany) and Rhamnaceae (mountain lilac) families. Reworked wood has been found in the upper Conejo Volcanics in the vicinity (Stadum and Weigand 1999).

Trancas Formation (Lower–Middle Miocene)

The Trancas Formation is only known from an area south of the Malibu Coast Fault. It is a heterogeneous unit of sandstone, mudstone, shale, claystone, and breccia, up to 290 m (950 ft) thick. The rocks are folded and faulted (Yerkes and Campbell 1979). The Trancas Formation interfingers with the Zuma Volcanics and overlying Monterey Formation (Dibblee 1982a). It has been suggested that some of the breccia found interbedded within this formation and the Zuma Volcanics represents the San Onofre Breccia (Yerkes and Campbell 1979; Dibblee 1982a) (see the CHIS summary in this report for more details concerning the San Onofre Breccia).

The Trancas Formation is a marine unit. Deposition occurred during the Early and Middle Miocene; Relizian and Saucian

foraminifera (23.0–15.0 Ma) have been found. It is fossiliferous within SAMO. Foraminifera are locally abundant in the siltstone, and gastropods have been collected from two localities along the shore in the southwestern-most part of the Point Dume quadrangle (Yerkes and Campbell 1979).

Zuma Volcanics (Lower–Middle Miocene)

Like the Trancas Formation, the Zuma Volcanics are only known from an area south of the Malibu Coast Fault. They are composed of basalt and andesite flows, volcanic and sedimentary breccias, and some interbedded siltstone, sandstone, and shale. The formation is 800 to 1,000 m (2,600 to 3,300 ft) thick (Yerkes and Campbell 1979). The volcanic rocks are probably related to the Conejo Volcanics, and may correlate to them (Dibblee 1982a; Weigand 1982; Weigand and Savage 1993). The Zuma Volcanics interfinger with the Trancas Formation and overlying Monterey Formation (Dibblee 1982a). As with the Trancas Formation, at least some of the breccia may be the San Onofre Breccia (Yerkes and Campbell 1979).

The Zuma Formation is a marine unit, with marine sediment and submarine volcanism (Yerkes and Campbell 1979). It dates to around the Early–Middle Miocene boundary, with volcanics from about 15 Ma (Weigand et al. 2002), and foraminifera of the Relizian and Luisian stages (17.5–13.6 Ma). Foraminifera, the only fossils known from this formation, have been found occasionally in siltstone and shale within SAMO (Yerkes and Campbell 1979).

Calabasas Formation/Upper Topanga Formation (Middle Miocene)

The Calabasas Formation is a heterogeneous unit of sandstone, siltstone, shale, and breccia, locally divisible into a number of members in the Point Dume and Malibu Beach quadrangles. From approximately oldest to youngest, these include the Escondido Canyon Shale, Latigo Canyon Breccia, Dry Canyon Sandstone (deposited during approximately the same interval as the previous two and later), Newell Sandstone, and Mesa Peak Breccia members (Yerkes and Campbell 1979). The formation is 1,100 to 1,200 m (3,600 to 4,000 ft) thick (Dibblee 1982a), and the upper contact with the Modelo Formation is disconformable (Fritsche 1993; McCulloh et al. 2002). The detrital sediments of Lindero Canyon, a local unit recognized in Dibblee Geological Foundation maps and publications, is a gray conglomerate 150 to 200 m (490 to 660 ft) thick in the Thousand Oaks area (see for example Dibblee and Ehrenspeck [1993a]). This unit is otherwise included in the Calabasas Formation (Dibblee and Ehrenspeck 1993a; Fritsche 1993).

The Calabasas Formation is also known as the Upper Topanga Formation (Dibblee 1982a). There is not necessarily a one-to-one equivalence; Dibblee and Ehrenspeck (1993a) intended to include only those rocks above the highest volcanic tongue of the Conejo Volcanics in their Upper Topanga Formation, with everything lower in the Middle Topanga Formation, which would remove the lower members of the Calabasas Formation

from the Upper Topanga Formation. Dibblee (1982a) proposed calling the western shaly rocks the lower Monterey Formation and the eastern sand-rich rocks the Calabasas Formation (this may have resulted from misidentification of rocks in the northwestern Topanga Quadrangle by Yerkes and Campbell [1979]; E. Fritsche, pers. comm., March 2012).

The Calabasas Formation is an offshore marine formation (Fritsche 1993), deposited by deep marine turbidites (Fritsche et al. 1993). The depositional environment became deeper going from east to west (Schwartz and Colburn 1987). The formation dates to the Middle Miocene, with fossils from the Luisian (15.0–13.6 Ma) (Fritsche et al. 1983) and early Mohnian stages (roughly 13.6 Ma) (Yerkes and Campbell 1979).

The fossil assemblage of the Calabasas Formation includes foraminifera, diatoms, natural casts of plants (Yerkes and Campbell 1979), root traces, bivalves, gastropods, barnacles (Taylor and White 1983), echinoids, invertebrate burrows and bioturbation (Fritsche et al. 1983), fish scales (Yerkes and Campbell 1979), whales (Fritsche et al. 1983), and reworked fossils (Yerkes and Campbell 1979; Stadum and Weigand 1999). The Calabasas Formation is fossiliferous within SAMO. In the northern Santa Monica Mountains, it has rare foraminifera, diatom-rich shale, locally abundant plant casts, and fish scales (Yerkes and Campbell 1979). Foraminifera have been collected between Topanga Canyon and Old Topanga Canyon (Campbell and Yerkes 1980). It also has reworked wood (Stadum and Weigand 1999), and possibly reworked mollusks have been found in the McCoy Canyon area (Yerkes and Campbell 1979). Potentially or definitely reworked fossils are known from several of the members as well. The Dry Canyon Sandstone Member has mollusks that are possibly reworked, the Latigo Canyon Breccia Member has fossiliferous rocks reworked from the Vaqueros Formation, and the Stokes Canyon Breccia Member has reworked Paleocene and Eocene fossils (Yerkes and Campbell 1979). Gastropods reworked into this member were found on the west side of the north tributary to Stokes Canyon, and have been described in several publications (Saul 1983; Squires 1997; Squires and Saul 2007). There are also fossil reports from the vicinity of SAMO. Root traces, bivalves, gastropods, barnacles, invertebrate burrows, and whale bones are known from the Simi Valley (Taylor and White 1983). Bivalves, gastropods, barnacles, echinoids, invertebrate burrows and general bioturbation, and a whale vertebra were found in shallow coastal rocks at Big Mountain, 16 km (10 miles) north of Simi Peak in SAMO (Fritsche et al. 1983).

Modelo Formation (Middle–Upper Miocene)

Like much of the stratigraphy of the Santa Monica Mountains, the upper Middle to Upper Miocene section has complex, conflicting nomenclature. This interval is one of the simpler cases: broadly, since the 1920s (Kew 1924; Hoots 1931) these rocks have usually been classified in the Modelo Formation, with two important exceptions: maps and publications by

Thomas Dibblee use the Monterey Formation instead of the Modelo Formation; and some rocks of this age south of the Malibu Coast Fault have been assigned to the Monterey Formation (Yerkes and Campbell 1979). The two names correspond to different depositional origins. The Modelo Formation was named for interbedded sandstone and shale deposited on submarine fans by turbidity currents and fine particles settling out of the water column, respectively. The Monterey Formation was named for fine particles settling onto a submarine basin plain. The rocks in the Santa Monica Mountains are generally more like the Modelo Formation than the Monterey Formation, so authors who use the Modelo Formation name for the SAMO area are emphasizing the lithological relationship. Authors who use the Monterey Formation are emphasizing regional stratigraphic relationships (Fritsche 1993).

The Modelo Formation has been mapped in the eastern half of SAMO (Yerkes and Campbell 1980, 1993, 1994; Yerkes and Showalter 1993; Yerkes 1996a, 1997a). Some exposures in the northern part of the mountains had previously been identified as the Pico Formation (Soper 1938). Hoots (1931) distinguished lower and upper members in the Modelo Formation of the eastern Santa Monica Mountains. The lower member is up to 686 m (2,250 ft) thick and is composed of brown and gray shale, sandstone, conglomeratic sandstone, and volcanic ash. The upper member is up to 700 m (2,300 ft) thick and is composed of white diatom- and foraminifera-rich shale and sandstone, laterally becoming clay shale and sandstone (Hoots 1931). Only the lower part of the formation is present in the central and western Santa Monica Mountains (Yerkes and Campbell 1979). The Sisquoc Formation name is sometimes used for the upper part (Fritsche 1993). The Modelo Formation is thickest in the Calabasas area and thins to the east and west (Rumelhart and Ingersoll 1997). Rumelhart and Ingersoll (1997) divided the Modelo Formation slightly differently, splitting it into three members by differentiating a thin (10 m [33 ft]) dark basal conglomeratic shale. The upper contact of the Modelo Formation with Quaternary rocks is a disconformity (Soper 1938).

The Modelo Formation is a marine formation, built by deposition on submarine fans by turbidity currents and settling sediments (Fritsche 1993). The water reached bathyal depths in the northern part of the Los Angeles Basin (Rumelhart and Ingersoll 1997). Four submarine fans were present in the basin during deposition, three along the eastern part of the basin and a fourth shed from the area of the future Simi Hills (Rumelhart and Ingersoll 1997). The deep part of the basin was anoxic (Schwartz and Colburn 1987). Deposition occurred through much of the latter half of the Miocene. The oldest foraminifera attributed to the formation are from the early Luisian (15.0 Ma) (Clark 1983), and the youngest are from the Delmontian (between 8.7 and 7.4–5.2 Ma) (Rumelhart and Ingersoll 1997), but much of the formation was deposited during the Mohnian stage (13.6–between 8.7 and 7.4 Ma); in fact, foraminifera from

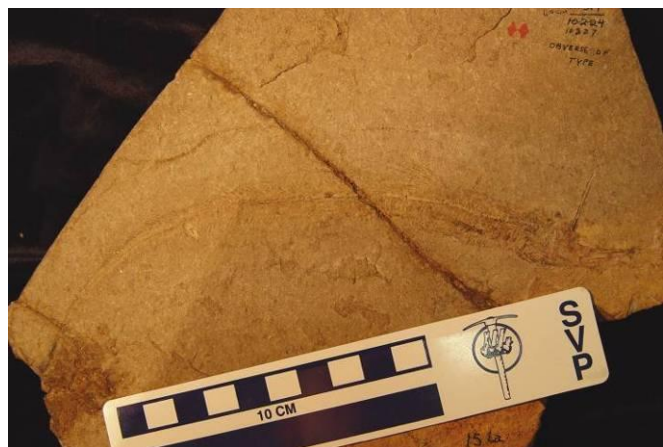
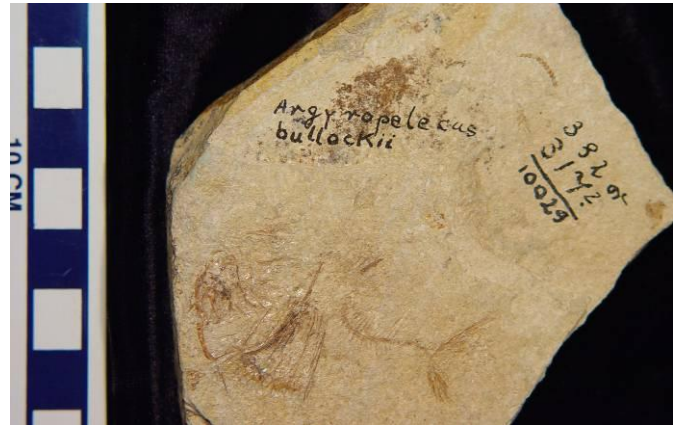
the basal Modelo Formation along Topanga Canyon Road were used to establish the Mohnian foraminiferal stage (Kleinpell 1938; Yerkes and Campbell 1979).

The Modelo Formation is fossiliferous within SAMO and the immediate vicinity. Arnold (1906) reported bivalves and gastropods in the Monterey Formation (=Modelo Formation) of the Santa Monica Mountains. Hoots (1931) described the fossils of the lower and upper members of the Modelo Formation in the eastern Santa Monica Mountains. The lower member yielded leaves of land plants, bivalves, gastropods, echinoids, shark teeth, fish, a sea lion metacarpal, a whale vertebra, and horse bones; the upper member yielded foraminifera, radiolarians, diatoms, silicoflagellates, petrified and lignitized wood, sponge spicules, rare bivalves, and fish teeth (Hoots 1931). Soper (1938) reported three fossil localities in the Modelo Formation of what is now SAMO. Foraminifera, diatoms, plant fossils including small pieces of petrified wood, shell fragments, abundant fish scales, and a few whale bones have been found in the central Santa Monica Mountains (Soper 1938). The silicoflagellates (golden-brown algae) collected by Cornell (1974) came from an area along Dixie Canyon Avenue starting at the intersection with Mulholland Drive; this collection area is at least partially within SAMO. Foraminifera and rare bivalves have been found in the western Santa Monica Mountains (Yerkes and Campbell 1979). Saul and Stadum (2005) described egg cases of argonaut cephalopods in the lower part of the upper Modelo Formation of the Topanga Canyon area.

The Modelo Formation has abundant fossils of cartilaginous and bony fish, some of which are known from SAMO (David 1943; Koch et al. 2004; Hunt et al. 2006). Many of the fish localities have been lost over the years to construction or have been otherwise made inaccessible, but some of them were preserved in Fossil Ridge Park, which is part of SAMO (Koch et al. 2004). The fish assemblage is best known from localities near Mulholland Drive in the Van Nuys quadrangle. David (1943) described fish from two clusters of localities: on the west side of Sepulveda Canyon, south of Mulholland Drive and west of the modern San Diego Freeway in the lower Modelo Formation; and in the vicinity of the modern Beverly Glen Road north of Mulholland Drive in the upper Modelo Formation. All of the localities in the Sepulveda Canyon cluster are within SAMO, and several of the Beverly Glen localities are within the park as well. The Sepulveda Canyon localities (California Institute of Technology [CIT] localities 317, 320, 321, and 334, and LACM 1029 and 1038) have yielded 20 genera of fish from 18 families, along with seaweeds and land plants. Six fish taxa (SAMO Figure 12) were named from this area: the genera and species *Chalcidichthys malacopterygius* (holotype CIT 10228; all CIT specimens are now in the LACM) and *Pseudoseriola gillilandi* (CIT 10000), and the species *Argyropelecus bullockii* (CIT 10029), *Eclipses sanctamonicae* (CIT 10223), *Laytonia californica* (CIT 10224), and *Sarda stockii* (LACM 1059). The fish lived under slightly warmer conditions than present, in an open coastal setting with water depths of 100 to 200 m (330 to

660 ft). The upper Modelo Beverly Glen localities (CIT 379, 380, and 382 within SAMO, and CIT 326, 326-B, 329, and 381 outside of SAMO) have a smaller fish assemblage. Diatoms, seaweeds, land plants, and bivalves were also found at these sites. This assemblage may have lived in water between 200 and 500 m (660 and 1,600 ft) deep (David 1943). Pierce (1955, 1956) described foraminifera, diatoms, and fish from a transect that cuts through SAMO adjacent to Benedict Canyon. Between

13 and 16 fish taxa, mostly pelagic forms, have been recognized by scales along this transect (Pierce 1956). Other publications on Modelo Formation fish from near SAMO include David (1939, 1948), David and Stock (1939), Crane (1966), Fritzsche (1980), Hunter and Stewart (1994), Stewart (1995), and Hakel and Stewart (2002).



SAMO Figure 12. Fish taxa named from the Modelo Formation of SAMO. Top row (left to right): *Pseudoseriola gillalandi* and *Argyropelecus bullockii*. Middle row: *Eclipses sanctamonicae* and *Sardra stockii*. Bottom row: *Laytonia californica* and *Chalcidichthys*

malacopterygius (all fossil vertebrate photographs in this chapter are courtesy of the LACM, and were taken by Alison Mims, Black Canyon of the Gunnison National Park/Curecanti National Recreation Area).

Parker and Dawson (1965) described a number of new seaweeds, including several from sites near or within SAMO. They reported the fossils as coming from the Monterey Formation, but the specimens from the Santa Monica Mountains come from areas previously mapped as the Modelo Formation, generally being from the same area as David's fish sites. Taxa named from locations within SAMO include the brown algae species *Paleohalidrys dendritica* (LACM PB-1525, now UCMP Paleobotany 10872; most of the LACM's paleobotany collections were transferred to the UCMP in 1990 [Kennedy and Schom 1991]), *P. liguliformis* (LACM PB-1527, now UCMP Paleobotany 10873), *P. linearis* (LACM PB-1526, now UCMP Paleobotany 10876), *P. superba* (LACM PB-395, now UCMP Paleobotany 10881), the red alga genus and species *Paleosiphonia oppositoclada* (LACM PB-2990, now UCMP Paleobotany 10887), and the red algae species *Chondrides flexilis* (LACM PB-1235, now UCMP Paleobotany 10882) and *C. recurva* (LACM PB-1542, now UCMP Paleobotany 10884).

Several other reports of fossils have been made from near but outside of SAMO, principally on the north flank of the eastern and central Santa Monica Mountains. Several of David Jordan's publications on fish (1907; Jordan and Beal 1913; Jordan and Gilbert 1919; Jordan and Hannibal 1923) include localities in the Santa Monica Mountains and vicinity, and some of his taxa may derive from SAMO. The gastropod *Haliotis palaea* was named from the basal Modelo Formation of Brown Canyon (Woodring 1931). Howard (1958) reported the birds *Sula pohli* from Studio City (SAMO Figure 13) and *Paleosula stocktoni* from El Sereno. Howard (1962) noted the presence of the birds *Osteodontornis* (an extinct "toothed" form), *Puffinus*, and *Sula* from Del Gado Drive near the intersection of Sepulveda and Ventura boulevards in Sherman Oaks, and Howard and White (1962) added fish to the assemblage from the diatomaceous shales at this location. The dolphin *Pithanodelphis nasalis* has also been found in the upper Modelo Formation of Studio City (SAMO Figure 14) (Barnes 1985). The cormorant *Phalacrocorax femoralis* was named from a specimen found just outside of SAMO near Calabasas, associated with foraminifera, diatoms, marine algae, sponge spicules, and fish (Miller 1929). Farther west, wood has been found in the Thousand Oaks area in what was described as the Monterey Formation (Stadum and Weigand 1999). In Lincoln Heights, a few km southeast of the eastern tip of SAMO, the Lincoln Heights Whale is a specimen of the mysticete *Mixocetus elysius* from the Modelo Formation (Kellogg 1934; Bussino and Barnes 1984).

Overall, the Modelo Formation fossil assemblage includes foraminifera, radiolarians, diatoms, silicoflagellates (Hoots 1931), seaweeds (non-calcareous green algae, brown algae, and red algae) (Parker and Dawson 1965), petrified and lignitized

wood, land plant leaves, sponge spicules, bivalves, gastropods, echinoids (Hoots 1931), argonaut egg cases (Saul and Stadum 2005), cartilaginous and bony fish (David 1943), birds (Miller 1929; Howard 1958, 1962), pinnipeds (Hoots 1931), dolphins (Barnes 1985), whales (Hoots 1931; Kellogg 1934; Barnes 1977), and horses (Hoots 1931).



SAMO Figure 13. *Sula pohli* (holotype LACM 2674) from Studio City.



SAMO Figure 14. Partial skull of *Pithanodelphis nasalis* (LACM 15196) from Studio City.

Monterey Formation (Middle–Upper Miocene)

As noted above in the Modelo Formation section, Dibblee and coauthors have historically interpreted the Modelo/Monterey stratigraphic interval differently than the USGS. There is one area in SAMO where the USGS also maps the Monterey

Formation: south of the Malibu Coast Fault in the Point Dume area (Yerkes and Campbell 1979; Campbell et al. 1996). The Monterey Formation in this area is about 1,000 m (3,300 ft) thick and composed of clay-rich shale, siltstone, and interbedded sandstone and tuff. It is interpreted as having been deposited under quiet marine water (Yerkes and Campbell 1979). The Monterey Formation is noted as recording marine upwelling, similar to what is seen today off of Peru and Chile (Williams 1984). The bottom waters became anoxic around 16 Ma, and the oxygen content stayed low throughout deposition, which led to the preservation of laminar deposits (Isaacs 1984). Foraminifera give a Luisian to Mohnian age (15.0–between 8.7 and 7.4 Ma). The Monterey Formation of SAMO is fossiliferous. In the Point Dume area, it has yielded foraminifera, and some of its rocks are made up of diatoms (Yerkes and Campbell 1979).

The Monterey Formation has been extensively described, and is noted for its “varved” diatomite deposits and petroleum production (Isaacs 1983). It is known from much of coastal California; the following discussion of fossils will be limited to reports from Los Angeles, Orange, Santa Barbara, and Ventura counties. The Palos Verdes Hills of Los Angeles County, about 25 km (16 miles) southeast of the nearest part of SAMO, and the Aliso Creek area of Orange County, over 75 km (47 miles) southeast of SAMO, are two productive areas. For reference, the Monterey Formation includes three members in the Palos Verdes Hills and other nearby areas. From oldest to youngest, they are the Altamira Shale Member, Valmonte Diatomite, and Malaga Mudstone Member (Hof and Schram 1998).

The Monterey Formation in the counties around SAMO has an extensive fossil assemblage. Protists are represented by coccoliths, foraminifera, radiolarians (Bandy and Kolpack 1963; Isaacs 1984; Finger 1988; Föllmi et al. 2005), and ebridians (a type of flagellate protist) (Finger 1988). Plants are represented by diatoms, silicoflagellates, dinoflagellates, green algae (Srivastava 1984; Finger 1988), filamentous algae (Finger et al. 2008), spores from mosses, spikemosses, and ferns, conifer and angiosperm pollen (Srivastava 1984; Finger 1988), angiosperm leaves (Finger et al. 2008), wood (Stadum and Weigand 1999), and plant debris (Föllmi et al. 2005). Invertebrates are represented by sponge spicules (Bandy and Kolpack 1963), bryozoans, bivalves (Fife 1979; Finger 1988), gastropods (Finger 1988; Finger et al. 2008), barnacles (Fife 1979; Finger 1988), crabs (Finger et al. 2008), mantis shrimp (Hof and Schram 1998), ostracodes (Finger 1988), echinoids (Fife 1979), and invertebrate trace fossils, such as burrows (Föllmi et al. 2005), worm tubes (Finger 1988), and argonaut egg cases (Saul and Stadum 2005). Vertebrates are represented by sharks, rays, bony fish (David 1943; Barnes et al. 1985), frogs (Barnes et al. 1985), turtles (Fife 1979; Barnes et al. 1985), crocodilians (Fife 1979), members of at least 13 families of seabirds and shorebirds (Howard 1978), pinnipeds (Barnes 1985; Barnes et al. 1985), sea cows (Barnes et al. 1985), desmostylians (Fife 1979), diverse cetaceans from both the odontocete (toothed

whales) and mysticete (baleen whales) lineages (Barnes 1977; Barnes et al. 1985), pronghorn- or deer-like artiodactyls (Barnes et al. 1985), and coprolites (Föllmi et al. 2005).

Unnamed Pliocene–Pleistocene rocks and sediments (Upper Pliocene–lower Pleistocene)

There are small exposures of unnamed Pliocene–Pleistocene rocks in the Temescal Canyon and Pacific Palisades area of SAMO in the Topanga quadrangle. They are classified as two units. The older unit is up to 230 m (750 ft) thick and is composed of marine siltstones, sandstones, and breccia. This unit includes Late Pliocene fossils, and was assigned to the San Diego Formation by Hoots (1931). The younger unit is a marine siltstone and sandstone formation up to 90 m (300 ft) thick, and is locally very fossiliferous. It dates to the Late Pliocene or early Pleistocene (Yerkes and Campbell 1994). Aside from the San Diego Formation of Hoots (1931), Pliocene rocks in the Santa Monica Mountains–Los Angeles area have also been assigned to the Fernando, Pico, and Repetto formations (Schwartz and Colburn 1987; Rumelhart and Ingersoll 1997). The Fernando Formation is today used in the Santa Ana Mountains and Puente Hills, the Pico Formation is used for Upper Pliocene rocks in the subsurface, and the Repetto Formation is used in the Palos Verde Hills. None of them are currently known from the Santa Monica Mountains (Schwartz and Colburn 1987).

The unnamed Pliocene–Pleistocene rocks are fossiliferous in SAMO: brachiopods, bivalves, and gastropods have been found at the mouth of Temescal Canyon (Arnold 1907; Hoots 1931). Echinoids are also known from the area of the canyon (Grant and Hertlein 1938). Axelrod (1967, 1990) described early Pleistocene-age pine cones (*Pinus radiata* and *P. remorata*) from the mouth of Potrero Canyon. Manzanita seeds were also found at this site (Axelrod 1967). A comparable marine invertebrate assemblage was found just outside of SAMO in Rustic Canyon, 850 m (2,800 ft) to the northeast of the Potrero Canyon plant locality (Axelrod 1967).

Other Quaternary rocks and sediments (upper Pleistocene–Holocene)

Several types of young Quaternary rocks and sediments can be found in the Santa Monica Mountains. They include a variety of marine and nonmarine sandstones, clays, and conglomerates, dating from the late Pleistocene to the Holocene (Hoots 1931). These deposits are fossiliferous within and just outside of SAMO. Bryozoans, chitons (sea cradles), bivalves, gastropods, and scaphopods have been found in late Pleistocene deposits in Potrero Canyon (Hoots 1931; Valentine 1956). Tens of thousands of mollusks were recovered from deposits near the head of the canyon, an area both within and outside of SAMO. Most of the deposits have been destroyed during various construction projects (Valentine 1956). The fossils were found on the 76 m (250 ft) Point Dume or Pacific Palisades Terrace; dates on bivalves indicate an age of 125,000 years (McGill et al. 1979). Escondido Beach near Point Dume also has fossils from the Point Dume Terrace, including bivalves, gastropods,

scaphopods, barnacles, decapod crustaceans (crabs, lobsters, and shrimp), and echinoids. They lived beneath 7 to 15 m (23 to 49 ft) of water, perhaps 150 m (500 ft) offshore. The water at this time was warmer than the present (Addicott 1964). Foraminifera have been reported from the terraces as well (Valentine 1956), and are known from the eastern Santa Monica Mountains (Hoots 1931). Arnold (1906) reported Pleistocene corals, bivalves, gastropods, echinoids, and rays from the SAMO area in what he identified as the San Pedro Formation.

Quaternary vertebrates are also known from SAMO, particularly from a site at Zuma Creek (LACM 1754) near Point Dume, but for the most part are undescribed. Bones of the extinct California turkey *Meleagris californica* (Bocheński and Campbell 2006), the mole *Scapanus latimanus* (Hutchison 1987), and the extinct tapir *Tapirus californicus* (Jefferson 1989) are known from Zuma Creek in sediments of about the same age as Rancho La Brea (see below). Koch et al. (2004) also reported fish, frogs, lizards, snakes, 20 bird species, ground sloths, rodents, mastodons, mammoths, horses, bison, and camels from localities in the recreation area. The flightless sea duck *Chendytes lawi* was named from bones collected in a “Pleistocene deposit just north of Santa Monica,” near SAMO (Miller 1925), and ground sloth fossils have been found in Quaternary alluvium in Woodland Hills, west of Topanga Canyon Boulevard and just south of Mulholland Drive (B. Lander, pers. comm., January 2012).



SAMO Figure 15. Quaternary mammals from SAMO. Left: *Scapanus latimanus*. Right: *Tapirus californicus*.

There are several noteworthy Quaternary localities in the vicinity of SAMO, which can be used as guides for possible future finds within SAMO. They include the world-famous fossils of Rancho La Brea, the diverse terrestrial and marine fossils of the northern Channel Islands, and the plants and associated animal fossils of Carpinteria.

The tar pits of Rancho La Brea, a little less than 4.5 km (2.8 miles) south of the eastern end of SAMO, are best known for their mammal fossils, but preserve examples of a wide range of terrestrial organisms. The environment included some standing water, with a cool moist pine coastal pine forest nearby, and chaparral and foothill woodlands at higher, drier elevations. Redwoods grew in sheltered sites in the foothills (Miller and Peck 1979). Most of the flora and fauna lived between about 50,000 and 10,000 years ago (O’Keefe et al. 2009). Plants and

algae are represented by: diatoms and charophyte algae; conifers including pines, sequoias, cypresses, and junipers; monocot angiosperms including bur-reeds, pondweeds, grasses, and blue-eyed grasses; and dicot angiosperms including walnuts, willows, hackberries, alders, oaks, buckwheat, docks, chenopod/amaranth herbs, buttercups, barberries, bay laurels, plane trees, roses, poison oaks, maples, balsamroots, buckthorns, globemallows, water parsnips, water parsley, dogwoods, manzanitas, bindweeds, sages, figworts, verbenas, bedstraws, elders, and asters. Invertebrates are represented by: bivalves; gastropods; ostracodes; arachnids including scorpions, spiders, and harvestmen; pill bugs; millipedes; centipedes; orthopterans including crickets and locusts; earwigs; termites; heteropterans including backswimmers, water bugs, water boatmen, pond skaters, squash bugs, assassin bugs, and jewel bugs; homopterans including leafhoppers and treehoppers; beetles; lepidopterans (butterflies and moths); flies; and hymenopterans including wasps and ants. Fish, amphibians, and reptiles are represented by trout, chubs, sticklebacks, frogs, toads, salamanders, pond turtles, lizards, and a number of snake species. Birds are represented by grebes, cormorants, herons, spoonbills, ibises, ducks, geese, swans, storks, vultures, condor-like teratorns, hawks, eagles, falcons, caracaras, turkeys, quails, rails, cranes, plovers, avocets, sandpipers, gulls, pigeons, roadrunners, owls, poorwills, woodpeckers, and diverse perching birds. Mammals are represented by shrews, moles, humans, bats, ground sloths, rabbits, rodents, weasels, bears, wolves, coyotes, foxes, raccoons, badgers, skunks, cats (both saber-toothed and non-saber-toothed), mastodons, Columbian mammoths, horses, tapirs, peccaries, deer, elk, pronghorns, shrubbox, bison, sheep, camels, and llamas (Stock and Harris 1992).

The Quaternary fossils of the northern Channel Islands (Anacapa Island being the nearest at about 25 km [16 miles] west of the western end of SAMO) are described in detail in the CHIS summary of this document. They include a small floral assemblage (Chaney and Mason 1930), abundant calcified plant remains (Johnson 1967), marine invertebrates such as chitons, bivalves, gastropods, barnacles, and echinoids (Orr

1960; Valentine and Lipps 1963; Lipps 1964), terrestrial gastropods (Cockerell 1938), and vertebrates such as fish (Rick et al. 2001), salamanders (Mead et al. 2004), lizards (Erlandson et al. 1999), snakes (Howard 1964), seabirds and shorebirds (Guthrie 1992, 2005), rodents (Wilson 1936; White 1966; Guthrie 1998), bats (Guthrie 1998), pinnipeds (Walker and Craig 1979), the famous pygmy mammoth (Stock and Furlong 1928; Stock 1935; Orr 1968; Agenbroad 2001, 2009, 2012), and whales (Orr 1968). Many Quaternary finds on the islands are linked to cultural resources as well.

Carpinteria, about 50 km (31 miles) northwest of the nearest part of SAMO, has a terrestrial assemblage comparable to Rancho La Brea. The plants and birds are the best-known segments of the assemblage. There was probably a marshy area nearby, and a pine and oak woodland (Guthrie 2009). Chaney and Mason (1933) reported 25 plant species in 18 families, including one fern species, eight conifers (four pines and one species each of Douglas fir, sequoia, cypress, and juniper), and 16 dicots (two species of manzanitas and one species each of bayberry, live oak, dwarf mistletoe, buckwheat, bay laurel, pear, poison oak, blue blossom, spring parsley, silk-tassel, mountain balm, blue elderberry, daisy, and cocklebur). Conifers and manzanitas are the most abundant forms. The floral assemblage is similar to the Monterey pine forests seen 320 km (200 miles) to the north, and is indicative of cooler, wetter conditions (Chaney and Mason 1933). Seventy-nine species of birds have also been recovered from the asphalt here, including representatives of Pelecaniformes (medium and large waterbirds), Anseriformes (ducks and geese), Falconiformes (falcons, eagles, and hawks), Gruiformes (crane-like birds), Charadriiformes (shorebirds and seabirds), Columbiformes (pigeons), Strigiformes (owls), Caprimulgiformes (nighthawks and nightjars), Piciformes (woodpeckers and allies), and Passeriformes (perching birds) (Guthrie 2009). Also found were beetles and other insects (Chaney and Mason 1933), amphibians, reptiles (Guthrie 2009), rodents, rabbits, dogs and wolves, foxes, skunks, horses, and deer (Chaney and Mason 1933). The insects (Chaney and Mason 1933), amphibians, reptiles, and mammals are undescribed (Guthrie 2009).

Potential Sources of Paleontological Resources

Fossils have not yet been documented from the following geologic units within SAMO. However, they are known to preserve fossils elsewhere, and future field investigations within the park may recover fossils from one or more of them.

Trabuco Formation (Upper Cretaceous)

The Trabuco Formation (or Conglomerate) is found in eastern SAMO (Yerkes and Campbell 1993, 1994). It is exposed along part of Mulholland Drive (the lower red part of the Chico Formation of Hoots [1931]). Its rocks were first identified as part of the Chico Formation. The Trabuco Formation was

named for rocks in the Santa Ana Mountains, and its usage was later extended to the Los Angeles area. It is a terrestrial conglomeratic unit, 210 m (700 ft) thick, deposited on a west-sloping alluvial fan (Dibblee 1982a). Fluvial and debris flow deposition alternated during its history (Carey and Colburn 1978). The alluvial fan is thought to have been steeply sloping, with braided streams (Shapiro et al. 2001). The formation is noted for its red color (Colburn 1973). Its age is not known for certain, but it includes fragments of rocks that formed between 117 and 93 Ma (Dibblee 1982a), and the overlying Tuna Canyon Formation began deposition during the late Turonian

stage (Carey and Colburn 1978), about 89 Ma. The upper contact with the Tuna Canyon Formation may be conformable (Shapiro et al. 2001) or disconformable (Carey and Colburn 1978). The Trabuco Formation is not known to be fossiliferous (Almgren 1973; Shapiro et al. 2001).

Las Virgenes Sandstone (Paleocene)

The Las Virgenes Sandstone is part of the Lower Cenozoic section of the Simi Hills (Dibblee 1982a), although Colburn et al. (1988), Noriega et al. (2002), and Abeja et al. (2005) have also reported it from the Solstice Canyon area. It is found west of the Runkle Canyon–Burrow Flats fault zone (Squires 1999). The formation is up to 195 m (640 ft) thick, and is composed of sandstone, mudstone (Squires and Filewicz 1983), and carbonaceous silty sandstone (Zinsmeister 1983a, 1983b). As noted above, it may represent a finer facies of the Simi Conglomerate (Zinsmeister 1983a, 1983b). Colburn et al. (1988) reassessed the Simi Conglomerate?–Coal Canyon Formation interval of Yerkes and Campbell (1979) and assigned the white coarse arkosic sandstone with distinctive green and red mudstone beds to the Las Virgenes Sandstone.

The Las Virgenes Sandstone was part of a marine transgression (Parker 1983a; Zinsmeister 1983a), and deposition occurred in both marine and nonmarine settings (Squires and Filewicz 1983). The formation changes from sandy fluvial deposition in the west to nearshore deposition to the east (Parker 1983a). The rocks attributed to the Las Virgenes Sandstone in Solstice Canyon include fluvial and overbank deposits (Colburn et al. 1988), and tropical soil deposits (Colburn et al. 1988; Noriega et al. 2002; Abeja et al. 2005). They interfinger with marine deposits (attributed to the Santa Susana Formation by Colburn et al. [1988]). Deposition near the top of the formation was in a low-energy nearshore coastal setting (Squires 1997). This unit is regarded as Paleocene in age (Zinsmeister 1983a).

The Las Virgenes Sandstone is not known to be fossiliferous within SAMO, and in general is sparsely fossiliferous. Its fossil assemblage outside of SAMO includes logs, bivalves (Parker 1983a), gastropods (Saul 1983b; Squires 1997), and burrows (Parker 1983a). The mollusks appear to be brackish-water forms (Sage 1975). Burrows are found in the upper part of the formation (Parker 1983b).

Santa Susana Formation (Upper Paleocene–Lower Eocene)

The Santa Susana Formation is found in the Simi Hills area (Dibblee 1982a; Squires and Filewicz 1983), and can be found in a small area of SAMO’s northern extension. It is up to 1,030 m (3,380 ft) thick, and is composed of sandstone and mudstone, with local conglomerate (Squires and Filewicz 1983). The Santa Susana Formation rocks were previously included in the Martinez and Meganos formations: the lower part of the formation was in the Martinez Formation, and the upper part was in the Meganos Formation (Squires 1999). Before the Meganos Formation was described, the upper part was in the

Tejon Formation (Kew 1924). The lower part of the formation is sometimes identified as the informal “Martinez Marine Member” (Sage 1975; Zinsmeister 1983a). It appears to interfinger with the rest of the formation (Saul 1983a) and is composed of three tongues of fine sandstone that thin to the east, interbedding with the siltstone of the rest of the formation (Zinsmeister 1983a). Saul (1983a) considered identifying the “Martinez Marine Member” that makes up the lower part of the Santa Susana Formation as the Coal Canyon Member. The Santa Susana Formation has a disconformable contact with the overlying Lajas Formation (Squires and Filewicz 1983; Saul 1983a).

The Santa Susana Formation is a marine unit. Water level varied greatly during its deposition. It is nearshore marine in places, including the “Martinez Marine Member”, which is a shallow-water to nearshore facies of the formation (Zinsmeister 1983b). Other parts of the formation record bathyal deposition (Squires 1997), including rocks in the eastern part of its depositional area (Parker 1983a). The western and eastern facies are juxtaposed by a fault (Parker 1983a; Strathearn et al. 1988). The formation was deposited during the Late Paleocene and Early Eocene (Filewicz and Hill 1983; Squires and Filewicz 1983; Zinsmeister 1983a). The early part of deposition occurred during a transgression (Sage 1975), while the upper part of the formation was deposited during a period of uplift (Parker 1983a), leading to shallower deposition (Saul 1983a; Squires 1997).

The Santa Susana Formation is not yet known to be fossiliferous within SAMO, unless the rocks of the Coal Canyon Formation are included within this unit, as discussed above. However, there are a number of fossil localities in the vicinity. The fossil assemblage of the Santa Susana Formation includes coccoliths, foraminifera (Filewicz and Hill 1983), spores, pollen, woody fragments (Frederickson 1983), corals (Waring 1917; Kew 1924), brachiopods (Waring 1917), bivalves, cephalopods, gastropods, scaphopods (Waring 1917; Kew 1924; Saul 1983b; Zinsmeister 1983b; Squires 1999), crabs, echinoids, burrows, bioturbation (Squires 1999), shark teeth (Waring 1917), and reworked Cretaceous fossils (Kew 1924). Kew (1924) reported foraminifera, corals, bivalves, cephalopods, gastropods, scaphopods, echinoids, and reworked Cretaceous fossils in the “Martinez Formation” of Los Angeles and Ventura counties; based on his localities, they pertain to the lower Santa Susana Formation. He also reported bivalves and gastropods in the “Meganos Formation”, the modern upper Santa Susana Formation. The “Martinez Marine Member” is noted for its mollusks (Saul 1983a).

Saugus Formation (lower Pleistocene)

A small area of nonmarine sandstone and conglomerate possibly belonging to the Saugus Formation has been mapped in the Newbury Park quadrangle portion of SAMO (Yerkes and Campbell 1997). This formation is better known in the valleys north of SAMO. In the Simi Valley, the Saugus Formation has

distinct lower and upper sequences. The lower Saugus Formation in the valley is 350 m (1,150 ft) thick and composed of marine sandstone and shell beds dating to the Late Pliocene. The upper Saugus Formation is at least 300 m (980 ft) thick and composed of nonmarine sandstone and conglomerate dating to the early Pleistocene (Squires and Filewicz 1983). The nonmarine part of the formation has Irvingtonian-age mammals, dating to between perhaps 850,000 and 780,000 years ago (Wagner et al. 2007), although older Pliocene fossils are known from the Sunshine Ranch Member in the Mission Hills, about 16 km (10 miles) north of SAMO (Barron and Ingle 1978).

The Saugus Formation is not known to be fossiliferous within SAMO. If the Saugus Formation is present at SAMO, it appears

Park Collections

SAMO has a small fossil collection, consisting mostly of petrified wood (approximately 150 specimens). Algal imprints, leaves, bivalves, gastropods, fish, and marine mammal bones are also in the recreation area's collections (Koch et al. 2004). Most fossils collected from SAMO are held in other institutions. The majority are in the collections of the LACM, which also houses the former collections of the California Institute of Technology (CIT; for example, some specimens in David [1943] and Matsumoto [1960]), California State–Northridge (CSUN; for example, some specimens in Flack [1993] and Squires and Saul [2000]), and the University of California–Los Angeles (UCLA; for example, some specimens in Soper [1938], Reinhart [1943], Valentine [1956], Cornell [1974], Saul [1978], Popenoe and Saul [1987], and McCulloh et al. [2002]). Most of the LACM's paleobotany collection is now at the UCMP, including the Miocene seaweeds of Parker and Dawson (1965) (Kennedy and Schom 1991). The UCMP also holds the Potrero Canyon specimens described by Axelrod (1967, 1990). The former collections of Stanford (LSJU), such as some other fossils described in Matsumoto (1963), are now held at the California Academy of Sciences (CAS) in San Francisco. Arnold (1907)'s specimens are at the National Museum of Natural History (USNM) in Washington, D.C., and Addicott (1964) described U.S. Geological Survey specimens. The San Diego Natural History Museum (SDNHM) has specimens described by Wiedey (1928). Koch et al. (2004) reported that the Peabody Museum of Natural History of Yale University (New Haven, CT) and the University of California–Riverside also had SAMO specimens in their collections. Finally, there are significant collections of SAMO fossils in private hands: because of the accessibility to Los Angeles, private collecting occurred for many years at a number of sites now within SAMO, such as the Old Topanga Canyon site (Koch et al. 2004).

that it is represented by its nonmarine facies, so terrestrial fossils would be the most likely finds. Terrestrial fossils are known from the Moorpark area a few km north of SAMO in the northern Simi Valley (Wagner et al. 2007). These include rodents, rabbits, mammoths (Wagner et al. 2007), tapirs (Jefferson 1989), horses, and llamas (Wagner et al. 2007). For reference, shallow coastal marine rocks and deposits in the lower Saugus Formation preserve marine fossils such as coralline algae, plant impressions (White 1983), bryozoans (Kew 1924), brachiopods, bivalves, gastropods, barnacles, echinoids, burrows, worm tubes, shark teeth, and whale vertebrae (White 1983).

Type specimens from SAMO, including holotypes, paratypes, and syntype series, are curated at several institutions. The CAS has the type specimens (originally from Stanford) of the bivalves *Crassatellites triangulatus* and *Inoceramus pembertoni*, the ammonites *Placenticerias sanctaemonicae* and *Hauericeras transitionale* (possibly not from SAMO), and the gastropod *Pugnella rotundus* (Waring 1917; Saul and Alderson 1981). The LACM has the type specimens of the gastropods *Deussenia californiana* (Squires and Saul 2000), *Pyropsis aldersoni* (Squires 2011), *Tenagodus californiensis* (Squires 1990), and *Zonaria (Zonaria) emmalingae* (Groves 1994), and crabs *Costacopluma squiresi* (Nyborg et al. 2009) and *Cyclocorystes aldersoni* (Squires 1980). Also at the LACM are the type specimens of the fish taxa *Argyropelecus bullockii*, *Chalcidichthys malacopterygius*, *Eclipses sanctamonicae*, *Laytonia californica*, *Pseudoseriola gillilandi*, and *Sarda stockii* (David 1943), formerly held at the CIT, and the type specimens of the bivalves *Anadara (Anadara) topangaensis* (Reinhart 1943) and *Yaadia robusta* (Saul 1978), formerly held at UCLA. The SDNHM has the type specimens of the bivalve species *Pterina jordani* and *Tellina oldroydi* (Wiedey 1928). The USNM has the type specimens of the bivalve *Mytilus mathewsonii* var. *expansus* and the gastropods *Cerithium topangensis*, *Chlorostoma (Omphalius) dalli*, *C. (O.) dalli* var. *inornatus*, *C. (O.) dalli* var. *subnodosus*, *Macron merriami*, *Ocenebra topangensis*, *Pleurotoma (Bathytoma) keepi*, *Purpura edmondi*, *Sigaretus perrini*, and *Turbo topangensis* (Arnold 1907). Finally, the UCMP has the type specimens (originally from the LACM's paleobotany collection) of the brown algae *Palaeohalidrys dendritica*, *P. liguliformis*, *P. linearis*, and *P. superba*, and the red algae *Chondrides flexilis*, *C. recurva*, and *Paleosiphonia oppositoclada* (Parker and Dawson 1965; Kennedy and Schom 1991). A table of type specimens from SAMO is included below (SAMO Table 3).

Taxon	Publication	Catalog Number	Provenance	Notes
<i>Crassatellites triangulatus</i>	Waring 1917	CASG 61944.02	Tuna Canyon Formation, Santa Ynez Canyon area	bivalve
<i>Inoceramus pambertoni</i>	Waring 1917	CASG 69909.00	Tuna Canyon Formation, Santa Ynez Canyon area	bivalve
<i>Placenticeras sanctaemonicae</i>	Waring 1917	syntypes CASG 61626.01 and 61944.01	Tuna Canyon Formation, Santa Ynez Canyon area	ammonite
<i>Pugnella rotundus</i>	Waring 1917	CASG 61959.01	Tuna Canyon Formation, Santa Ynez Canyon area	gastropod
<i>Hauericeras transitionale</i>	Waring 1917	CASG 61946.01	Tuna Canyon Formation?, probably from Temescal Canyon area, not Simi Hills as originally described (Saul and Alderson 1981)	ammonite
<i>Deussenia californica</i>	Squires and Saul 2000	LACMIP 12718	Tuna Canyon Formation, south fork of Garapito Creek	gastropod
<i>Pyropsis aldersoni</i>	Squires 2011	LACMIP 13721	Tuna Canyon Formation, upper tributary to Garapito Creek	gastropod
<i>Cyclocorystes aldersoni</i>	Squires 1980	LACMIP 5863	Coal Canyon/Santa Susana Formation, south fork of Garapito Creek	crab
<i>Tenagodus californiensis</i>	Squires 1990	LACMIP 8086	Coal Canyon/Santa Susana Formation, Garapito Creek area	gastropod
<i>Costacopluma squiresi</i>	Nyborg et al. 2009	LACMIP 13560	Coal Canyon/Santa Susana Formation, head of Quarry Canyon	crab
<i>Mytilus mathewsonii</i> var. <i>expansus</i>	Arnold 1907	USNM 164968	Topanga Canyon Formation, Cold Creek Member, head of Topanga Canyon	bivalve
<i>Cerithium topangensis</i>	Arnold 1907	USNM 164976	Topanga Canyon Formation, Cold Creek Member, head of Topanga Canyon	gastropod, usually referred to <i>Bittium</i>
<i>Chlorostoma (Omphalius) dalli</i>	Arnold 1907	USNM 164984	Topanga Canyon Formation, Cold Creek Member, head of Topanga Canyon	gastropod
<i>Chlorostoma (Omphalius) dalli</i> var. <i>inornatus</i>	Arnold 1907	USNM 164986	Topanga Canyon Formation, Cold Creek Member, head of Topanga Canyon	gastropod
<i>Chlorostoma (Omphalius) dalli</i> var. <i>subnodosus</i>	Arnold 1907	USNM 164985	Topanga Canyon Formation, Cold Creek Member, head of Topanga Canyon	gastropod

Taxon	Publication	Catalog Number	Provenance	Notes
<i>Macron merriami</i>	Arnold 1907	USNM 164982	Topanga Canyon Formation, Cold Creek Member, head of Topanga Canyon	gastropod
<i>Ocenebra topangensis</i>	Arnold 1907	USNM 164995	Topanga Canyon Formation, Cold Creek Member, head of Topanga Canyon	gastropod; more properly <i>Ocenebra</i>
<i>Pleurostoma (Bathystoma) keepi</i>	Arnold 1907	USNM 164993	Topanga Canyon Formation, Cold Creek Member, head of Topanga Canyon	gastropod
<i>Purpura edmondi</i>	Arnold 1907	USNM 164983	Topanga Canyon Formation, Cold Creek Member, head of Topanga Canyon	gastropod
<i>Sigaretus perrini</i>	Arnold 1907	USNM 164979	Topanga Canyon Formation, Cold Creek Member, head of Topanga Canyon	gastropod
<i>Turbo topangensis</i>	Arnold 1907	USNM 164980	Topanga Canyon Formation, Cold Creek Member, head of Topanga Canyon	gastropod
<i>Zonaria (Zonaria) emmakingae</i>	Groves 1994	LACMIP 12277	Topanga Canyon Formation, Cold Creek Member, south side of Old Topanga Road	gastropod
<i>Pterina jordani</i>	Wiedey 1928	SDNHM 25	Topanga Canyon Formation, probably Cold Creek Member, near head of Dry Canyon	bivalve
<i>Tellina oldroydi</i>	Wiedey 1928	SDNHM 36	Topanga Canyon Formation, probably Cold Creek Member, head of Dry Canyon	bivalve
<i>Anadara (Anadara) topangaensis</i>	Reinhart 1943	UCLA 3258 (now LACMIP 10095)	Topanga Canyon Formation?, near Upper Franklin Canyon Reservoir	bivalve
<i>Chalcidichthys malacopterygius</i>	David 1943	CIT 10228 (now at LACM)	Modelo Formation, Sepulveda Canyon area	fish
<i>Pseudoseriola gillalandi</i>	David 1943	CIT 10000 (now at LACM)	Modelo Formation, Sepulveda Canyon area	fish
<i>Argyropelecus bullocki</i>	David 1943	CIT 10029 (now at LACM)	Modelo Formation, Sepulveda Canyon area	fish
<i>Eclipes sanctamonicae</i>	David 1943	CIT 10223 (now at LACM)	Modelo Formation, Sepulveda Canyon area	fish
<i>Laytonia californica</i>	David 1943	CIT 10224 (now at LACM)	Modelo Formation, Sepulveda Canyon area	fish

Taxon	Publication	Catalog Number	Provenance	Notes
<i>Sarda stockii</i>	David 1943	LACM 1059	Modelo Formation, Sepulveda Canyon area	fish
<i>Paleohalidrys dendritica</i>	Parker and Dawson 1965	LACM PB-1525 (now UCMP Paleobotany 10872)	Modelo Formation, Sepulveda Canyon area	brown alga
<i>Paleohalidrys liguliformis</i>	Parker and Dawson 1965	LACM PB-1527 (now UCMP Paleobotany 10873)	Modelo Formation, northern Topanga Canyon	brown alga
<i>Paleohalidrys linearis</i>	Parker and Dawson 1965	LACM PB-1526 (now UCMP Paleobotany 10876)	Modelo Formation, Sepulveda Canyon area	brown alga
<i>Paleohalidrys superba</i>	Parker and Dawson 1965	LACM PB-395 (now UCMP Paleobotany 10881)	Modelo Formation, Sepulveda Canyon area	brown alga
<i>Paleosiphonia oppositoclada</i>	Parker and Dawson 1965	LACM PB-2990 (now UCMP Paleobotany 10887)	Modelo Formation, near Beverly Glen	red alga
<i>Chondrides flexilis</i>	Parker and Dawson 1965	LACM PB-1235 (now UCMP Paleobotany 10882)	Modelo Formation, Topanga Canyon	red alga
<i>Chondrides recurva</i>	Parker and Dawson 1965	LACM PB-1542 (now UCMP Paleobotany 10884)	Modelo Formation, Sepulveda Canyon area	red alga

SAMO Table 3. Type specimens from SAMO. The taxon column presents the original name used; because taxonomy is subjective and under constant revision, names will vary from source to source. Significant alternatives are included in the notes column. Other types may derive from SAMO, but locality information is insufficient.

Cultural Resource Contexts

SAMO is an archeologically rich NPS unit, and humans are known to have been on the neighboring northern Channel Islands beginning at least 13,000 years ago (Erlandson et al. 2007). Paleontological resources have not yet been documented in cultural resource contexts at SAMO, but CHIS exhibits a diverse suite of fossils in cultural contexts, providing a model for possibilities at SAMO. The majority are examples of human interaction with contemporaneous organisms, such as ancient shell middens, and tools and other artifacts made of plant

matter, shells, and bones (Fergusson and Libby 1963; Orr 1968; Guthrie 1980; Rick 2002; Vellanoweth et al. 2003; Reeder et al. 2008). The fossils of SAMO have a cultural connection to historical Los Angeles; many fossil enthusiasts of the Los Angeles area got their start visiting and collecting in the Santa Monica Mountains (Koch et al. 2004). Kenworthy and Santucci (2006) presented an overview and cited selected examples of National Park Service fossils found in cultural resource contexts.

Paleontological Resource Management, Preliminary Recommendations

- The recreation area should consider future field inventories for paleontological resources to more fully document *in situ* occurrences of fossils. The recreation area 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 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. 2009). Threats of particular concern for SAMO include coastal erosion, mountain erosion (for example at the Old Topanga Canyon fossil site [Koch et al. 2004]), landslides, theft, and vandalism.
- SAMO should maintain a contact list of local paleontological researchers, including their areas of specialization. The purpose of this would be two-fold; it would make it easier to evaluate fossil resources, particularly new discoveries; and these researchers could be contacted on a regular basis, perhaps annually, about new discoveries and updated information relevant to SAMO, keeping the recreation area's knowledge up to date.
- The recommendations proposed by Koch et al. (2004) should be reviewed, to check progress and to determine if any should be modified or dropped. Their recommendations included: active resource management at Old Topanga Canyon fossil site; promoting research, particularly at the Old Topanga Canyon site, the Modelo fossil fish beds, and fossil wood deposits; patrolling known sites; continuing cooperation with state parks, conservancies, museums, and universities; developing a PMIS statement for fossil resource protection; assessing the commercial value of fossils preserved within SAMO; providing fossil resource protection training for SAMO staff; and increasing the public awareness of NPS fossil regulations.
- Because paleontological research has gone on for many decades at numerous locations within and just outside of SAMO, it would benefit the recreation area if further work was done to collate publications, discoveries, and locality information. For example, the recreation area should have eventually have maps with the locations of historical sites plotted, and an annotated library of relevant publications.
- As an area with extensive fossil resources in close proximity to an urban setting, SAMO is uniquely positioned for paleontological outreach. Recreation area staff may want to consider if and how to pursue this.
- Recreation area staff should be encouraged to observe exposed sedimentary rocks and associated eroded deposits for fossil material while conducting their usual duties. Staff should photodocument and monitor any occurrences of paleontological resources that may be observed *in situ*. Fossils and their associated geologic context (surrounding rock) should be documented but left in place unless they are subject to imminent degradation by artificially accelerated natural processes or direct human impacts. When opportunities arise to observe paleontological resources in the field and take part in paleontological field studies with trained paleontologists, monument staff should take advantage of them.
- Fossils found in a cultural context should be documented as other fossils, but will also require the input of an archeologist. Any fossil with cultural context may be culturally sensitive as well (e.g. subject to NAGPRA) and should be regarded as such until otherwise established. The Geologic Resources Division can coordinate additional documentation/research of such material.
- Future infrastructure developments or archeological excavations should consider scheduling site monitoring by a trained paleontologist in order to document and protect fossil resources.
- Contact the NPS Geologic Resources Division for technical assistance with paleontological resource management issues.

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Data Sets

Santa Monica Mountains National Recreation Area Paleontological Archives

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

Santa Monica Mountains National Recreation Area Collections

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

California Academy of Sciences (Leland Stanford Junior University collections)

1910–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by LSJU staff; status: Active.

National Museum of Natural History

Pre-1907–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by USNM staff; status: Active.

Natural History Museum of Los Angeles County

1913–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by LACM staff; status: Active.

Natural History Museum of Los Angeles County (California Institute of Technology collections)

Pre-1960–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by CIT staff; status: Active.

Natural History Museum of Los Angeles County (California State–Northridge collections)

Pre-1993–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by CSUN staff; status: Active.

Natural History Museum of Los Angeles County (University of California–Los Angeles collections)

Pre-1938–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by UCLA staff; status: Active.

Peabody Museum of Natural History

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

San Diego Natural History Museum

1928–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by SDNHM staff; status: Active.

United States Geological Survey

Pre-1964–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by USGS staff; status: Active.

University of California Museum of Paleontology

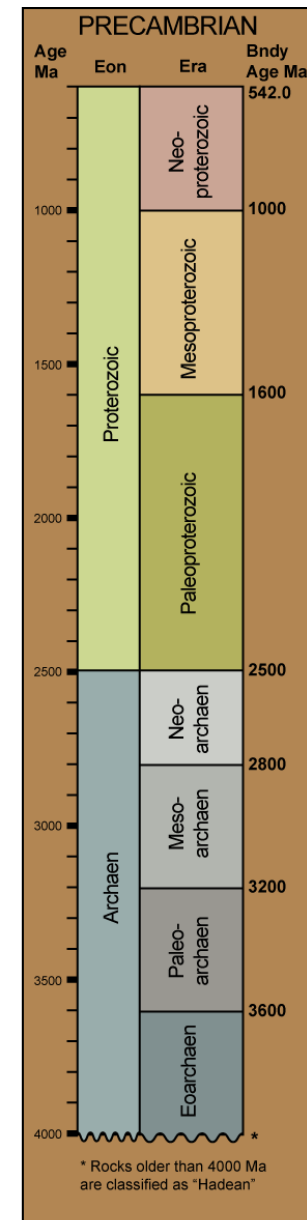
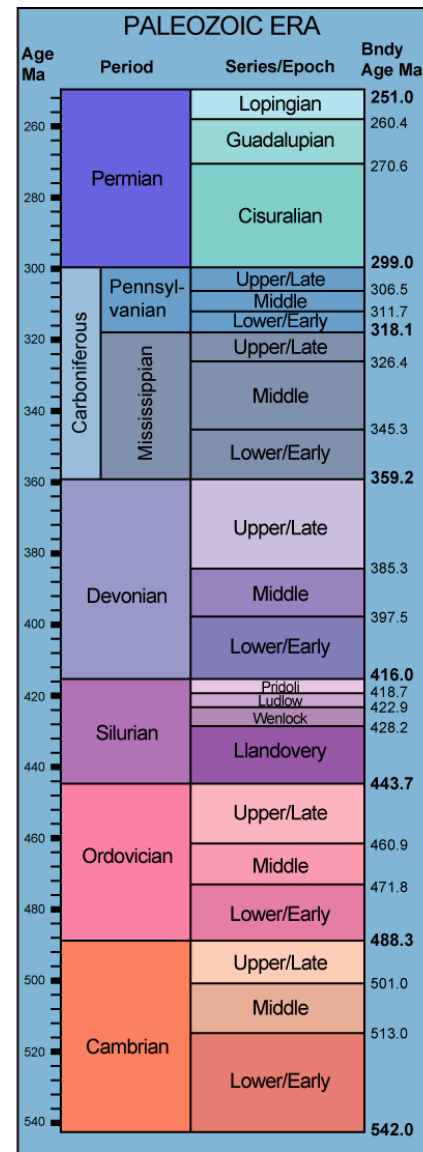
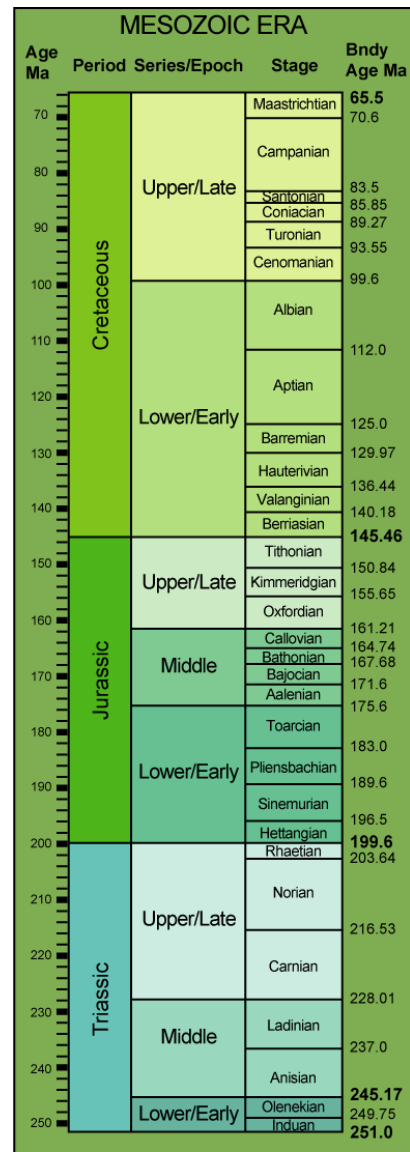
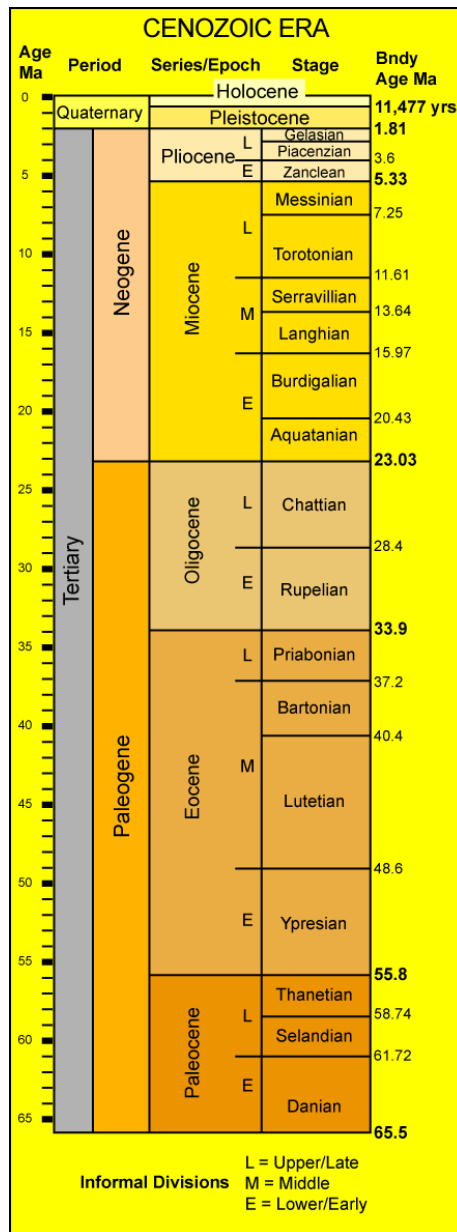
1990–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by UCMP staff; status: Active.

University of California Museum of Paleontology (Natural History Museum of Los Angeles County paleobotany collections)

Pre-1965–present. (museum specimens; associated specimen notes; collection records; maps; etc.). Originated by LACM staff; status: Active.

University of California–Riverside

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



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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