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## DOCUMENTING THE PALEONTOLOGICAL RESOURCES OF NATIONAL PARK SERVICE AREAS OF THE SOUTHERN CALIFORNIA COAST AND ISLANDS

Justin S. Tweet<sup>1</sup>, Vincent L. Santucci<sup>2</sup>, and Tim Connors<sup>3</sup>

**ABSTRACT.**—Paleontological resource inventories for the parks of the National Park Service’s Mediterranean Coast Inventory and Monitoring Network (MEDN) indicate a significant Late Cretaceous and Cenozoic fossil record for the southern California coast and islands. These inventories document over 100 million years of biologic and geologic changes along the Pacific coast of southern California. During 2012, comprehensive paleontological resource data were compiled for Cabrillo National Monument (CABR), Channel Islands National Park (CHIS), and Santa Monica Mountains National Recreation Area (SAMO). This recent work expands the paleontological resource data previously compiled for each of the parks in 2003 and during the SAMO paleontological survey of 2004. Fossil plants, invertebrates, and vertebrates and trace fossils represent both marine and terrestrial life along the ancestral coast of southern California. Within the boundaries of SOMA, 38 fossil taxa have been described from specimens discovered there, and 19 more have been described from CHIS. Among the significant fossils found within the MEDN are the pygmy mammoths of CHIS, which continue to be a subject of scientific research. Recent work at SAMO has helped refine the stratigraphic interpretation of the park’s geology; helped provide additional documentation of the Miocene flora and fauna; and led to the description of new taxa, including the Upper Cretaceous gastropod *Pyropsis aldersoni* (Squires 2011) and the Paleocene crab *Costacopluma squiresi* (Nyborg et al. 2009). The recent MEDN paleontological resource inventory will help stimulate future research, education, interpretation, and proper management of these important paleontological resources.

**RESUMEN.**—Los inventarios de recursos paleontológicos de los parques de la Red de Monitoreo e Inventario de la Costa del Mediterráneo del Servicio de Parques Nacionales (MEDN por sus siglas en inglés) señalan la existencia de registros de fósiles del período Cretácico Tardío y de la era Cenozoica del sur de las islas y la costa de California. En esta investigación se documentan los cambios biológicos y geológicos en la costa del Pacífico del sur de California, a lo largo de más de 100 millones de años. Durante el año 2012 se reunió información completa sobre los recursos paleontológicos del Monumento nacional Cabrillo (CABR por sus siglas en inglés), el Parque nacional Channel Islands (CHIS) y el Área Nacional de Recreación Montañas de Santa Mónica (SAMO por sus siglas en inglés). Este trabajo extiende la información sobre recursos paleontológicos que se había reunido anteriormente sobre cada uno de los parques en el año 2003 y durante la investigación paleontológica del SAMO del año 2004. Los fósiles de plantas, los invertebrados, los vertebrados y las huellas fósiles representan la vida marina y la vida terrestre de la costa del sur de California ancestral. Se describieron 38 taxones de fósiles que se descubrieron dentro de los límites del SAMO, y se describieron 19 taxones más del CHIS. Entre los restos fósiles relevantes que se encontraron dentro del MEDN, se pueden mencionar mamuts pigmeos de CHIS, que continúan siendo objeto de investigación científica. La investigación reciente que se realizó en el SAMO contribuyó a refinar la interpretación estratigráfica de la geología del parque; aportó documentación adicional sobre la flora y la fauna del Mioceno; y permitió describir nuevos taxones, incluyendo el gasterópodo del período Cretácico Superior *Pyropsis aldersoni* (Squires 2011) y el cangrejo del Paleoceno *Costacopluma squiresi* (Nyborg et al. 2009). El inventario reciente de recursos paleontológicos del MEDN contribuirá a fomentar la investigación, la educación, la interpretación y el control adecuado de estos importantes recursos paleontológicos en el futuro.

**ACRONYMS AND ABBREVIATIONS.**—CAS—California Academy of Sciences, San Francisco, California; CABR—Cabrillo National Monument; CHIS—Channel Islands National Park; LACM—Natural History Museum of Los Angeles County, Los Angeles, California; LACMIP—Invertebrate Paleontology Collections, Natural History Museum of Los Angeles County; Ma—megaannum (million years ago); MEDN—Mediterranean Coast Inventory and Monitoring Network; NPS—National Park Service; SAMO—Santa Monica Mountains National Recreation Area; SDNHM—San Diego Natural History Museum; UCMP—University of California Museum of Paleontology, Berkeley, California.

The National Park Service Inventory and Monitoring Program was established to coordinate baseline natural resource inventories

and to develop methods and strategies for monitoring various natural resources within the National Park Service (NPS) areas. To this

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Fig. 1. Map of the Mediterranean Coast Network.

end, the 270 NPS units with significant natural resources have been divided into 32 networks based on their shared natural features and systems. Among these networks is the Mediterranean Coast Network (MEDN), which encompasses the southern third of the California coast (Fig. 1). Within the MEDN are 3 park units: Cabrillo National Monument (CABR), Channel Islands National Park (CHIS), and Santa Monica Mountains National Recreation Area (SAMO). Although none of these units were created with fossil resources in mind, each of them includes abundant fossils. In fact, CHIS and SAMO have some of the most extensive fossil records of any NPS unit.

The original MEDN paleontological inventory (Koch and Santucci 2003) was the second such inventory report to be produced and was approved in June 2003. At the time, resources for the network inventory project were limited, and the project was in its infancy. As a result, the 2003 report is much shorter and less detailed than more recent reports, and it does not deal with all the topics that more recent reports include. Additionally, since then the NPS changed the format for inventory reports. Upon completion of the last network reports in 2011, we turned our attention to the

earliest issued reports, with aims of incorporating our advances in research and presentation and updating the information to the new standard format. The resulting revised Mediterranean Coast Network paleontological inventory (Tweet et al. 2012) is the second revised report. This report takes full advantage of what has been learned during the previous decade of preparing inventories and incorporates nearly 10 years of new research and discoveries. What follows is a brief summary of the paleontological resources of the 3 MEDN parks.

#### CABRILLO NATIONAL MONUMENT

Cabrillo National Monument (CABR) protects an area at the tip of Point Loma in San Diego. It commemorates the landing of explorer Juan Rodríguez Cabrillo in 1542. Point Loma has been known to yield fossils since the late 19th century (Cooper 1894, Anderson 1902). Many fossils can be seen along the coast in CABR and in the monument's well-known tidal pools. Constant coastal erosion at CABR can rapidly expose and destroy fossils, which presents challenges to their management and protection.

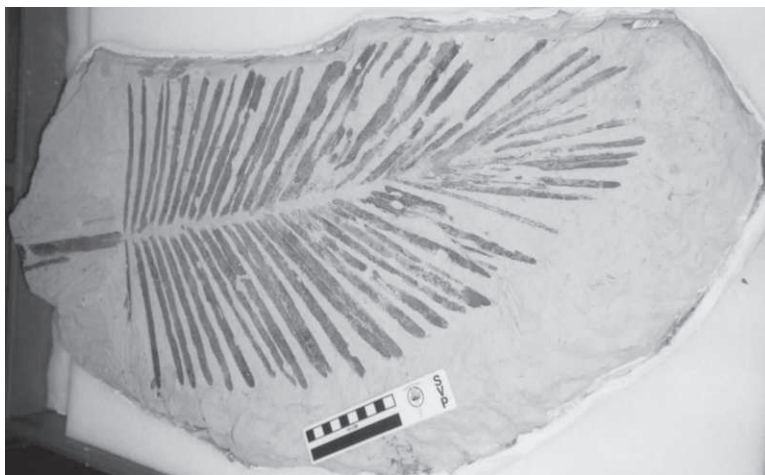


Fig. 2. A cycad leaf from Cabrillo National Monument (CABR) (SDMNH 48361).

TABLE 1. Stratigraphic units exposed within Cabrillo National Monument (CABR).

Period/Age	Geologic unit
Quaternary 2.59–0 Ma	“Bay Point Formation” “Lindavista Formation”
Cretaceous 145.0–66.0 Ma	Cabrillo Formation Point Loma Formation

CABR has bedrock of Upper Cretaceous marine formations, with overlying deposits of Pleistocene marine and coastal sediments in some areas (Table 1; Kennedy 1975, Kennedy and Tan 2008). Both the Cretaceous and Pleistocene units have produced fossils within the monument, many of which are now curated at the LACM (primarily the LACMIP), SDNHM, and UCMP (Tweet et al. 2012).

The Cretaceous strata include 2 formations: the Point Loma Formation and the overlying Cabrillo Formation (Kennedy 1975, Kennedy and Tan 2008). These 2 formations are part of a submarine fan complex, extending perhaps as far as the continental rise and deposited during the Campanian and Maastrichtian stages of the Late Cretaceous (between approximately 84 and 66 Ma; Kennedy and Moore 1971, Nilsen and Abbott 1979). Fossils from the Point Loma Formation within CABR include a rare cycad leaf (Fig. 2; Koch and Santucci 2003) and abundant invertebrate burrows (Fig. 3; Tweet et al. 2012). Ammonites with attached bivalves, a partial mosasaur jaw (Koch and Santucci 2003), and a hadrosaurid dinosaur

specimen have been found near but outside the monument on the Point Loma peninsula (Hilton 2003), and a variety of other marine fossils are known from the formation on the peninsula as well (Tweet et al. 2012).

The Cabrillo Formation of CABR has yielded significant fossils, documented primarily by Dawson (1978), who reported wood fragments, corals, brachiopods, bivalves, ammonites, gastropods, and echinoderms. These fossils were probably reworked from the underlying Point Loma Formation or older deposits of the Cabrillo Formation itself (Dawson 1978). Koch and Santucci (2003) reported that a tooth of the shark *Squalicorax* was found either just within or just outside of CABR. Other marine fossils have been found elsewhere in the Cabrillo Formation on the Point Loma peninsula (Tweet et al. 2012); both formations are exposed in many parts of CABR, and these other types of fossils have the potential to be found in the monument.

The Pleistocene deposits of the monument are primarily associated with several marine terraces, including the Nestor Terrace and Bird Rock Terrace (Kennedy and Tan 2008). The Nestor Terrace dates to about 120,000 years ago, and the younger Bird Rock Terrace dates to about 80,000 years ago (Muhs et al. 1994, 2002). Sediments from an older marine highstand, perhaps 855,000 years old (Kern and Rockwell 1992), can be found in the higher elevations of the monument (Kennedy and Tan 2008). The Nestor Terrace has proved extensively



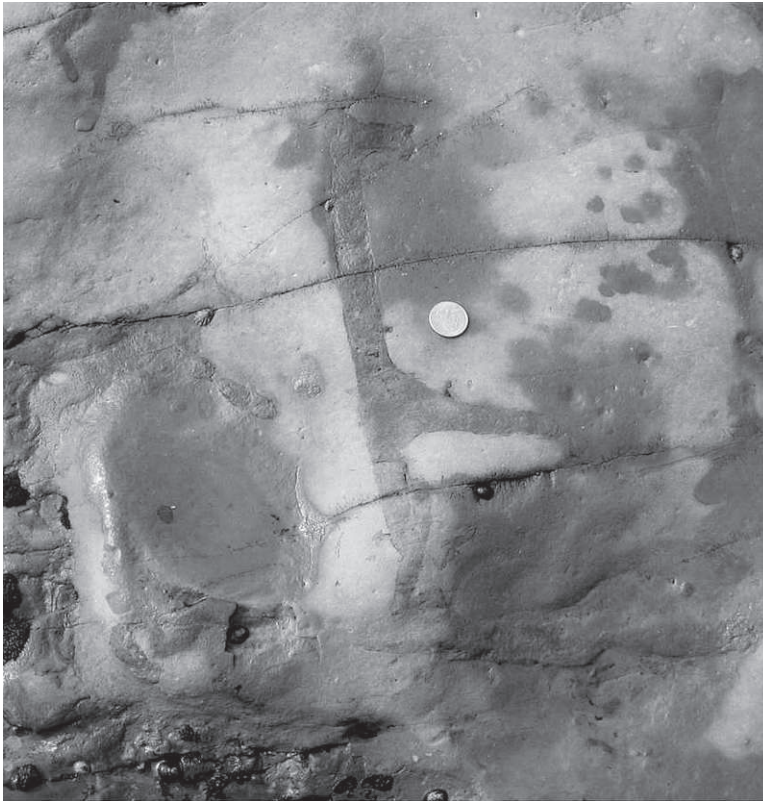


Fig. 3. Invertebrate burrows at Cabrillo National Monument (CABR).

fossiliferous within CABR, with several fossil localities yielding abundant bivalves and gastropods as well as sponges, corals, bryozoans, chitons, barnacles, crabs, and bony fish (Kern 1977, Tweet et al. 2012).

#### CHANNEL ISLANDS NATIONAL PARK

Channel Islands National Park (CHIS) protects the natural and cultural resources of 5 of the 8 Channel Islands of California. These islands include (from west to east) San Miguel Island, Santa Rosa Island, Santa Cruz Island, Anacapa Island, and Santa Barbara Island. The last is isolated to the southeast of the others. Each island has somewhat different geology, but all have broadly similar geologic histories (Table 2). Sedimentary deposition is mostly marine from the Cretaceous into the Miocene, with a brief but voluminous mid-Miocene volcanic event. A depositional hiatus exists from the end of the Miocene until the Quaternary. The Quaternary includes coastal marine and

terrestrial deposition. The 4 northern islands were periodically connected during the Quaternary because of low sea levels (Palmer 2004, Tweet et al. 2012).

The 4 northern islands are part of the Transverse Ranges, which underwent significant changes in location and orientation during the Middle Cenozoic in response to major tectonic events (Atwater 1998, Weigand et al. 2002). Briefly, as the Farallon Plate was subducted beneath the North American Plate during the Mesozoic and early Cenozoic, small fragments “caught” onto the continent, setting off a chain of events that disrupted the many small crustal fragments attached to the continent (Weigand et al. 2002). The Transverse Ranges were wrenched out of place around 19 Ma (Weigand et al. 2002), rotated approximately 90° clockwise, and moved north of San Diego (Bartling and Abbott 1983).

With the exception of some marine microfossils and bivalves from Upper Cretaceous rocks on San Miguel Island (Weaver 1969), the

TABLE 2. Stratigraphic units exposed within the 3 large islands of Channel Islands National Park (CHIS). Units on Anacapa and Santa Barbara islands are limited to Quaternary rocks and sediments over Middle Miocene volcanics and interbedded sedimentary rocks. Miocene units on the 3 large islands have complex relationships, simplified here.

Period/Epoch	Age	San Miguel Island	Santa Rosa Island	Santa Cruz Island
Quaternary	2.59–0 Ma	Quaternary rocks & deposits	Quaternary rocks & deposits	Quaternary rocks & deposits Middle Anchorage Fm. Potato Harbor Formation
Miocene	23.01–5.33 Ma	Monterey Formation San Miguel Island Volcs.	Beechers Bay Fm. San Onofre Breccia Monterey Formation Santa Rosa Island Volcanics Rincon Formation Vaqueros Formation	Blanca Formation Monterey Formation Beechers Bay Formation Santa Cruz Island Volcanics San Onofre Breccia Rincon Formation
		Vaqueros/Rincon Fm.		Vaqueros Formation
Oligocene	33.9–23.01 Ma		Sespe Formation	
Eocene	56.0–33.9 Ma	South Point Formation	Cozy Dell Formation South Point Formation	Cozy Dell Formation Jolla Vieja Formation Cañada Formation
		Pozo–Cañada Formation (undifferentiated)		Pozo Formation
Paleocene	66.0–56.0 Ma			
Cretaceous	145.0–66.0 Ma	Upper Cretaceous rocks	Upper Cretaceous rocks?	Upper Cretaceous sed. rocks Alamos Tonalite
Jurassic	201.3–145.0 Ma			Metamorphic & igneous rocks

fossils of CHIS are Cenozoic. The bulk of the pre-Pleistocene record consists of marine microfossils and mollusks. San Miguel, Santa Cruz, and Santa Rosa islands have yielded Paleocene, Eocene, and Oligocene fossils (Bereskin and Edwards 1969, Doerner 1969, Weaver and Doerner 1969). The most diverse of these Paleogene fossil assemblages comes from Santa Cruz Island, where a series of formations ranging in age from the Late Paleocene to the Early Miocene have yielded fossils including coccoliths, foraminiferans, bryozoans, brachiopods, bivalves, gastropods, scaphopods, barnacles, echinoids, shark and ray teeth, and possible whale bones (Bereskin and Edwards 1969, Doerner 1969). The tectonically and volcanically active Miocene of CHIS is represented by fossiliferous strata on all 5 islands. For the most part, the fossil assemblages from these formations are similar to the Paleogene assemblage (Tweet et al. 2012). One notable difference is the appearance of rare marine mammal material, as seen on Santa Cruz Island. Cetacean fossils have been reported from the Santa Cruz Island Volcanics and Monterey Formation (Weaver and Meyer 1969), and a skull and vertebrae from the Monterey Formation represent a new genus and species of desmostylian (Barnes and Aranda-Manteca 1997).

The Pleistocene and Holocene fossils of CHIS are by far the best-known fossils of the park to the public, exemplified by the famous pygmy mammoth *Mammuthus exilis* (Fig. 4). The alternation of marine and terrestrial deposition has given each of the 5 islands a combination of marine and terrestrial fossils (Tweet et al. 2012). The Quaternary fossils of the islands are of interest not just to paleontologists but also to archeologists because the islands have yielded human remains among the oldest in the Americas. Arlington Springs Man, from Santa Rosa Island, lived over 13,000 calibrated radiocarbon years ago at the end of the Pleistocene (Chawkins 2006, Dandridge 2006), and many areas have been inhabited over the entire Holocene. Fossils associated with cultural contexts, such as from long-term fishing sites, have been the subject of several publications (Erlandson et al. 1999, 2008, 2011, Rick and Erlandson 2000, Rick et al. 2001, 2008, 2009, Reeder et al. 2008). An early impetus to the study of the islands’ mammoths was the possibility that humans hunted and coexisted with the animals (Orr 1956, 1968). With improved dating techniques and the discovery of more fossils, it now appears that mammoths went extinct at approximately the same time humans appear on the islands (Agenbroad et al.



Fig. 4. The pygmy mammoth discovery of 1994 on Santa Rosa Island.



Fig. 5. A "fossil forest" on San Miguel Island.

2005). The discovery of a nearly complete pygmy mammoth skeleton in 1994 renewed interest in the fossils of the islands (Agenbroad and Morris 1999), and numerous publications concerning these animals have appeared, the most recent being Agenbroad (2012).

Although the pygmy mammoths have received the most attention, many other types of Quaternary fossils are known from the islands. Calcified plant roots and trunks are found on San Miguel Island (Fig. 5) and Santa Rosa

Island (Johnson 1967). They are particularly well developed on San Miguel Island, where they form "fossil forests" (Palmer 2004). Santa Cruz Island is home to a small Late Pleistocene floral assemblage, including 9 species of trees, shrubs, and herbs. These plants would have formed a woodland comparable to what is now found around Fort Bragg, Mendocino County, California, 685 km (425 miles) to the north-northwest (Chaney and Mason 1930). Among the unusual components is Douglas-fir,



which is now not found within 100 km (60 miles) of the island (Anderson et al. 2008).

Quaternary marine invertebrates from the islands are of interest for studies of paleoclimate, paleoceanography, and distribution of species. Two examples of invertebrate assemblages have been described from Anacapa Island (Lipps et al. 1968) and Santa Barbara Island (Valentine and Lipps 1963). The terrestrial gastropod *Helminthoglypta ayresiana* is exceedingly abundant on San Miguel Island. Johnson (1971) estimated that millions of specimens were present. Anacapa Island (Lipps 1964), San Miguel Island (Guthrie 2005), and Santa Rosa Island (Guthrie 1998) have produced a number of Quaternary bird fossils. San Miguel Island has yielded over 17,000 bones from 61 species of birds, as well as eggshells. The specimens have been collected from 19 sites, including seabird nesting colonies, owl roosts, and eagle nests. The vast majority of the bones come from 4 species of seabirds: the extinct puffin *Fratercula dowi*, Cassin's Auklet (*Ptychoramphus aleuticus*), Ancient Murrelet (*Synthliboramphus antiquus*), and the extinct flightless sea duck *Chendytes lawi* (Guthrie 2005). Columbian mammoths are also present: they arrived by swimming from the mainland and are thought to be the ancestors of the pygmy mammoths (Agenbroad 2012).

Finally, the islands are known as the home of extinct "giant deer mice," which were among the few mammal species present during Pleistocene isolation. Extinct deer mice are represented by *Peromyscus anyapahensis* from Anacapa Island (White 1966) and the more recent *Peromyscus nesodytes* (Wilson 1936). The latter species is well known from Santa Rosa Island (Orr 1962), where thousands of bones have been found in owl pellets (Tweet et al. 2012). The species persisted until approximately 8000 years ago (Knowlton et al. 2007).

Fossils from CHIS have been researched for over a century and are curated by several institutions. The Santa Barbara Museum of Natural History has been the official repository for CHIS since 1994 (Agenbroad 2012). Other significant collections are at the Academy of Natural Sciences of Drexel University, CAS, LACM (primarily the LACMIP), SDNHM, UCMP, and the University of California at Santa Barbara. Among the described fossils from CHIS islands are the type specimens of 19 extinct species, subspecies, and varieties.

The 19 taxa named from fossils found on the islands include 9 bivalves, 5 gastropods, 2 echinoids, 2 Pleistocene deer mice, and *Mammuthus exilis*. Most are from the Oligocene and Miocene rocks of Santa Rosa Island; but Anacapa, San Miguel, and Santa Cruz islands have also been sources of new species (Tweet et al. 2012).

#### SANTA MONICA MOUNTAINS NATIONAL RECREATION AREA

Santa Monica Mountains National Recreation Area (SAMO) protects a large area along the spine of the Santa Monica Mountains and part of the Simi Hills in Los Angeles and Ventura counties. The recreation area has one of the most extensive and diverse fossil records in the National Park System and should be considered among the top NPS units with fossils. Reasons for this position of importance include its large land area, numerous fossiliferous formations, abundant outcrops, and proximity to Los Angeles and the city's many universities and geoscientists. The complicated geology and long history of exploration by many researchers have also given the Santa Monica Mountains multiple systems of nomenclature (Fritsche 1993), which can make stratigraphic and paleontologic research confusing. SAMO and CHIS have many broad geologic events in common because both are part of the Transverse Ranges (Atwater 1998). The rock record of the recreation area encompasses the Upper Jurassic, Cretaceous, and Cenozoic (Table 3). From the Upper Cretaceous to the Holocene, there are relatively few depositional hiatuses (Koch et al. 2004, Tweet et al. 2012).

The exposed geologic history of SAMO begins with moderately metamorphosed Jurassic sedimentary rocks and Early Cretaceous igneous and metamorphic rocks, reflecting SAMO's origin as part of a volcanic arc (Sorenson 1985). Although there are some Late Jurassic bivalve fossils that may be from within SAMO (Imlay 1963), the fossil record of the recreation area essentially begins in the Late Cretaceous. A Late Cretaceous mollusk-dominated fauna has been known since at least the 1910s (Waring 1917). Marine fossils are found in several formations through the Paleocene and into the Eocene (Waring 1917, Hoots 1931, Yerkes and Campbell 1979, Koch et al. 2004). Microbial limestones (Hoots 1931, Mack 1993) and crabs



TABLE 3. Stratigraphic units exposed within Santa Monica Mountains National Recreation Area (SAMO), divided between the main portion of the park, the portion in the Simi Hills, and the portion south of the Malibu Coast Fault.

Period/Epoch	Age	Santa Monica Mountains	Simi Hills Section	South of Malibu Coast Fault
Quaternary	2.59–0 Ma	Quaternary rocks & deposits Saugus Formation		
Pliocene	5.33–2.59 Ma	Unnamed rocks & deposits		
Miocene	23.01–5.33 Ma	Modelo/Monterey Formation Calabasas/Upper Topanga Formation Conejo Volcanics Topanga Canyon/Lower Topanga Fm.		Monterey Fm. Zuma Volcanics Trancas Fm.
		Vaqueros Formation		
Oligocene	33.9–23.01 Ma	Sespe Formation		
Eocene	56.0–33.9 Ma			
		Llajas Formation	Llajas Formation	
			Santa Susana Formation	
Paleocene	66.0–56.0 Ma			
		Santa Susana/Coal Canyon Fm. Simi Conglomerate	Las Virgenes Sandstone Simi Conglomerate	
Cretaceous	145.0–66.0 Ma	Tuna Canyon Formation Trabuco Formation Lower Cretaceous intrusives	Chatsworth Fm.	Catalina Schist?
Jurassic	201.3–145.0 Ma	Santa Monica Schist		

(Fig. 6; Squires 1980, Nyborg et al. 2009) are among the more unusual fossils of the Paleocene rocks found in and around the eastern part of the recreation area, which is also the source of several new species of mollusks (Tweet et al. 2012).

In the Santa Monica Mountains, the Middle Cenozoic was a time when a coastal terrestrial setting was replaced by a marine setting over the course of millions of years and several smaller transgression-regression cycles (Yerkes and Campbell 1979, Lander 2011). This process occurred against the larger tectonic backdrop discussed above for CHIS. The primary terrestrial formation, the Sespe Formation, has only recently begun to yield fossils in the recreation area, including bones of frogs, tortoises, rodents, pikas, and camels of the Lower and Upper Piuma Road local faunas (Whistler and Lander 2003, Lander 2011). A marine tongue is interposed between the local faunas, and it features logs and palm fronds as well as snails, ray teeth, and mammal bones (Lander 2011). These rocks are overlaid by the Topanga Canyon Formation (also known as the Lower Topanga Formation), one of the most fossiliferous rock units in SAMO. This variable unit, with both marine and terrestrial deposition (Flack 1993), has terrestrial fossils of land plants,

small reptiles, and mammals (Lander 2011) and abundant marine fossils, especially mollusks (Fig. 7; Koch et al. 2004). Mollusks have been collected from these rocks since the beginning of the 20th century (Arnold 1907), with important localities in Topanga and Old Topanga canyons (Campbell et al. 2007), such as the locally popular Amphitheater locality (Koch et al. 2004). Fossils from Topanga and Old Topanga canyons include the remains of bivalves, gastropods, barnacles, crabs, echinoids, sharks and rays, ray-finned fish, sea lions, and whales (Lander 2011). Among these fossils are a number of new species of mollusks (Arnold 1907, Tweet et al. 2012).

The Topanga Canyon/Lower Topanga Formation is overlaid by the Conejo Volcanics, a thick sequence of volcanic rocks with interbedded sedimentary rocks (Yerkes and Campbell 1979) and early marine and younger sub-aerial components (Williams 1983). Stanton and Alderson (2013) described a mollusk-dominated fossil assemblage in this formation in eastern SAMO, representing transported fossils. A plant assemblage is known from just outside of SAMO (Stadum and Weigand 1999). The youngest unit of this sequence, the Calabasas or Upper Topanga Formation, is not known for its fossils to the same extent as the

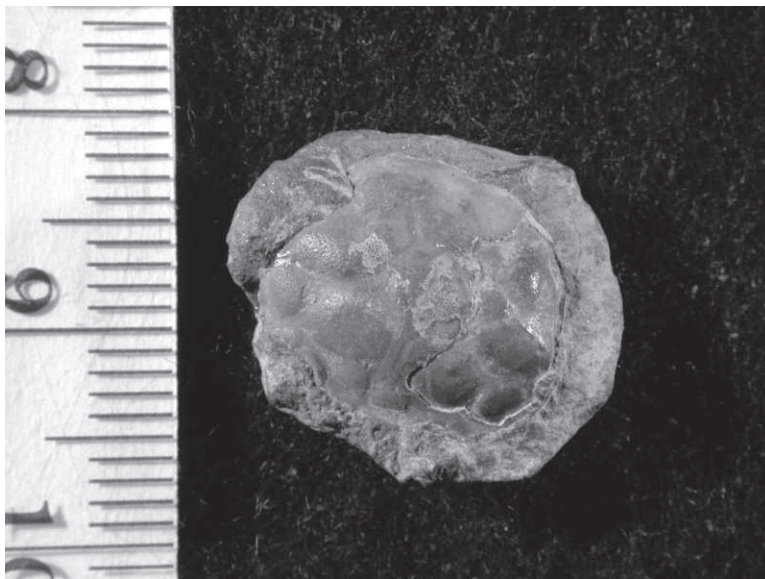


Fig. 6. *Cyclocorystes aldersoni* Squires 1980, dorsal view (holotype LACMIP 5863), from the Paleocene Santa Susana Formation (also known as the Coal Canyon Formation) of Santa Monica Mountains National Recreation Area (SAMO). Photo by Caitlin De La Cruz, LACM.



Fig. 7. *Anadara (Anadara) topangaensis* Reinhart 1943, right valve (holotype LACMIP 10095 [ex UCLA 3258]), from the Miocene Topanga Canyon Formation of Santa Monica Mountains National Recreation Area (SAMO). Photo by Caitlin De La Cruz, LACM.

older formations; but it does have several microfossil localities in the recreation area (Yerkes and Campbell 1979, Campbell and Yerkes 1980).

One of the most outstanding fossiliferous formations of SAMO is the marine Middle–Upper Miocene Modelo Formation. It is best known for its fish fauna (Fig. 8), produced primarily



Fig. 8. *Sardra stockii*, a fish from the Modelo Formation of Santa Monica Mountains National Recreation Area (SAMO) (holotype LACM 1059).

from several localities in and around the eastern end of SAMO. A half-dozen species of fish were named from specimens probably recovered from land now within the recreation area's boundaries (David 1943). Another notable group of fossils from the recreation area and immediate vicinity is an assemblage of rare seaweeds (Parker and Dawson 1965). Egg cases of argonaut cephalopods have also been described (Saul and Stadum 2005). Other more typical fossils discovered in the formation within SAMO include several groups of marine microfossils, bivalves, gastropods, and echinoids and a few marine mammal bones (Hoots 1931). Good specimens of birds (Miller 1929, Howard 1958, 1962) and dolphins (Barnes 1985) have been found just outside of SAMO.

The Upper Pliocene and Quaternary are also well represented by fossils in SAMO, particularly in the vicinity of Temescal and Potrero canyons in the southeastern part of the recreation area (Arnold 1907, Hoots 1931). The oldest fossils from these deposits are mostly marine invertebrates (Arnold 1907, Hoots 1931), but pinecones from the Lower Pleistocene have been recovered from Potrero Canyon (Axelrod 1967). Potrero Canyon is also the source of tens of thousands of Upper Pleistocene mollusks, but unfortunately most of the deposits have been destroyed by construction projects (Valentine 1956). Another fauna of comparable

age is known from Escondido Beach (Addicott 1964). Representatives of the extinct Pleistocene megafauna have been recovered from Zuma Creek where a substantial fauna is present (Koch et al. 2004) but has not been described in detail.

Of the 3 MEDN units, SAMO has seen the most work since the publication of the original MEDN paleontological inventory (Koch and Santucci 2003). In addition to the dedicated SAMO inventory (Koch et al. 2004), there have been other notable publications, including (1) several papers on Cretaceous and Paleocene mollusks that include SAMO specimens (Squires and Saul 2006, 2007, 2009); (2) more work on the Middle Cenozoic mammals, summarized by Lander (2011); (3) a description of the Conejo Volcanics invertebrates (Stanton and Alderson 2013); (4) a publication including Zuma Creek fossils of the extinct Californian Turkey *Meleagris californica* (Bocheński and Campbell 2006); and (5) the description of 2 new invertebrates from specimens found within SAMO: the crab *Costacophuma squiresi* (Nyborg et al. 2009) and the gastropod *Pyropsis alderi* (Squires 2011). The enormous size and complex geology of the recreation area ensure that there are many remaining questions to be answered and outcrops to be explored.

The majority of fossils collected from SAMO are in the collections of the LACM (primarily the LACMIP), which includes not only its own

collections but several orphaned collections that were transferred to the LACM, such as the fossils originally held at the California Institute of Technology. Other collections of note can be found at the CAS, SDNHM, UCMP, and the National Museum of Natural History. Additionally, many private collectors have gathered fossils from lands now within the recreation area (Koch et al. 2004), some of which have been donated to the LACMIP. Among the specimens from SAMO are the type specimens for at least 38 taxa. These include 15 gastropods, 7 seaweeds, 6 bivalves, 6 fish, 2 ammonites, and 2 crabs. Seven are from the Upper Cretaceous Tuna Canyon Formation, 3 are from the Paleocene Coal Canyon or Santa Susana Formation, 15 are from the Miocene Topanga Canyon/Lower Topanga Formation, and 13 are from the Miocene Modelo Formation (Tweet et al. 2012).

#### FUTURE RESEARCH

All 3 MEDN units are paleontologically rich and warrant further exploration. CABR, because of its ongoing erosion, could be aided by a detailed geological survey that establishes the location of particularly fossiliferous zones for resource management. The geology of CHIS was studied in great detail in the 1960s, but there has been relatively little new work on the pre-Quaternary rocks and fossils since that time. Continuing research on the pygmy mammoths and Holocene sites associated with human occupation are also areas of priority. Finally, SAMO has the most potential for further discoveries. Its many acres no doubt hold important undiscovered fossils, and its proximity to Los Angeles makes it a convenient study area for professional paleontologists and graduate and undergraduate students in need of projects. Likewise, the MEDN borders a substantial geoscience community in southern California, and park staff should be encouraged to establish and maintain contacts. There should also be some provision to establish and maintain a library of relevant publications and maps, and the latter would be particularly helpful for SAMO because of its complex boundaries and land ownership.

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