National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

National Park Service Geologic Type Section Inventory

Mediterranean Coast Inventory & Monitoring Network

Natural Resource Report NPS/MEDN/NRR—2021/2279

ON THE COVER
Marine terrace exposures of the Point Loma Formation at the type locality along the western side of Point Loma Peninsula, Cabrillo National Monument (NPS).

National Park Service Geologic Type Section Inventory

Mediterranean Coast Inventory & Monitoring Network

Natural Resource Report NPS/MEDN/NRR—2021/2279

Tim Henderson,[1] Justin S. Tweet,[2] Vincent L. Santucci,[1] and Tim Connors[3]

[1] National Park Service
Geologic Resources Division
1849 "C" Street, NW
Washington, D.C. 20240

[2] National Park Service
9149 79th Street S.
Cottage Grove, Minnesota 55016

[3] National Park Service
Geologic Resources Division
Post Office Box 25287
Denver, Colorado 80225

July 2021

U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science
Fort Collins, Colorado

The National Park Service, Natural Resource Stewardship and Science office in Fort Collins, Colorado, publishes a range of reports that address natural resource topics. These reports are of interest and applicability to a broad audience in the National Park Service and others in natural resource management, including scientists, conservation and environmental constituencies, and the public.

The Natural Resource Report Series is used to disseminate comprehensive information and analysis about natural resources and related topics concerning lands managed by the National Park Service. The series supports the advancement of science, informed decision-making, and the achievement of the National Park Service mission. The series also provides a forum for presenting more lengthy results that may not be accepted by publications with page limitations.

All manuscripts in the series receive the appropriate level of peer review to ensure that the information is scientifically credible, technically accurate, appropriately written for the intended audience, and designed and published in a professional manner.

This report received informal peer review by subject-matter experts who were not directly involved in the collection, analysis, or reporting of the data.

This report is available in digital format from the Mediterranean Coast Inventory and Monitoring Network and Natural Resource Publications Management websites. If you have difficulty accessing information in this publication, particularly if using assistive technology, please email irma@nps.gov.

Please cite this publication as:

Henderson, T., J. S. Tweet, V. L. Santucci, and T. Connors. 2021. National Park Service geologic type section inventory: Mediterranean Coast Inventory & Monitoring Network. Natural Resource Report NPS/MEDN/NRR—2021/2279. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/nrr-2286702.

NPS 963/176694, 342/176694, 159/176694, 638/176694, July 2021

Contents

Contents (continued)

Page

Figures

Page

Figures (continued)

Page

Tables

Page

Photographs

Page

Executive Summary

A fundamental responsibility of the National Park Service is to ensure that park resources are preserved, protected, and managed in consideration of the resources themselves and for the benefit and enjoyment by the public. Through the inventory, monitoring, and study of park resources, we gain a greater understanding of the scope, significance, distribution, and management issues associated with these resources and their use. This baseline of natural resource information is available to inform park managers, scientists, stakeholders, and the public about the conditions of these resources and the factors or activities that might threaten or influence their stability.

There are several different categories of geologic or stratigraphic units (supergroup, group, formation, member, bed) which represent a hierarchical system of classification. The mapping of stratigraphic units involves the evaluation of lithologies, bedding properties, thickness, geographic distribution, and other factors. If a new mappable geologic unit is identified, it may be described and named through a rigorously defined process that is standardized and codified by the professional geologic community (North American Commission on Stratigraphic Nomenclature 2005). In most instances when a new geologic unit such as a formation is described and named in the scientific literature, a specific and well-exposed section of the unit is designated as the type section or type locality (see Definitions). The type section is an important reference section for a named geologic unit which presents a relatively complete and representative profile. The type or reference section is important both historically and scientifically, and should be recorded such that other researchers may evaluate it in the future. Therefore, this inventory of geologic type sections in NPS areas is an important effort in documenting these locations in order that NPS staff recognize and protect these areas for future studies.

The documentation of all geologic type sections throughout the 423 units of the NPS is an ambitious undertaking. The strategy for this project is to select a subset of parks to begin research for the occurrence of geologic type sections within particular parks. The focus adopted for completing the baseline inventories throughout the NPS was centered on the 32 inventory and monitoring (I&M) networks established during the late 1990s. The I&M networks are clusters of parks within a defined geographic area based on the ecoregions of North America (Fenneman 1946; Bailey 1976; Omernik 1987). These networks share similar physical resources (geology, hydrology, climate), biological resources (flora, fauna), and ecological characteristics. Specialists familiar with the resources and ecological parameters of the network, and associated parks, work with park staff to support network level activities (inventory, monitoring, research, data management).

Adopting a network-based approach to inventories worked well when the NPS undertook paleontological resource inventories for the 32 I&M networks. The network approach is also being applied to the inventory for the geologic type sections in the NPS. The planning team from the NPS Geologic Resources Division who proposed and designed this inventory selected the Greater Yellowstone Inventory and Monitoring Network (GRYN) as the pilot network for initiating this project. Through the research undertaken to identify the geologic type sections within the parks of the GRYN methodologies for data mining and reporting on these resources was established.

Methodologies and reporting adopted for the GRYN have been used in the development of this type section inventory for the Mediterranean Coast Inventory & Monitoring Network.

The goal of this project is to consolidate information pertaining to geologic type sections that occur within NPS-administered areas, in order that this information is available throughout the NPS to inform park managers and to promote the preservation and protection of these important geologic landmarks and geologic heritage resources. The review of stratotype occurrences for the MEDN shows CABR has two type localities; CHIS has one type section, seven type localities, and three type areas; and SAMO has seventeen type localities and eight type areas.

This report concludes with a recommendation section that addresses outstanding issues and future steps regarding park unit stratotypes. These recommendations will hopefully guide decision-making and help ensure that these geoheritage resources are properly protected and that proposed park activities or development will not adversely impact the stability and condition of these geologic exposures.

Acknowledgments

Many individuals were consulted in the preparation of this report on the geologic type sections for the national parks of the Mediterranean Coast Inventory and Monitoring Network. We first want to extend our sincere appreciation to Randy Orndorff, David Soller, and Nancy Stamm (U.S. Geological Survey [USGS]) for their assistance with this geologic type section inventory and other important NPS projects. Randy, Nancy and David manage the National Geologic Map Database for the United States (NGMDB, https://ngmdb.usgs.gov/ngm-bin/ngm_compsearch.pl?glx=1) and the U.S. Geologic Names Lexicon ("GEOLEX", https://ngmdb.usgs.gov/Geolex/search), critical sources of geologic map information for science, industry and the American public. We also extend our appreciation to John Alderson (Natural History Museum of Los Angeles County) and Bruce Lander (Paleo Environmental Associates, Inc.) for their assistance with peer review of this inventory report.

We thank our colleagues and partners in the Geological Society of America (GSA) and Stewards Individual Placement Program for their continued support to the NPS with the placement of geologic interns and other ventures. Additionally, we are grateful to Rory O'Connor-Walston and Alvin Sellmer from the NPS Technical Information Center in Denver for their assistance with locating hard-to-find publications.

Thanks to our NPS colleagues in the Mediterranean Coast Inventory and Monitoring Network and various network parks including: Stacey Ostermann-Kelm and Lena Lee (MEDN), Linh Anh Cat and Keith Lombardo (CABR), Ken Convery and Laura Kirn (CHIS), and John Tiszler (SAMO), and Denise Louie for continued support for this and other important geology projects in the Department of Interior Regions 8, 9, 10 and 12 of the NPS.

This project is possible through the support from research associates and staff in the National Park Service Geologic Resources Division and we extend our thanks to Carol McCoy, Hal Pranger, Julia Brunner, Jason Kenworthy, and Jim Wood. We especially appreciate the dedicated assistance from Lima Soto, the Geoscientists-in-the-Parks Program (GIP) Coordinator, to ensure a highly qualified geology intern was hired for this project.

Dedication

This Mediterranean Coast Inventory and Monitoring Network Geologic Type Section Inventory is dedicated to Kate Roney Faulkner. Kate's career with the National Park Service spanned 36 years until her retirement in 2016. Kate began her NPS career at the national parklands of northwest Alaska as a seasonal park ranger. She was hired as a permanent Natural Resources Specialist in northwest Alaska in 1985 after completion of a M.S. degree in biology and natural resource management at the University of Minnesota and a B.S. in wildlife management from the University of Michigan. Kate was lead natural resource specialist for Kobuk Valley National Park, Noatak National Preserve, and Cape Krusenstern National Monument.

In 1990, Kate was selected as the Chief of Natural Resources Management at Channel Islands National Park. Her primary programs at CHIS were: long-term ecological monitoring; eradication of non-native species; reintroduction of extirpated native vertebrates; and support for scientific research. Kate's leadership, strategic vision, and passion for her work are widely recognized by her colleagues and we are proud to dedicate this report to a valued NPS alumna. Thanks for your service, Kate!

Kate Roney Faulkner conducting field work on Anacapa Island, Channel Islands National Park (photo courtesy of Kate Faulkner).

Introduction

The NPS Geologic Type Section Inventory Project ("Stratotype Inventory Project") is a continuation of and complements the work performed by the Geologic Resources Inventory (GRI). The GRI is funded by the NPS Inventory and Monitoring Program and administered by the Geologic Resources Division (GRD). The GRI is designed to compile and present baseline geologic resource information available to park managers, and advance science-informed management of natural resources in the national parks. The goals of the GRI team are to increase understanding and appreciation of the geologic features and processes in parks and provide robust geologic information for use in park planning, decision making, public education, and resource stewardship.

Documentation of stratotypes (i.e., type sections/type localities/type areas) that occur within national park boundaries represents a significant component of a geologic resource inventory, as these designations serve as the standard for defining and recognizing geologic units (North American Commission on Stratigraphic Nomenclature 2005). The importance of stratotypes lies in the fact that they store information, represent important comparative sites where knowledge can be built up or reexamined, and can serve as teaching sites for students (Brocx et al. 2019). The geoheritage significance of stratotypes is analogous to that of libraries and museums, in that they are natural reservoirs of Earth history spanning ~4.5 billion years and record the prodigious forces and evolving life forms that define our planet and our understanding as a contributing species.

The goals of this project are to: (1) systematically report the assigned stratotypes that occur within national park boundaries; (2) provide detailed descriptions of the stratotype exposures and their locations, and (3) reference the stratotype assignments from published literature. It is important to note that this project cannot verify a stratotype for a geologic unit if one has not been formally assigned and/or published. Additionally, numerous stratotypes are located geographically outside of national park boundaries, but only those within 48 km (30 mi) of park boundaries will be presented in this report.

This geologic type section inventory for the parks of the Mediterranean Coast Inventory & Monitoring Network (MEDN) follows standard practices, methodologies, and organization of information introduced in the Greater Yellowstone I&M Network type section inventory (Henderson et al. 2020). All network-specific reports are prepared, peer-reviewed, and submitted to the Natural Resources Stewardship and Science Publications Office for finalization. A small team of geologists and paleontologists from the NPS Geologic Resources Division and the NPS Paleontology Program have stepped up to undertake this important inventory for the NPS.

This inventory fills a current void in basic geologic information not currently compiled by the NPS either at most parks and at the servicewide level. This inventory requires some intensive and strategic data mining activities to determine instances where geologic type sections occur within NPS areas. Sometimes the lack of specific locality or other data presents limitations in determining if a particular type section is geographically located within or outside NPS administered boundaries. Below are the primary considerations warranting this inventory of NPS geologic type sections.

- Geologic type sections are a part of our national geologic heritage and are a cornerstone of the scientific value used to define the societal significance of geoheritage sites (https://www.nps.gov/articles/scientific-value.htm);
- Geologic type sections are important geologic landmarks and reference locations that define important scientific information associated with geologic strata. Geologic formations are commonly named after geologic features and landmarks that are recognizable to park staff;
- Geologic type sections are both historically and scientifically important components of earth sciences and mapping;
- Understanding and interpretation of the geologic record is largely dependent on the stratigraphic occurrences of mappable lithologic units (formations, members). These geologic units are the foundational attributes of geologic maps;
- Geologic maps are important tools for science, resource management, land use planning, and other areas and disciplines;
- Geologic type sections are similar in nature to type specimens in biology and paleontology, serving as "gold standards" that help to define characteristics used in classification;
- The documentation of geologic type sections in NPS areas has not been previously inventoried and there is a general absence of baseline information for this geologic resource category.
- NPS staff in parks may not be aware of the concept of geologic type sections and therefore may not understand the significance or occurrence of these natural landmarks in parks;
- Given the importance of geologic type sections as geologic landmarks and geologic heritage resources, these locations should be afforded some level of preservation or protection when they occur within NPS areas;
- If NPS staff are unaware of geologic type sections within parks, the NPS would not proactively monitor the stability, condition, or potential impacts to these locations during normal park operations or planning. The lack of baseline information pertaining to the geologic type sections in parks would limit the protection of these localities from activities that might involve ground disturbance or construction. Therefore, considerations need to be addressed about how the NPS may preserve geologic type sections and better inform NPS staff about their existence in the park;
- This inventory will inform important conversations on whether or not geologic type sections rise to the level of national register documentation. The NPS should consider if any other legal authorities (e.g., National Historic Preservation Act), policy, or other safeguards currently in place can help protect geologic type sections that are established on NPS administered lands. Through this inventory, the associated report, and close communication with park and I&M Network staff, the hope is there will be an increased awareness about these important geologic landmarks in parks. In turn, the awareness of these resources and their significance may be recognized in park planning and operations, to ensure that geologic type sections are preserved and available for future study.

Geology and Stratigraphy of the Mediterranean Coast I&M Network Parks

The Mediterranean Coast Inventory & Monitoring Network (MEDN) includes three NPS areas in coastal southern California (Figure 1). These parks are within one of the world's few areas of Mediterranean biome, characterized by a combination of distinct geography (mid-latitudinal west coast), climate (mild rainy winters and warm dry summers, with cool offshore ocean currents), and vegetation (evergreen or drought-adapted deciduous shrublands). The Mediterranean biome of southern California is an area where a highly diverse flora and fauna with significant endemism has been strongly impacted by human utilization.

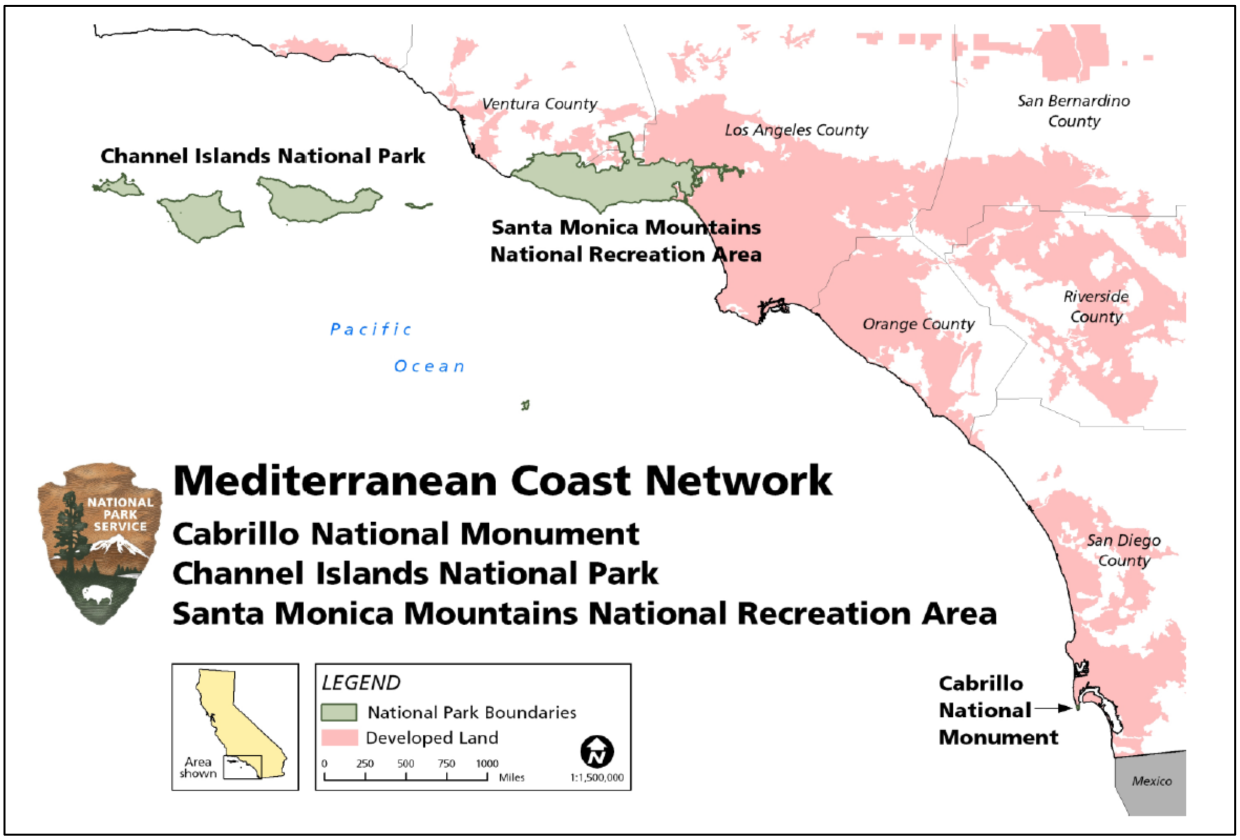


Figure 1. Map of the Mediterranean Coast Network parks: Cabrillo National Monument (CABR), Channel Islands National Park (CHIS), and Santa Monica Mountains National Recreation Area (SAMO) (NPS).

The following summary of MEDN geology is paraphrased after Tweet et al. (2012). The Mediterranean Coast area of southern California has complex geology stemming from the interactions of the western margin of the North American Plate with adjacent oceanic plates. The MEDN is composed of terranes (distinct blocks of continental crust) that had accreted to western North America by the late Mesozoic (see Appendix B for a geologic time scale). Cabrillo National Monument is located within the Peninsular Ranges terrane, and Channel Islands National Park and Santa Monica Mountains National Recreation Area are within the Transverse Ranges terrane. These two terranes were adjacent to each other when they were accreted. During the mid-Cenozoic, subduction of oceanic crust beneath the North American Plate set off a series of events including the creation of the San Andreas fault system, rifting of Baja California from the rest of Mexico, and the displacement of the Transverse Ranges block from near San Diego, which resulted in it moving north and rotating approximately 90° clockwise.

Precambrian and Paleozoic

The MEDN parks do not include any exposed or mapped Precambrian or Paleozoic rocks within park boundaries.

Mesozoic

Mesozoic rocks can be observed at all three MEDN parks. The oldest rocks date to the latter part of the Jurassic and include the Santa Monica Slate of SAMO and the Santa Cruz Island Schist and Willows Diorite of CHIS. These are interpreted as representing parts of oceanic volcanic arcs and associated areas. Convergent tectonic activity through the Early Cretaceous produced intrusive igneous rocks at CHIS (Alamos Plutonite) and SAMO (unnamed granitic rocks). The metamorphic Catalina Schist has also been reported at SAMO. Unmetamorphosed sedimentary rocks first appear in the Late Cretaceous. The Cabrillo and Point Loma Formations make up the bedrock of CABR. Rocks of Late Cretaceous age are known at San Miguel Island of CHIS, but the designation has long been controversial. Three Late Cretaceous units have been identified in SAMO, the Chatsworth, Trabuco, and Tuna Canyon Formations. The CABR and CHIS rocks were deposited in submarine fan systems between a subduction zone to the west and an Andean-type mountain range to the east, whereas the SAMO rocks represent a range of environments from terrestrial to deep-water submarine fans. Cretaceous rocks in the Santa Monica Mountains area remain poorly understood.

Cenozoic

There is no record of deposition at CABR after the Cretaceous until the Pleistocene, but CHIS and SAMO have excellent Cenozoic records documenting a variety of settings over most of the era. The CHIS record is split among five islands. Two of the islands, Anacapa Island and Santa Barbara Island, are limited to mid-Miocene volcanics and associated sedimentary rocks, and a veneer of Quaternary sedimentation. The other three have complex geologic histories that are only partly understood, and the names of many of the formations may be revised after further study. The basic pattern for these islands is marine deposition during the late Paleocene and Eocene, then continental shelf to terrestrial deposition or no deposition in the Oligocene, followed by marine conditions in the early Miocene interrupted by extensive volcanism brought on by the movement of the Transverse Ranges block, and preserved deposition ending in the middle Miocene.

San Miguel Island's Cenozoic bedrock includes undifferentiated rocks of the Pozo–Cañada Formation (middle Paleocene–middle Eocene), the South Point Formation (middle–upper Eocene), an interval that includes either or both of the Vaqueros and Rincon Formations (upper Oligocene?–lower Miocene), the San Miguel Volcanics (lower Miocene), the Beechers Bay Formation (lower–middle Miocene), and the Monterey Formation (middle Miocene). Santa Rosa Island has a broadly similar stratigraphic sequence: the South Point Formation (middle Eocene), Cozy Dell Shale (middle–upper Eocene), Sespe Formation (Oligocene), Vaqueros Formation (lower Miocene), Rincon Formation (lower Miocene), Santa Rosa Island Volcanics (lower Miocene), Monterey Formation (lower–middle Miocene), San Onofre Breccia (lower–middle Miocene), and Beechers Bay Formation (lower–middle Miocene). Santa Cruz Island is composed of two juxtaposed crustal fragments, with most of the stratigraphic diversity south and west of the island-spanning Santa Cruz Island Fault. South of the fault, the stratigraphic section includes the Pozo Formation (upper Paleocene–lower Eocene), Cañada Formation (lower–middle Eocene), Jolla Vieja Formation (middle–upper Eocene), Cozy Dell Shale (middle–upper Eocene), Vaqueros Formation (Oligocene–lower Miocene), Rincon Formation (lower Miocene), San Onofre Breccia (lower–middle Miocene), Beechers Bay Formation (lower–middle Miocene), and Blanca Formation (middle Miocene). The bedrock north of the fault is limited to the Santa Cruz Island Volcanics and Monterey Formation, both of lower–middle Miocene age. All three islands are covered with Quaternary deposits. The deposits on Santa Cruz and Santa Rosa Islands are sometimes known as the Santa Cruz Island Formation and Santa Rosa Island Formation, respectively. Santa Cruz Island also has two areally limited older Pleistocene units, the Potato Harbor Formation and Middle Anchorage Alluvium. Quaternary deposition on CHIS includes marine terrace deposits and terrestrial alluvium.

SAMO is an areally extensive park with somewhat distinct Cenozoic stratigraphic sequences in different areas of the park. In some cases, this difference is partly a result of distance. The most complete Cenozoic section at SAMO is preserved in the Santa Monica Mountains proper, where a sequence ranging from Paleocene to Pleistocene in age is present. The rock record here is exceedingly complex because of facies changes. The Cenozoic record begins with three Paleocene–Eocene units, the Simi Conglomerate (a locally present Paleocene unit), Coal Canyon Formation / Santa Susana Formation (middle–late Paleocene), and the Llajas Formation (early–middle Eocene, also only present locally). Next is the middle Eocene–early Miocene terrestrial Sespe Formation found in the central and western area of the mountains, intertonguing in part with the late Oligocene–early Miocene marine Vaqueros Formation. Above them are the three formations of the early–middle Miocene Topanga Group (Topanga Formation of earlier workers), in ascending order the dominantly marine Topanga Canyon Formation, the dominantly volcanic Conejo Volcanics, and the marine Calabasas Formation. A marine unit known variously as the Modelo or Monterey Formation (middle–late Miocene) unconformably overlies all older units. The area south of the Malibu Coast fault has a different Miocene sequence that includes the early–middle Miocene Trancas Formation and Zuma Volcanics, which are overlain by the Monterey Formation (middle–late Miocene). In the Simi Hills section in northern SAMO there is a slightly different Cenozoic sequence. It begins with the Simi Conglomerate and the overlying Las Virgenes Sandstone (Paleocene), which are succeeded by the Santa Susana Formation (late Paleocene–early Eocene) and Llajas Formation (early–middle Eocene). A section of younger rocks broadly similar to those of the Santa Monica Mountains proper are present north of the Simi Hills. As with CHIS, there is a general paucity of post-Miocene strata at SAMO until the surficial cover of the late Quaternary age, although there are small isolated exposures of Pliocene and Pleistocene rocks in the Santa Monica Mountains proper.

National Park Service Geologic Resource Inventory

The Geologic Resources Inventory (GRI) provides digital geologic map data and pertinent geologic information on park-specific features, issues, and processes to support resource management and science-informed decision-making in more than 270 natural resource parks throughout the National Park System. The GRI is one of 12 inventories funded by the National Park Service (NPS) Inventory and Monitoring Program. The Geologic Resources Division (GRD) of the NPS Natural Resource Stewardship and Science Directorate administers the GRI. The GRI team consists of a partnership between the GRD and the Colorado State University Department of Geosciences to produce GRI products.

GRI Products

The GRI team undertakes three tasks for each park in the Inventory and Monitoring program: (1) conduct a scoping meeting and provide a summary document, (2) provide digital geologic map data in a geographic information system (GIS) format, and (3) provide a GRI report. These products are designed and written for non-geoscientists.

Scoping meetings bring together park staff and geologic experts to review and assess available geologic maps, develop a geologic mapping plan, and discuss geologic features, processes, and resource management issues that should be addressed in the GRI report. Scoping sessions were held on the following dates for the MEDN parks: CHIS on May 5–6, 2008; CABR on May 6, 2008; and SAMO on May 7–8, 2008.

Following the scoping meeting, the GRI map team converts the geologic maps identified in the mapping plan to GIS data in accordance with the GRI data model. After the map is completed, the GRI report team uses these data, as well as the scoping summary and additional research, to prepare the GRI report. As of 2020, GRI reports have been completed for Cabrillo National Monument and Santa Monica Mountains National Recreation Area. The GRI team conducts no new field work in association with their products.

The compilation and use of natural resource information by park managers is called for in the 1998 National Parks Omnibus Management Act (§ 204), 2006 National Park Service Management Policies, and the Natural Resources Inventory and Monitoring Guideline (NPS-75). Additional information regarding the GRI, including contact information, is available at https://www.nps.gov/subjects/geology/gri.htm.

Geologic Map Data

A geologic map in GIS format is the principal deliverable of the GRI program. GRI GIS data produced for the MEDN parks follows the selected source maps and includes components such as: faults, mine area features, mine point features, geologic contacts, geologic units (bedrock, surficial, glacial), geologic line features, structure contours, and so forth. These are commonly acceptable geologic features to include in a geologic map.

Posters display the data over imagery of the park and surrounding area. Complete GIS data are available at the GRI publications website: https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm.

Geologic Maps

A geologic map is the fundamental tool for depicting the geology of an area. Geologic maps are two-dimensional representations of the three-dimensional geometry of rock and sediment at, or beneath the land surface (Evans 2016). Colors and symbols on geologic maps correspond to geologic map units. The unit symbols consist of an uppercase letter indicating the geologic age and lowercase letters indicating the formation's name. Other symbols depict structures such as faults or folds, locations of past geologic hazards that may be susceptible to future activity, and other geologic features. Anthropogenic features such as mines or quarries, as well as observation or collection locations, may be indicated on geologic maps. The American Geosciences Institute website (https://www.americangeosciences.org/environment/publications/mapping) provides more information about geologic maps and their uses.

Geologic maps are typically one of two types: surficial or bedrock. Surficial geologic maps typically encompass deposits that are unconsolidated and formed during the past 2.6 million years (the Quaternary Period). Surficial map units are differentiated by geologic process or depositional environment. Bedrock geologic maps encompass older, typically more consolidated sedimentary, metamorphic, and/or igneous rocks. Bedrock map units are differentiated based on age and/or rock type. GRI has produced various maps for the MEDN parks.

Source Maps

The GRI team does not conduct original geologic mapping. The team digitizes paper maps and compiles and converts digital data to conform to the GRI GIS data model. The GRI GIS data set includes essential elements of the source maps such as map unit descriptions, a correlation chart of units, a map legend, map notes, cross sections, figures, and references. These items are typically included in a master geology document (PDF) for a specific park. The GRI team uses a unique "GMAP ID" value for each geologic source map, and all sources used to produce the GRI GIS datasets for the MEDN parks can be found in Appendix A.

GRI GIS Data

The GRI team standardizes map deliverables by using a data model. The most recent GRI GIS data for CHIS and SAMO were compiled using data model version 2.3, which is available at https://www.nps.gov/articles/gri-geodatabase-model.htm; the CABR data are based on data model 2.1 and need to be upgraded to the most recent version. This data model dictates GIS data structure, including layer architecture, feature attribution, and relationships within ESRI ArcGIS software. The GRI website (https://www.nps.gov/subjects/geology/gri.htm) provides more information about the program's products.

GRI GIS data are available on the GRI publications website (https://www.nps.gov/subjects/geology/geologic-resources-inventory-products.htm) and through the NPS Integrated Resource Management Applications (IRMA) Data Store portal (https://irma.nps.gov/DataStore/Search/Quick). Enter “GRI” as the search text and select CABR, CHIS, or SAMO from the unit list.

The following components are part of the data set:

- A GIS readme file that describes the GRI data formats, naming conventions, extraction instructions, use constraints, and contact information;
- Data in ESRI geodatabase GIS format;
- Layer files with feature symbology;
- Federal Geographic Data Committee (FGDC)-compliant metadata;
- An ancillary map information document that contains information captured from source maps such as map unit descriptions, geologic unit correlation tables, legends, cross-sections, and figures;
- ESRI map documents that display the GRI GIS data; and
- A version of the data viewable in Google Earth (.kml / .kmz file)

GRI Map Posters

Posters of the GRI GIS draped over shaded relief images of the park and surrounding area are included in GRI reports. Not all GIS feature classes are included on the posters. Geographic information and selected park features have been added to the posters. Digital elevation data and added geographic information are not included in the GRI GIS data, but are available online from a variety of sources. Contact GRI for assistance locating these data.

Use Constraints

Graphic and written information provided in this report is not a substitute for site-specific investigations. Ground-disturbing activities should neither be permitted nor denied based on the information provided. Please contact GRI with any questions.

Minor inaccuracies may exist regarding the locations of geologic features relative to other geologic or geographic features on the posters. Based on the source map scales (1:100,000, 1:62,500, and 1:24,000) and US National Map Accuracy Standards, geologic features represented in the geologic map data are expected to be horizontally within 51 m (167 ft), 32 m (104 ft), and 12 m (40 ft), respectively, of their true locations.

Methods

This section of the report presents the methods employed and definitions adopted during this inventory of geologic type sections located within the administrative boundaries of the parks in the MEDN. This report is part of a more extensive inventory of geologic type sections throughout the National Park System. Therefore, the methods, definitions, and challenges identified here pertain not only to the parks of the MEDN, but also to other inventory and monitoring networks and parks.

There are a number of considerations to be addressed throughout this inventory. The most up-to-date information available is necessary, either found online or in published articles and maps. Occasionally, there is a lack of specific information that limits the information contained in the final report. This inventory does not include any field work and is dependent on the existing information related to individual park geology and stratigraphy. Additionally, this inventory does not attempt to resolve any unresolved or controversial stratigraphic interpretations, which is beyond the scope of the project.

Stratigraphic nomenclature may change over time with refined stratigraphic field assessments and discovery of information through the expansion of stratigraphic mapping and measured sections. One important observation regarding stratigraphic nomenclature relates to differences in use of geologic names for units that transcend state boundaries. Geologic formations and other units that cross state boundaries are sometimes identified by different names in each of the states where the units are mapped. An example would be the Triassic Chugwater Formation in Wyoming, which is laterally equivalent to the Spearfish Formation in the Black Hills of South Dakota.

The lack of a designated and formal type section, or inadequate and vague geospatial information associated with a type section, limits the ability to capture precise information for this inventory. The available information related to geologic type sections is included in this report.

Finally, it is worth noting that this inventory report is intended for a wide audience, including NPS staff who might not have a background in geology. Therefore, this document has been developed as a reference document that supports science, resource management, and a historic framework for geologic information associated with NPS areas.

Methodology

The process of determining whether a specific stratotype occurs in an NPS area involves multiple steps. The process begins with an evaluation of the existing park-specific GRI map to prepare a full list of recognized map units (Figure 2).

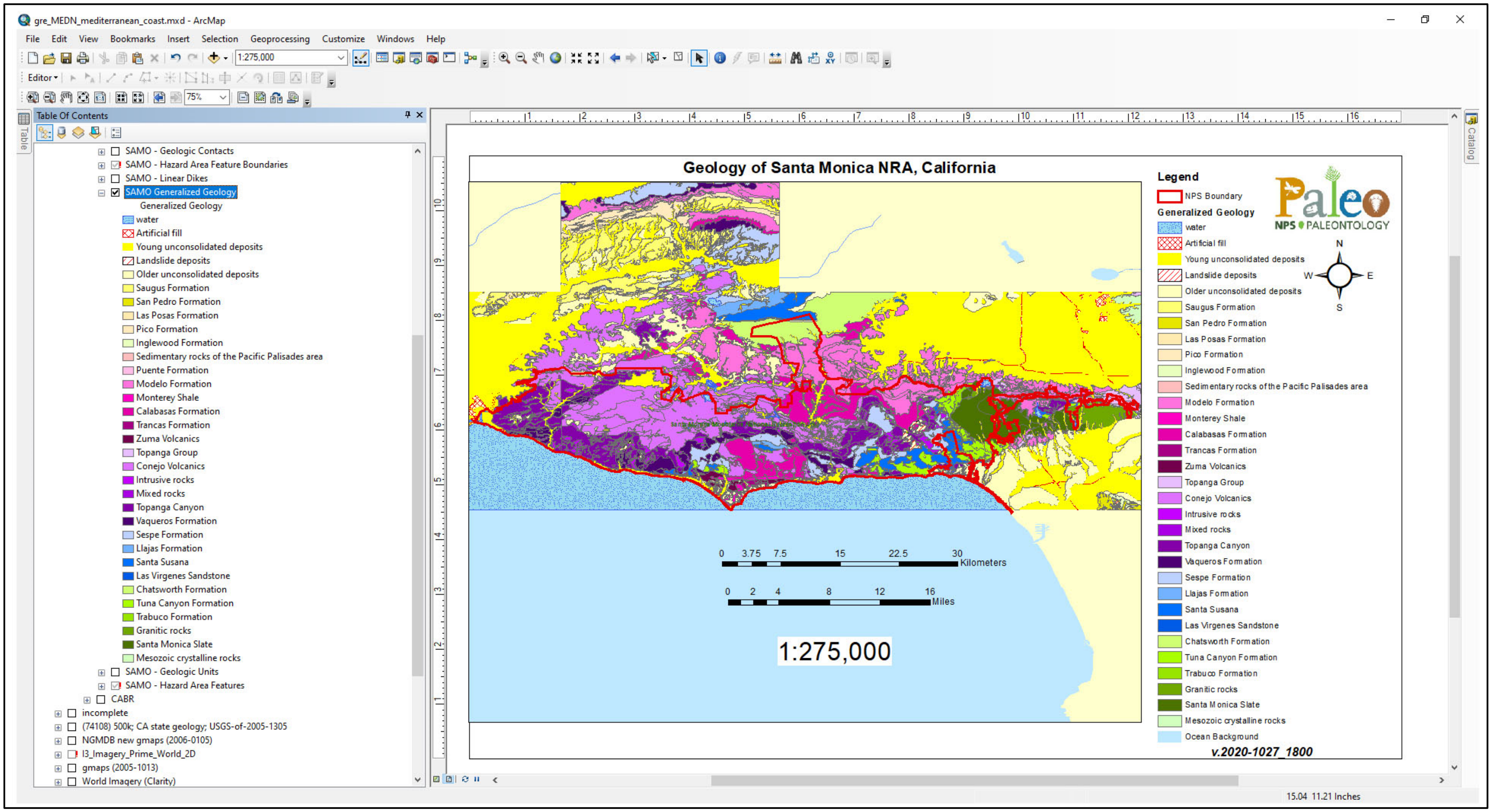


Figure 2. Screenshot of digital bedrock geologic map of Santa Monica Mountains National Recreation Area showing mapped units.

Each map unit name is then queried in the U.S. Geologic Names Lexicon online database ("GEOLEX", a national compilation of names and descriptions of geologic units) at https://ngmdb.usgs.gov/Geolex/search. Information provided by GEOLEX includes unit name, stratigraphic nomenclature usage, geologic age, published stratotype location descriptions, and the database provides a link to significant publications as well as the USGS Geologic Names Committee Archives (Wilmarth 1938; Keroher et al. 1966). Figure 3 below is taken from a search on the Zuma Volcanics.

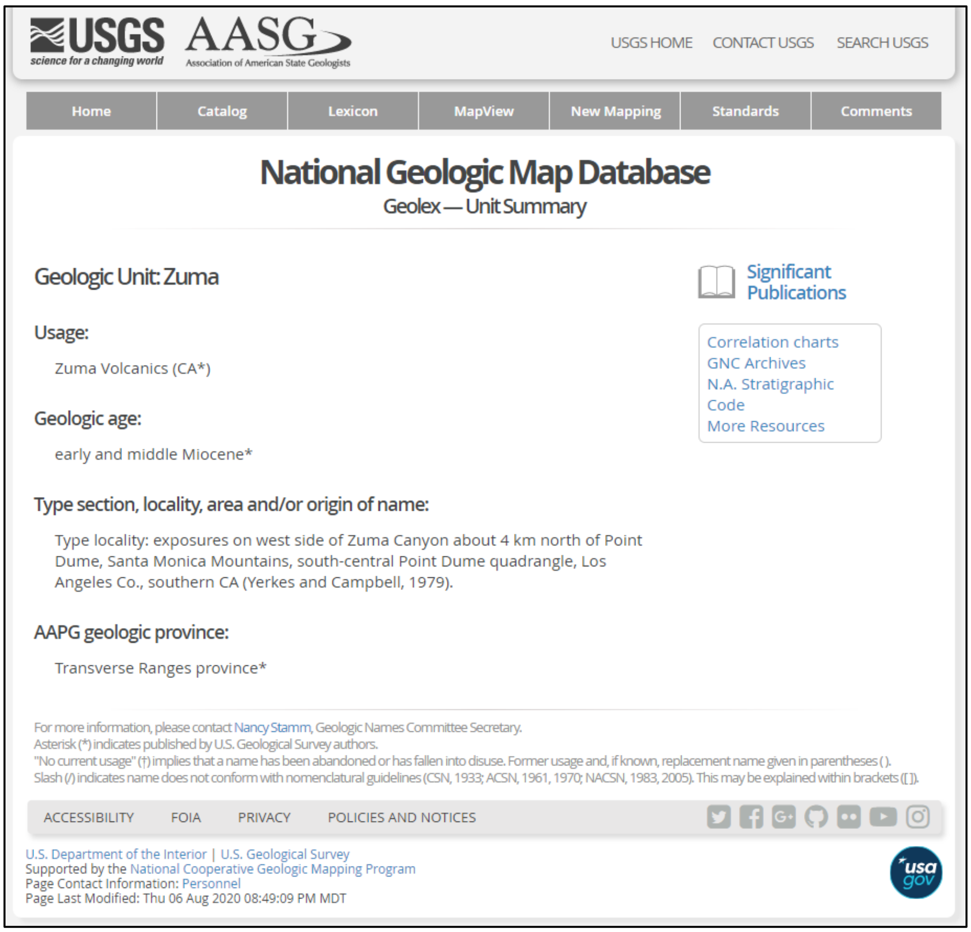
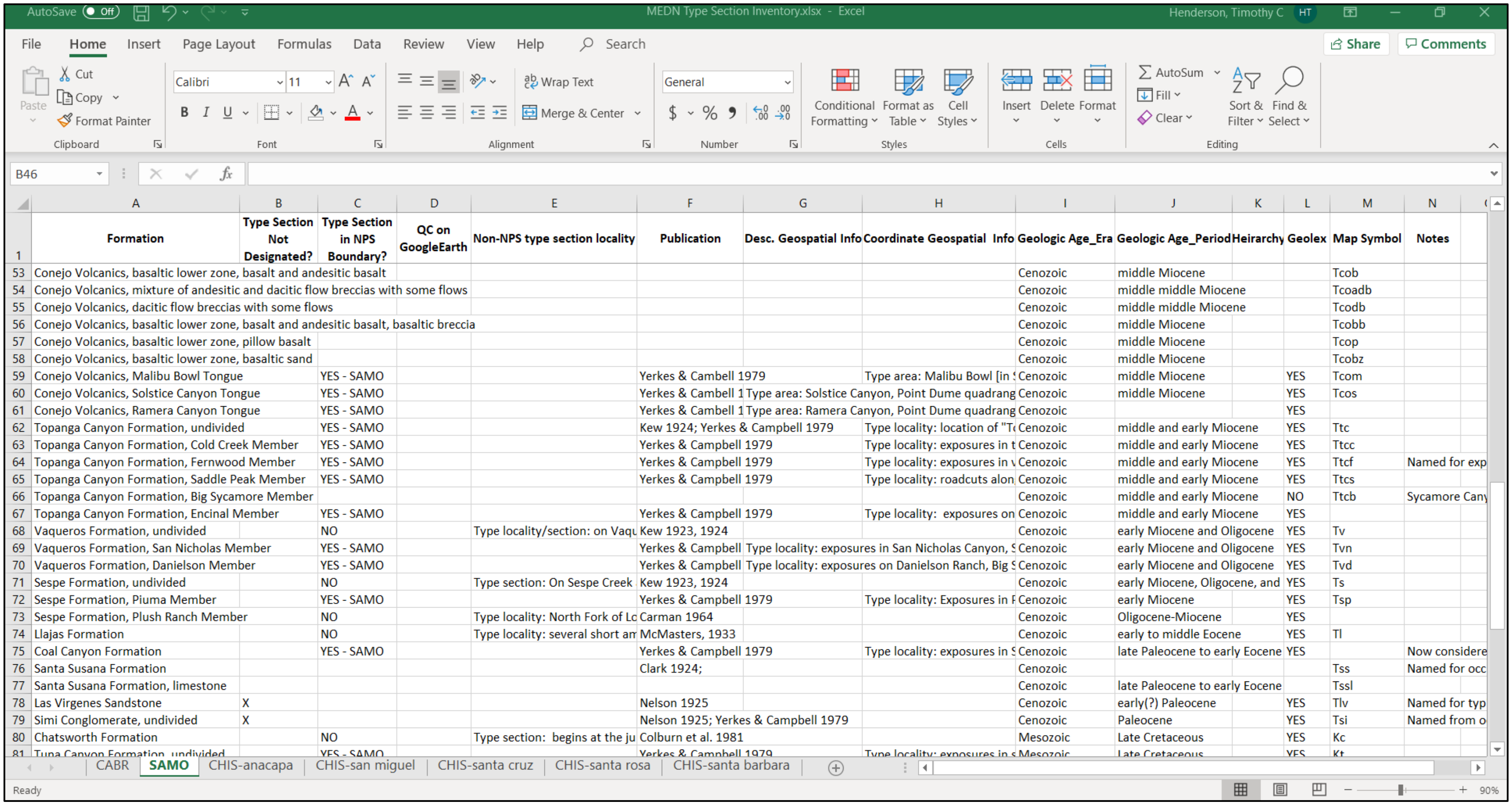


Figure 3. GEOLEX search result for Zuma Volcanics unit.

Published GEOLEX stratotype spatial information is provided in three formats: (1) descriptive, using distance from nearby points of interest; (2) latitude and longitude coordinates; or (3) Township/Range/Section (TRS) coordinates. TRS coordinates are based on subdivisions of a single 93.2 km^2 (36 mi^2) township into 36 individual 2.59 km^2 (1 mi^2) sections, and were converted into Google Earth (.kmz file) locations using Earth Point (https://www.earthpoint.us/TownshipsSearchByDescription.aspx). The most accurate GEOLEX descriptions using TRS coordinates can help locate features within 0.1618 km^2 (0.0625 mi^2). Once stratotype locality information provided for a given unit is geolocated using Google Earth, a GRI digital geologic map of the national park is draped over it. This step serves two functions: to improve accuracy in locating the stratotype, and validating the geologic polygon for agreement with GEOLEX nomenclature. Geolocations in Google Earth are then converted into an ArcGIS format using a "KML to Layer" conversion tool in ArcMap.

After this, a Microsoft Excel spreadsheet is populated with information pertinent to the geologic unit and its stratotype attributes. Attribute data recorded in this way include: (1) is a stratotype officially designated; (2) is the stratotype on NPS land; (3) has it undergone a quality control check in Google Earth; (4) reference of the publication citing the stratotype; (5) description of geospatial information; (6) coordinates of geospatial information; (7) geologic age (era, period, epoch, etc.); (8) hierarchy of nomenclature (supergroup, group, formation, member, bed, etc.); (9) was the geologic unit found in GEOLEX; and (10) a generic notes field (Figure 4).



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Formation	Type Section Not Designated?	Type Section in NPS Boundary?	QC on GoogleEarth	Non-NPS type section locality	Publication	Desc. Geospatial Info	Coordinate Geospatial Info	Geologic Age_Era	Geologic Age_Period	Heirarchy	Geolex	Map Symbol	Notes
53	Conejo Volcanics, basaltic lower zone, basalt and andesitic basalt								Cenozoic	middle Miocene			Tcob	
54	Conejo Volcanics, mixture of andesitic and dacitic flow breccias with some flows								Cenozoic	middle middle Miocene			Tcoadb	
55	Conejo Volcanics, dacitic flow breccias with some flows								Cenozoic	middle middle Miocene			Tcodb	
56	Conejo Volcanics, basaltic lower zone, basalt and andesitic basalt, basaltic breccia								Cenozoic	middle Miocene			Tcobb	
57	Conejo Volcanics, basaltic lower zone, pillow basalt								Cenozoic	middle Miocene			Tcop	
58	Conejo Volcanics, basaltic lower zone, basaltic sand								Cenozoic	middle Miocene			Tcobz	
59	Conejo Volcanics, Malibu Bowl Tongue		YES - SAMO			Yerkes & Cambell 1979		Type area: Malibu Bowl [in S	Cenozoic	middle Miocene		YES	Tcom	
60	Conejo Volcanics, Solstice Canyon Tongue		YES - SAMO			Yerkes & Cambell 1	Type area: Solstice Canyon, Point Dume quadrang		Cenozoic	middle Miocene		YES	Tcos	
61	Conejo Volcanics, Ramera Canyon Tongue		YES - SAMO			Yerkes & Cambell 1	Type area: Ramera Canyon, Point Dume quadrang		Cenozoic			YES		
62	Topanga Canyon Formation, undivided		YES - SAMO			Kew 1924; Yerkes & Campbell 1979		Type locality: location of "To	Cenozoic	middle and early Miocene		YES	Ttc	
63	Topanga Canyon Formation, Cold Creek Member		YES - SAMO			Yerkes & Campbell 1979		Type locality: exposures in t	Cenozoic	middle and early Miocene		YES	Ttcc	
64	Topanga Canyon Formation, Fernwood Member		YES - SAMO			Yerkes & Campbell 1979		Type locality: exposures in v	Cenozoic	middle and early Miocene		YES	Ttcf	Named for exp
65	Topanga Canyon Formation, Saddle Peak Member		YES - SAMO			Yerkes & Campbell 1979		Type locality: roadcuts alon	Cenozoic	middle and early Miocene		YES	Ttcs	
66	Topanga Canyon Formation, Big Sycamore Member								Cenozoic	middle and early Miocene		NO	Ttcb	Sycamore Cany
67	Topanga Canyon Formation, Encinal Member		YES - SAMO			Yerkes & Campbell 1979		Type locality: exposures on	Cenozoic	middle and early Miocene		YES		
68	Vaqueros Formation, undivided		NO		Type locality/section: on Vaqu	Kew 1923, 1924			Cenozoic	early Miocene and Oligocene		YES	Tv	
69	Vaqueros Formation, San Nicholas Member		YES - SAMO			Yerkes & Campbell	Type locality: exposures in San Nicholas Canyon, S		Cenozoic	early Miocene and Oligocene		YES	Tvn	
70	Vaqueros Formation, Danielson Member		YES - SAMO			Yerkes & Campbell	Type locality: exposures on Danielson Ranch, Big S		Cenozoic	early Miocene and Oligocene		YES	Tvd	
71	Sespe Formation, undivided		NO		Type section: On Sespe Creek	Kew 1923, 1924			Cenozoic	early Miocene, Oligocene, and		YES	Ts	
72	Sespe Formation, Piuma Member		YES - SAMO			Yerkes & Campbell 1979		Type locality: Exposures in F	Cenozoic	early Miocene		YES	Tsp	
73	Sespe Formation, Plush Ranch Member		NO		Type locality: North Fork of Lo	Carman 1964			Cenozoic	Oligocene-Miocene		YES		
74	Llajas Formation		NO		Type locality: several short an	McMasters, 1933			Cenozoic	early to middle Eocene		YES	Tl	
75	Coal Canyon Formation		YES - SAMO			Yerkes & Campbell 1979		Type locality: exposures in S	Cenozoic	late Paleocene to early Eocene		YES		Now considere
76	Santa Susana Formation					Clark 1924;			Cenozoic				Tss	Named for occ
77	Santa Susana Formation, limestone								Cenozoic	late Paleocene to early Eocene			Tssl	
78	Las Virgenes Sandstone	X				Nelson 1925			Cenozoic	early(?) Paleocene		YES	Tlv	Named for typ
79	Simi Conglomerate, undivided	X				Nelson 1925; Yerkes & Campbell 1979			Cenozoic	Paleocene		YES	Tsi	Named from o
80	Chatsworth Formation		NO		Type section: begins at the ju	Colburn et al. 1981			Mesozoic	Late Cretaceous		YES	Kc	
81	Tuna Canyon Formation, undivided		YES - SAMO			Yerkes & Campbell 1979		Type locality: exposures in s	Mesozoic	Late Cretaceous		YES	Kt	

Figure 4. Stratotype inventory spreadsheet of the MEDN displaying attributes appropriate for geolocation assessment.

Definitions

In order to clarify, standardize, and consistently reference stratigraphic concepts, principles, and definitions, the North American Stratigraphic Code is recognized and adopted for this inventory. This code seeks to describe explicit practices for classifying and naming all formally defined geologic units. An important designation for a geologic unit is known as a ***stratotype***–the standard (original or subsequently designated) for a named geologic unit or boundary and constitutes the basis for definition or recognition of that unit or boundary (North American Commission on Stratigraphic Nomenclature 2005). There are several variations of stratotype referred to in the literature and this report, and they are defined as following:

(1) Unit stratotype: the **type section** for a stratified deposit or the **type area** for a non-stratified body that serves as the standard for recognition and definition of a geologic unit (North American Commission on Stratigraphic Nomenclature 2005). Once a unit stratotype is assigned, it is never changed. The term "unit stratotype" is commonly referred to as "type section" and "type area" in this report.

(2) **Type locality**: the specific geographic locality encompassing the unit stratotype of a formally recognized and defined unit. On a broader scale, a type area is the geographic territory encompassing the type locality. Before development of the stratotype concept, only type localities and type areas were designated for many geologic units that are now long- and well-established (North American Commission on Stratigraphic Nomenclature 2005).

(3) **Reference sections**: for well-established geologic units for which a type section was never assigned, a reference section may serve as an invaluable standard in definitions or revisions. A principle reference section may also be designated for units whose stratotypes have been destroyed, covered, or are otherwise inaccessible (North American Commission on Stratigraphic Nomenclature 2005). Multiple reference sections can be designated for a single unit to help illustrate heterogeneity or some critical feature not found in the stratotype. Reference sections can help supplement unit stratotypes in the case where the stratotype proves inadequate (North American Commission on Stratigraphic Nomenclature 2005).

(4) **Lithodeme**: the term "lithodeme" is defined as a mappable unit of plutonic and highly metamorphosed or pervasively deformed rock and is a term equivalent in rank to "formation" among stratified rocks (North American Commission on Stratigraphic Nomenclature 2005). The formal name of a lithodeme consists of a geographic name followed by a descriptive term that denotes the average modal composition of the rock (example: Cathedral Peak Granodiorite). Lithodemes are commonly assigned type localities, type areas, and reference localities.

Cabrillo National Monument

Cabrillo National Monument (CABR) is located at the southern end of Point Loma Peninsula, approximately 8 km (5 mi) southwest of downtown San Diego in San Diego County, California (Figure 5). Established on October 14, 1913, CABR memorializes Iberian explorer Juan Rodriguez Cabrillo and his 1542 voyage, during which he claimed the coastal region for Spain. The monument encompasses ~65 hectares (160 acres) and 49 offshore hectares (120 acres) that preserve rare natural and cultural resources on the peninsula. The Old Point Loma Lighthouse in CABR serves as a cultural centerpiece and has become a landmark symbol of the city of San Diego (KellerLynn 2018). CABR provides on-land opportunities to view marine life and is a popular whale-watching location from December through February when Pacific gray whales migrate by to the monument. The monument is also a popular birding destination as CABR is an important stopover site for birds along the Pacific Flyway. The monument boasts one of the world's most spectacular harbor views while also providing scenic panoramas that stretch from Mexico to the mountains east of Los Angeles. Historically, Point Loma has been used for observation of the Pacific Ocean and San Diego Bay, serving strategic military, navigational, and recreational purposes (KellerLynn 2018).

The geology of CABR is represented by a small number of geologic units; these units date back to the Late Cretaceous (100–66 million years ago) and were originally deposited in the Pacific Ocean at great depth (Figure 6). These rocks do not represent the entire Late Cretaceous. Sediments shed from the Peninsular Ranges were transported through a submarine fan system that would later be uplifted due to tectonic deformation and faulting related to the Rose Canyon fault zone (KellerLynn 2018). These uplifted submarine fan deposits form the bedrock of CABR and are known as the Rosario Group. The Point Loma and Cabrillo Formations of the Rosario Group crop out at the monument in an area of marine terraces and wave-cut platforms. The Old Point Loma Lighthouse is partly constructed of locally sourced sandstone of the Cabrillo and Point Loma Formations. The offshore area west of the Point Loma Peninsula consists of undivided rocks of the Rosario Group, and the eastern offshore area consists of Holocene (less than 11,700 years old) marine deposits that make up the seafloor of the Pacific Ocean and San Diego Bay (KellerLynn 2018).

CABR contains two identified stratotypes, both of which are type localities (Figure 7; Table 1).

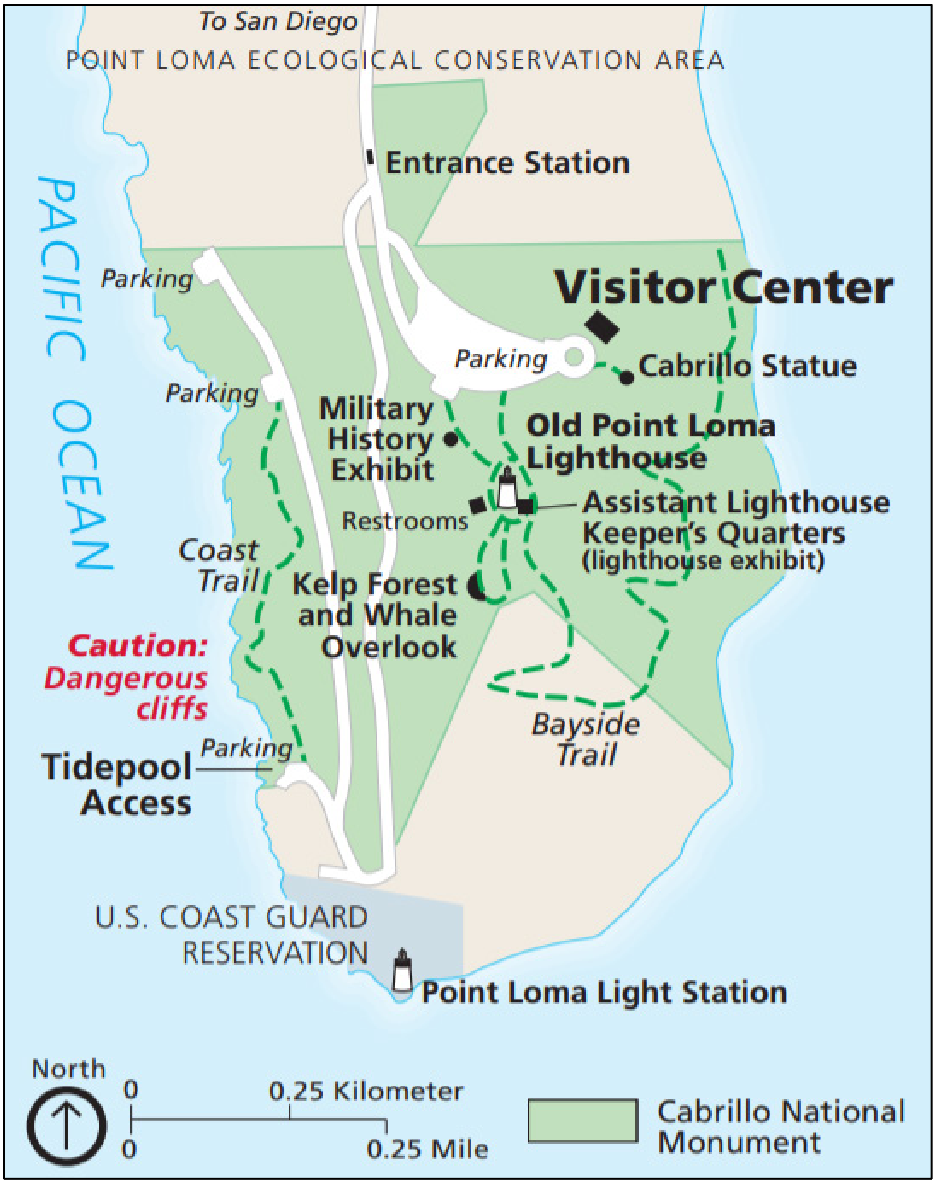


Figure 5. Park map of CABR (NPS).

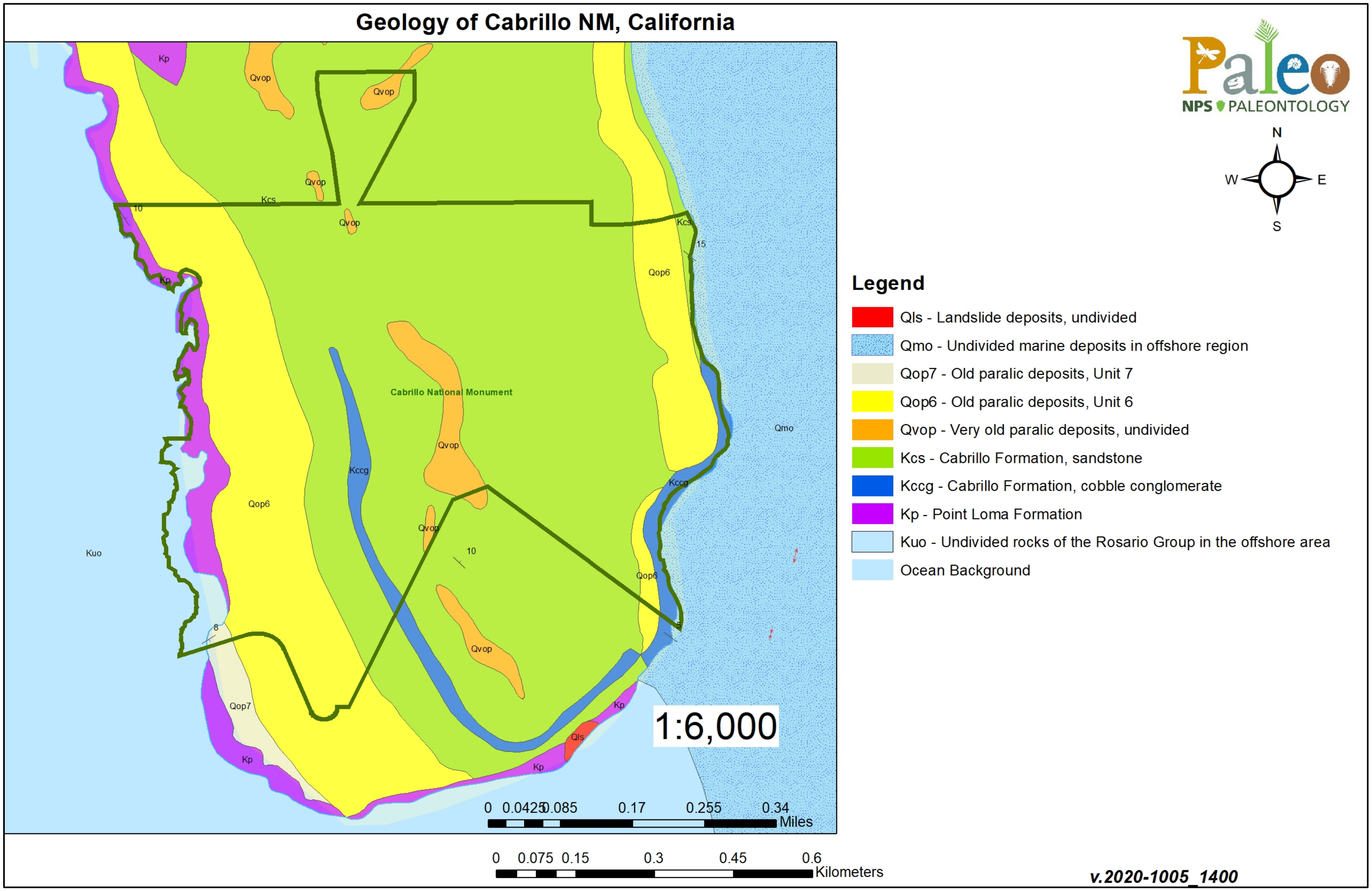


Figure 6. Geologic map of CABR and immediate vicinity.

Table 1. List of CABR stratotype units sorted by age with associated reference publications and locations.

Unit Name (map symbol)	Reference	Stratotype Location	Age
Cabrillo Formation (Kcs)	Kennedy and Moore 1971	Type locality: along the east side of the Point Loma Peninsula	Cretaceous
Point Loma Formation (Kp)	Kennedy and Moore 1971	Type locality: along the sea cliffs on the west side of the Point Loma Peninsula	Cretaceous

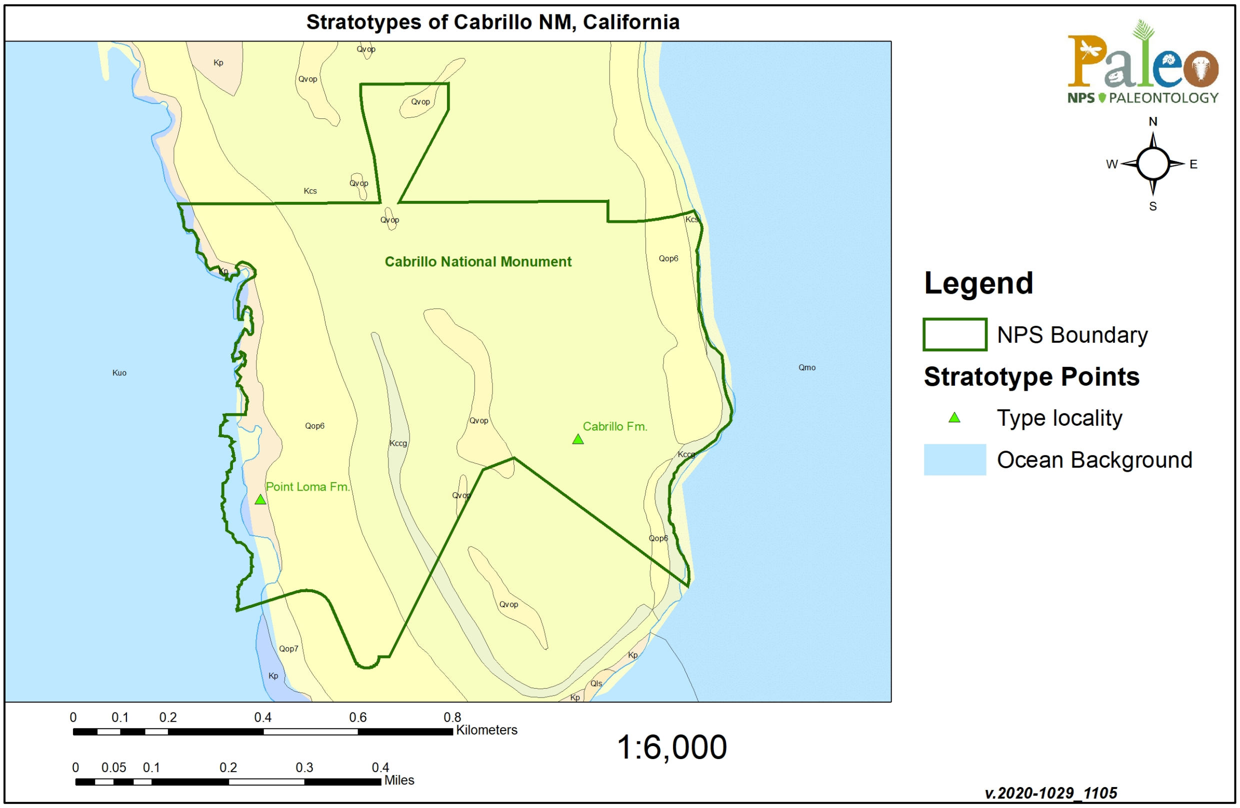


Figure 7. Modified geologic map of CABR showing stratotype locations. The transparency of geologic units has been increased.

The Point Loma Formation, of Late Cretaceous age, was named by Kennedy and Moore (1971) for its type locality exposures along the sea cliffs on the west side of the Point Loma Peninsula (Figures 7 and 8; Table 1). At the type locality the base of the formation consists a 4 m (13 ft)-thick submarine slide marked by greatly contorted bedding (Kennedy and Moore 1971). Upper exposures at the type locality consist of interbedded, fine-grained, yellow sandstone and olive-gray shale that grade into massive, grayish-black siltstone that contain three or more submarine landslides ranging in thickness from 3–17 m (10–56 ft) (Figure 9; Kennedy and Moore 1971). The upper contact of the formation at the type locality is placed at the base of the first sandstone bed marking the transition from siltstone of the Point Loma Formation and coarser rocks in the overlying Cabrillo Formation. Within the type locality area, the type section is just outside of CABR, along the cliff at the southern of the peninsula, passing through the base of a sea stack near the north boundary of the U.S Coast Guard station (Kennedy and Moore 1971).

Figure 8. Type locality exposures of the Point Loma Formation along the western side of Point Loma Peninsula, CABR. The surface on which the visitors are walking is the Nestor terrace, which consists of a wave-cut platform and overlying paralic deposits (NPS).

Figure 9. Type locality exposures of the Point Loma Formation consisting of alternating beds of sandstone and mudstone located in the tidepools region of CABR (NPS).

The Late Cretaceous Cabrillo Formation was designated by Kennedy and Moore (1971) for its type locality exposures in CABR along the east side of the Point Loma Peninsula from the southern tip to approximately Nimitz Street (Figure 7; Table 1). Type locality exposures measure approximately 81 m (266 ft) thick and can be subdivided into a basal sequence that consists of massive, medium-grained sandstone with thin beds of siltstone; a middle sequence of massive, cross-bedded, cobble conglomerate; and an upper sequence of medium-grained sandstone that contains a 2 m (7 ft)-thick conglomerate lens (Figure 10; Kennedy and Moore 1971). At the type locality, the Cabrillo Formation is unconformably overlain by Pleistocene deposits and conformably overlies massive siltstone of the Point Loma Formation. Within this type locality area, the type section is just outside of CABR, in the sea cliff 250 m (820 ft) east of the new Point Loma lighthouse (Kennedy and Moore 1971).

In addition to the designated stratotypes located within CABR, a list of stratotypes located within 48 km (30 mi) of park boundaries is included here for reference. These nearby stratotypes include the Cretaceous units of the Point Loma Formation (type section), Cabrillo Formation (type section), and Lusardi Formation (type locality).

Figure 10. Cobble conglomerate and sandstone of the Cabrillo Formation that occur in the type locality along the Cabrillo Memorial Road on the western slope of the Point Loma peninsula (NPS).

Channel Islands National Park

Channel Islands National Park (CHIS) is located off the coast of southern California in Santa Barbara and Ventura Counties (Figure 11). Close to the California mainland, yet worlds apart, the park includes five of the eight Channel Islands (Anacapa, Santa Cruz, San Miguel, Santa Rosa, and Santa Barbara) and the surrounding one nautical mile of marine waters. Originally designated as a national monument on April 26, 1938, CHIS was redesignated as a national park on March 5, 1980 (Anderson 2017). The park encompasses 100,994 hectares (249,561 acres) and preserves a wealth of natural and cultural resources ranging from more than 2,000 plant and animal species to hundreds of archeological sites as old as the late Pleistocene (Tweet et al. 2020). The islands are wonderful places to explore history, hike, camp, snorkel, kayak, birdwatch, take photographs, sketch, or just relax to the sounds of the natural world. The park was designated a Biosphere Reserve in 1976.

The geology of CHIS records a history of changes governed by plate tectonics in the region of southern California. The northern Channel Islands have been part of a complex 30-million-year-long series of events associated with the collision of the North American and Pacific Plates, leading to displacement and rotation of the Transverse Ranges and related volcanism (Weigand et al. 2002). Each of the five islands of CHIS has a distinct geologic history. Anacapa Island and Santa Barbara Island, the two smallest islands, are primarily composed of Miocene volcanic rocks interfingered with minor amounts of sedimentary rock and covered with a veneer of Quaternary sediments (Figures 12 and 13). San Miguel Island and Santa Rosa Island consist primarily of Eocene and Miocene units, with the oldest rocks of San Miguel Island dating to the Late Cretaceous (Figures 14 and 15). Santa Cruz Island has the most varied geology of the islands, as well as the longest rock record exposed at the surface in terms of rock age, beginning with Jurassic metamorphic and intrusive igneous rocks (Figure 16; Tweet et al. 2020).

Figure 11. Regional map of CHIS (NPS).

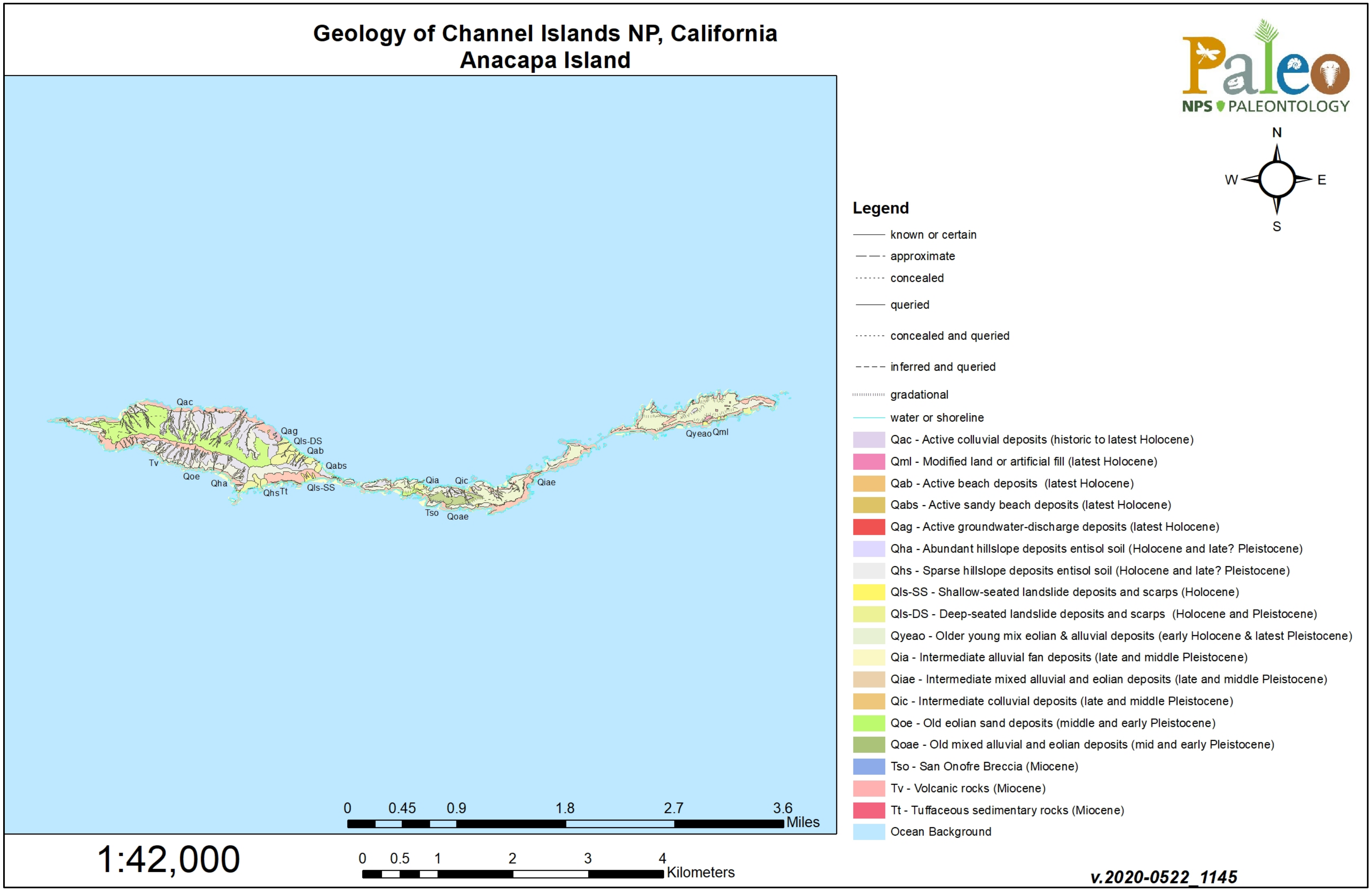


Figure 12. Bedrock geologic map of Anacapa Island, CHIS, California.

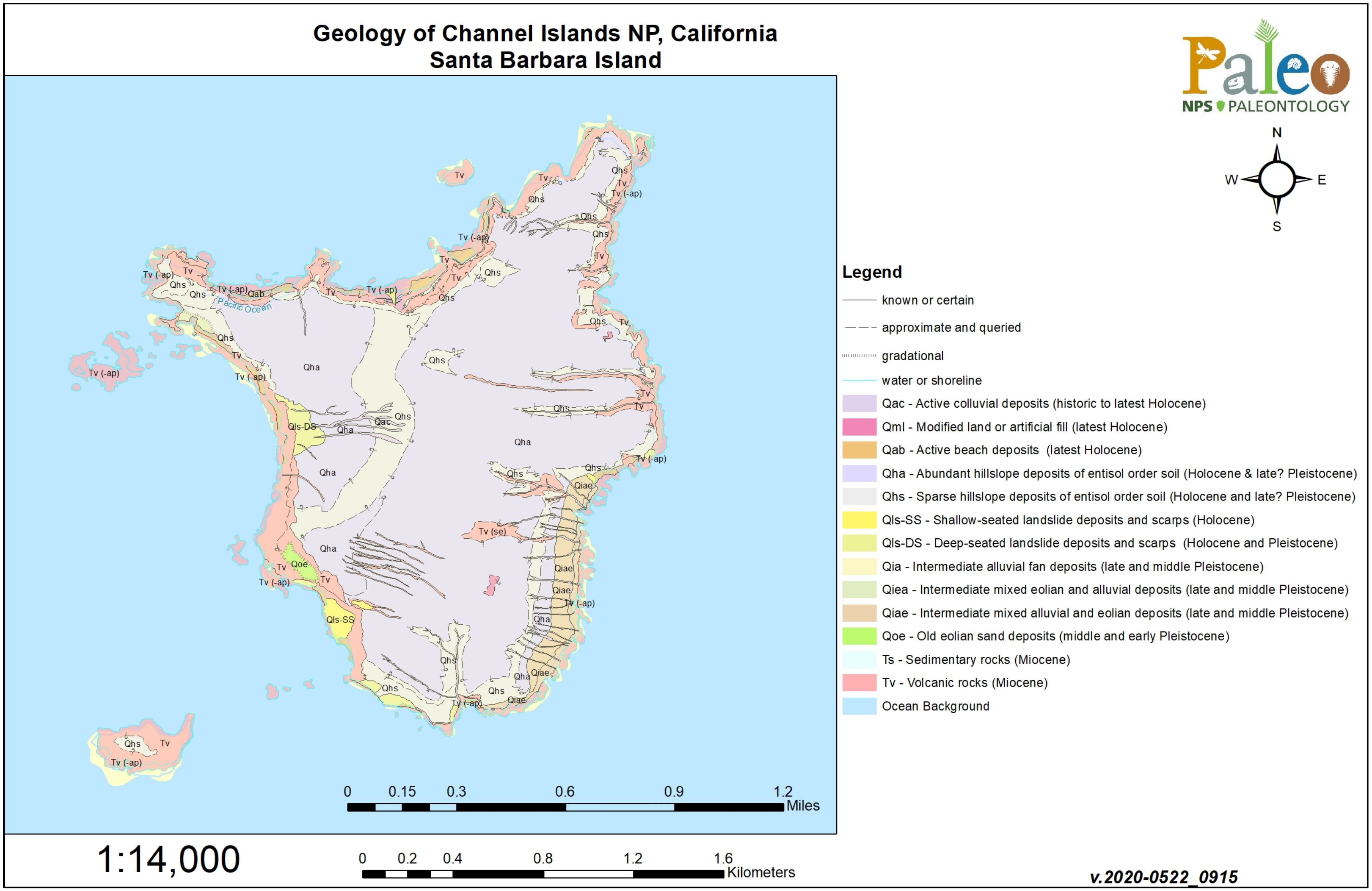


Figure 13. Bedrock geologic map of Santa Barbara Island, CHIS, California.

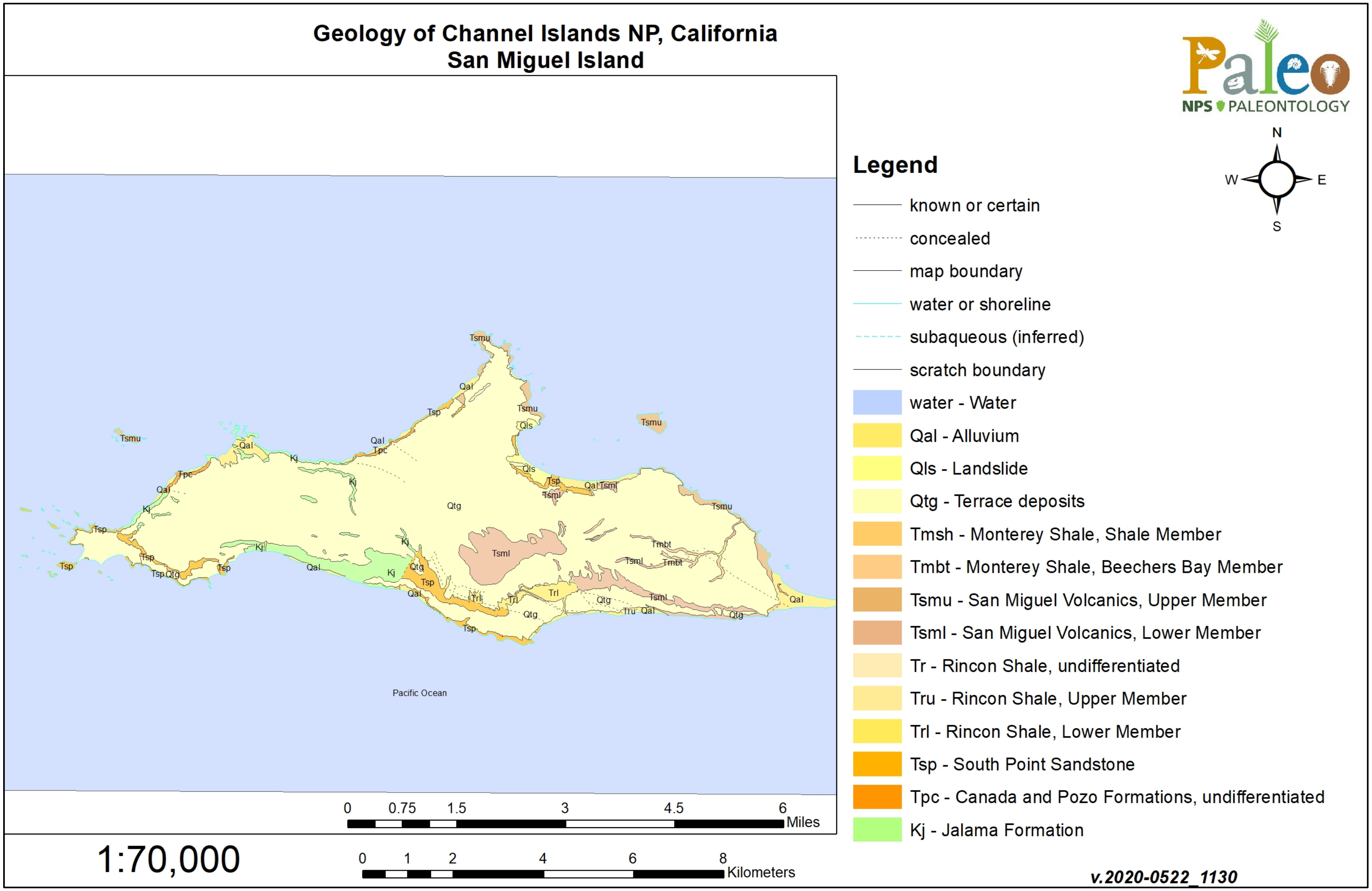


Figure 14. Bedrock geologic map of San Miguel Island, CHIS, California.

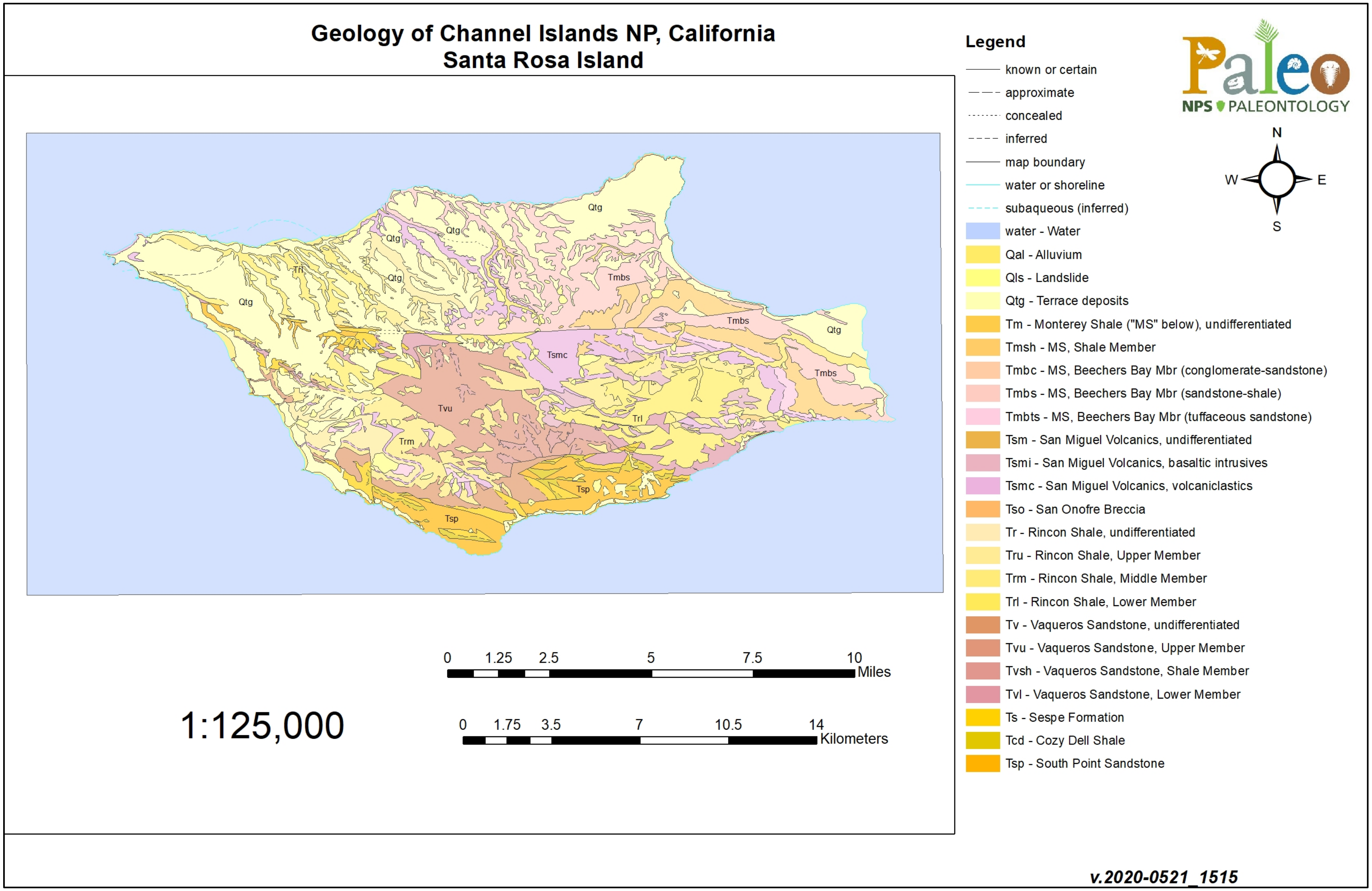


Figure 15. Bedrock geologic map of Santa Rosa Island, CHIS, California.

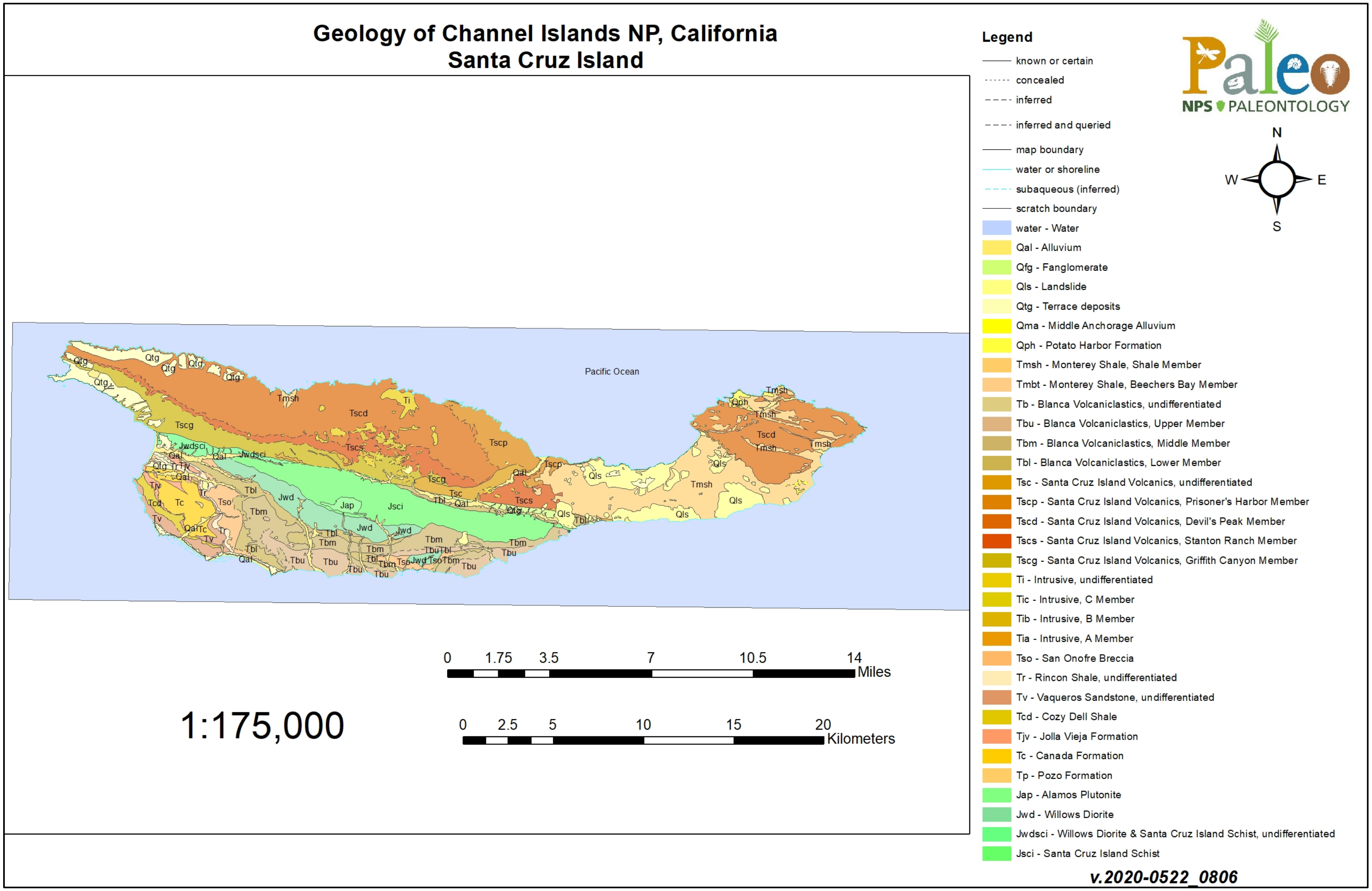


Figure 16. Bedrock geologic map of Santa Cruz Island, CHIS, California.

CHIS contains eleven identified stratotypes that include one type section, seven type localities, and three type areas, on Santa Cruz, San Miguel, and Santa Rosa Islands (Figures 17–19; Table 2). In addition to these, there are several units in local use on the islands that do not have formal stratotypes. Two were named from San Miguel Island: the San Miguel Volcanics and the South Point Formation or Sandstone. Six were named from Santa Cruz Island: the Blanca Formation, Cañada Formation, Jolla Vieja Formation, Middle Anchorage Alluvium, Pozo Formation, and the Santa Cruz Island Formation. Finally, two units, one with three members, were named from Santa Rosa Island: the Santa Rosa Island Formation (including the Fox, Garañon, and Tecolote Members) and the Santa Rosa Island Volcanics. It also appears that the unit identified as the Vaqueros Formation on Santa Cruz and Santa Rosa Islands represents a distinct and yet-to-be-named formation (Powell and Geiger 2019). The large number of units without stratotypes indicates the need for further geological work on the islands (see "Recommendations" below).

Table 2. List of CHIS stratotype units sorted by age with associated reference publications and locations.

Unit Name (map symbol)	Reference	Stratotype Location	Age
Potato Harbor Formation (Qph)	Weaver and Meyer 1969	Type locality: exposures at Potato Harbor on the northeast shore of Santa Cruz Island	Pleistocene
Beechers Bay Member, Monterey Shale Formation (Tmbt)	Avila and Weaver 1969	Type locality: exposures at Bechers Bay on eastern Santa Rosa Island	Miocene
Santa Cruz Island Volcanics (Tsc)	Nolf and Nolf 1969	Type locality: exposures north of the Santa Cruz Island Fault, Santa Cruz Island	Miocene
Prisoners Harbor Member, Santa Cruz Island Volcanics (Tscp)	Nolf and Nolf 1969	Type locality: exposures in the quarry and sea cliffs at Prisoners Harbor, Santa Cruz Island	Miocene
Devils Peak Member, Santa Cruz Island Volcanics (Tscd)	Nolf and Nolf 1969	Type locality: on the south and east slopes of Devils Peak on Santa Cruz Island	Miocene
Stanton Ranch Member, Santa Cruz Island Volcanics (Tscs)	Nolf and Nolf 1969	Type locality: exposures on the steep slopes northwest of the Stanton Ranch, Santa Cruz Island	Miocene
Griffith Canyon Member, Santa Cruz Island Volcanics (Tscg)	Nolf and Nolf 1969	Type area: occurs as a NW–SE trending belt that extends approximately 21 km (13 mi) along strike of the north side of the Santa Cruz Island Fault, Santa Cruz Island	Miocene
Mirounga Formation	Bartling and Abbott 1983	Type section: beach cliffs from Point Bennett northeastward to the west side of Otter Harbor, and from the mouth to the head of west Green Mountain Canyon, west end of San Miguel Island	Cretaceous
Alamos Plutonite (Jap)	Weaver 1969	Type locality: exposures located 3.2 km (2 mi) north of Alamos Anchorage, south-central Santa Cruz Island	Cretaceous
Willows Diorite (Jwd)	Weaver 1969	Type area: an elongate semicircular body that has been brought up along the south side of the Willows Fault, Santa Cruz Island	Jurassic
Santa Cruz Island Schist (Jsci)	Weaver 1969	Type area: exposures that form an elongate core in the central part of Santa Cruz Island	Jurassic

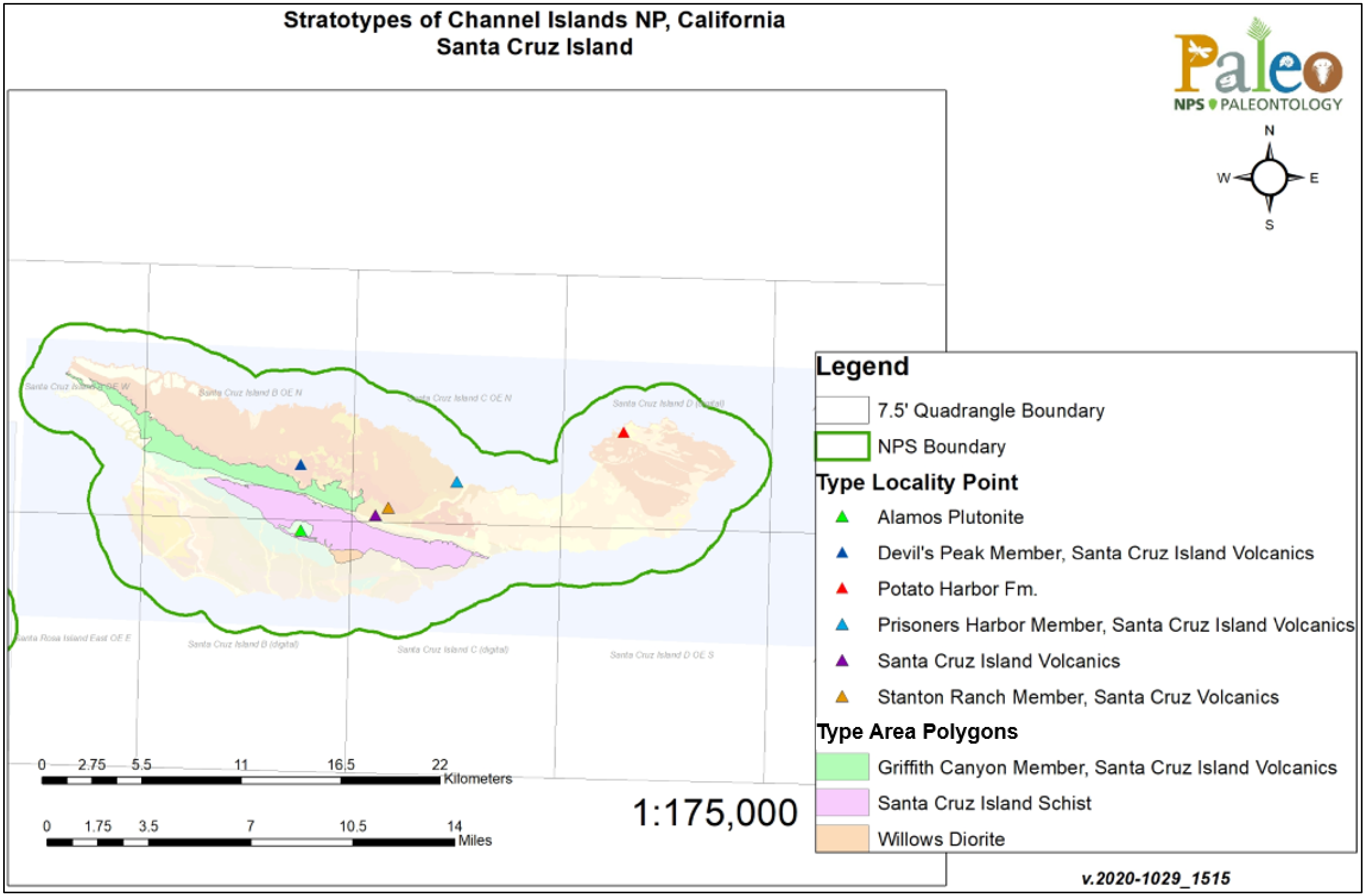


Figure 17. Modified geologic map of Santa Cruz Island, CHIS showing stratotype locations. The transparency of geologic units has been increased.

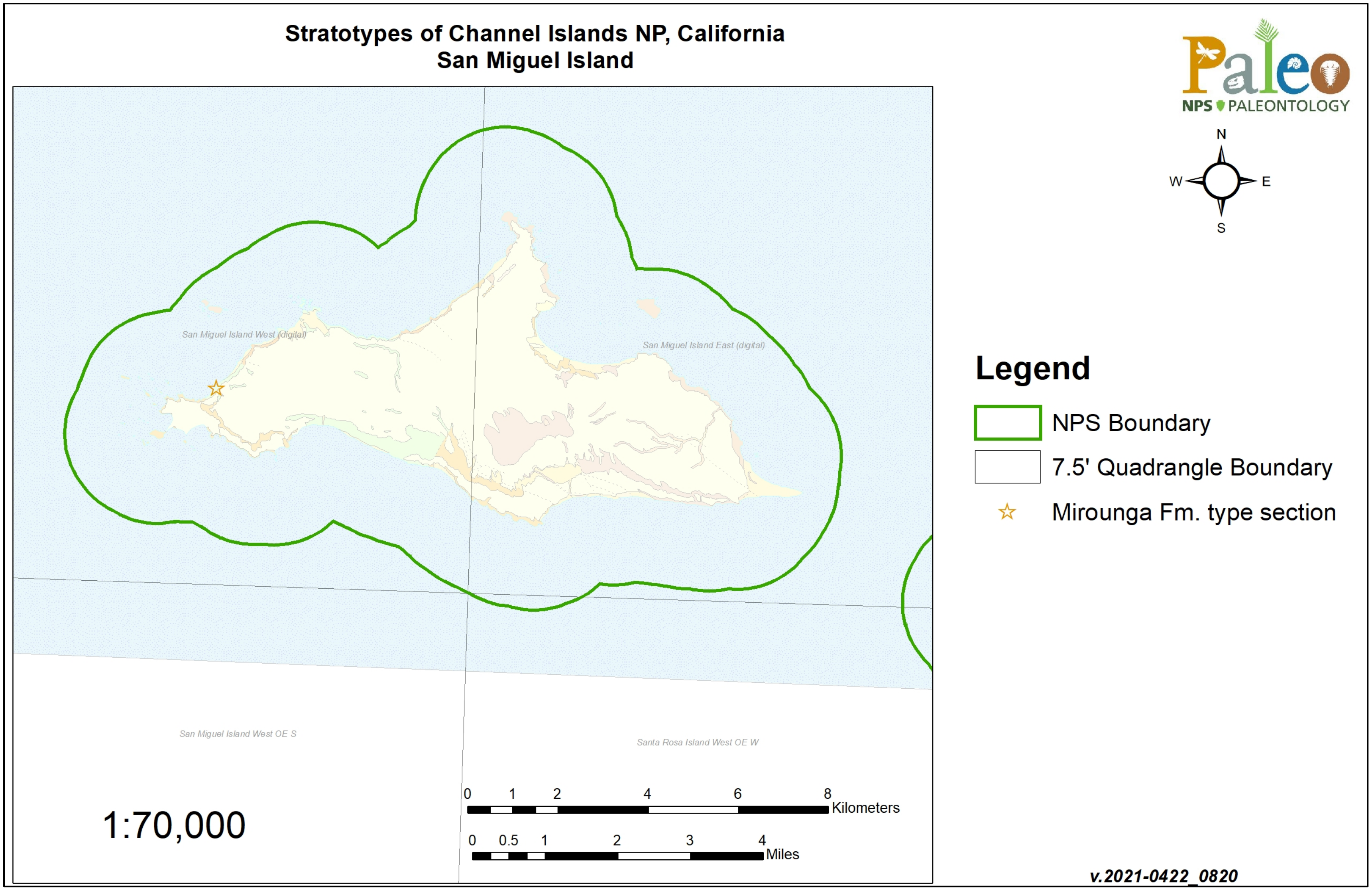


Figure 18. Modified geologic map of San Miguel Island, CHIS showing stratotype locations. The transparency of geologic units has been increased.

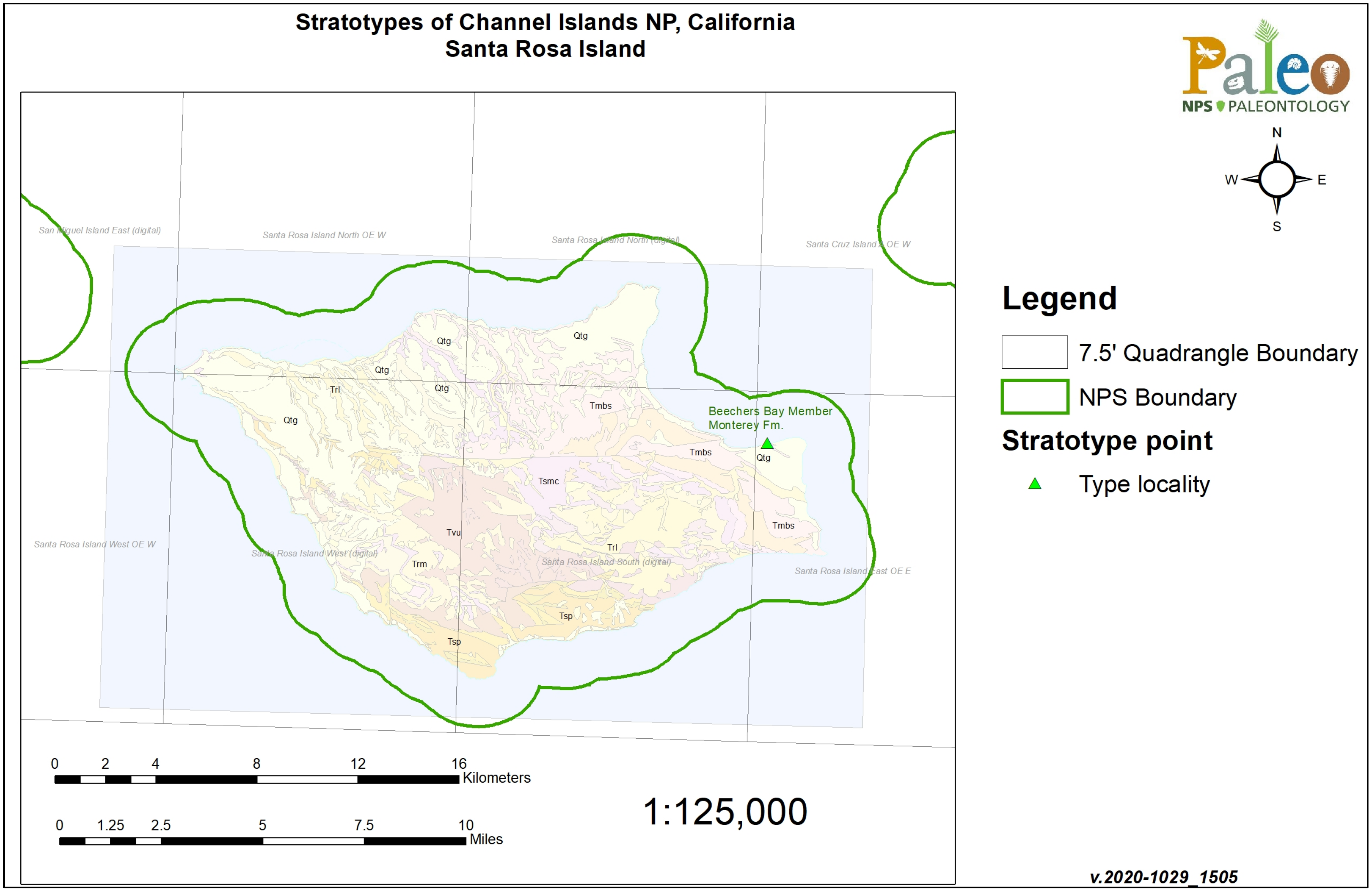


Figure 19. Modified geologic map of Santa Rosa Island, CHIS showing stratotype locations. The transparency of geologic units has been increased.

The Santa Cruz Island Schist, of Jurassic age, was named by Weaver (1969) for its type area exposures that form an elongate core in the central part of Santa Cruz Island, CHIS (Figure 17; Table 2). The core of schist crops out as a band approximately 16 km (10 mi) long and 2.4 km (1.5 mi) wide below the sharp northern boundary of the Santa Cruz Island Fault. The unit consists of a series of dynamically metamorphosed, olive-green to grayish-green chloritic schists and greenstones that have been intruded by the Alamos Tonalite and faulted against by the Willows Diorite (Weaver 1969). The schists are fine- and even-grained and display well-developed schistosity with cleavages that are even and parallel so that exposures resemble stratified sediments (Weaver 1969).

The Jurassic Willows Diorite was designated by Weaver (1969) for its type area exposures along the Willows Fault north of Willows Anchorage, western Santa Cruz Island, CHIS. The type area is an elongate semicircular body that has been brought up along the south side of the Willows Fault (Figure 17; Table 2; Weaver 1969). The Willows Diorite is a heterogeneous unit consisting of yellowish-tan, coarse-grained hornblendite and medium-grained diorite that are unstrained and considerably fractured, and grade into each other (Weaver 1969).

The Cretaceous Alamos Plutonite was designated by Weaver (1969); it was originally thought to be Jurassic in age but is now known to date to the Cretaceous (Mattinson and Hill 1976). Type locality exposures of the unit are located 3 km (2 mi) north of Alamos Anchorage, south-central Santa Cruz Island, CHIS (Figure 17; Table 2). The unit is characterized as a homogeneous, highly quartzose, massive, coarse-grained, metamorphosed quartz-diorite that is light gray with a greenish tinge (Weaver 1969). The Alamos Plutonite postdates and intrudes the Santa Cruz Island Schist, but age relationships with the Willows Diorite are obscured at the contact by shearing and crushing (Weaver 1969).

The Late Cretaceous Mirounga Formation was named by Bartling and Abbott (1983) after the northern elephant seal (*Mirounga augustirostris*) which breeds at the base of the exposures on San Miguel Island, California. Bartling and Abbott (1983) designated the type section in the beach cliffs of western San Miguel Island, from Point Bennett northeastward to the west side of Otter Harbor, and from the mouth to the head of Green Mountain Canyon (Figure 18; Table 2). The type section measures 2,400 m (7,800 ft) thick and consists of interbedded sandstone, mudstone, and conglomerate dominated by black rhyodacite giving the rock a salt-and-pepper appearance (Bartling and Abbott 1983). The Mirounga Formation underlies Eocene-age submarine fan deposits and its basal contact is not exposed (Bartling and Abbott 1983). Dibblee and Ehrenspeck (2001) substituted a different new name for the same rocks, the Point Bennett Formation.

The Miocene Santa Cruz Island Volcanics were designated by Nolf and Nolf (1969) to describe andesitic flows and volcaniclastics cropping out at the type locality north of the Santa Cruz Island Fault (Figure 17; Table 2). Exposures of the Santa Cruz Island Volcanics occur in a northward dipping homoclinal sequence bounded and broken by numerous high angle faults. Maximum cumulative exposure thickness of the volcanics is estimated at ~1,700 m (5,500 ft) with an additional inferred 760 m (2,500 ft) in the subsurface (Nolf and Nolf 1969). The Santa Cruz Island Volcanics are overlain by the Monterey Formation, and although the basal contact is obscured on Santa Cruz

Island, it is inferred to overlie the San Onofre Breccia or Vaqueros Formation based on available well data (Nolf and Nolf 1969).

The Griffith Canyon Member is the oldest of the Santa Cruz Island Volcanics units designated by Nolf and Nolf (1969). The member forms a sequence of basalt and andesite flows and breccias at the base of the Santa Cruz Island Volcanics and is named after a small, locally named canyon at the head of Cañada Del Portezuelo. The type area of the member occurs as a northwest–southeast trending belt that extends approximately 21 km (13 mi) along strike of the north side of the Santa Cruz Island Fault (Figure 17; Table 2; Nolf and Nolf 1969). Surface exposures of the member reach a maximum thickness of about 370 m (1,200 ft). Lithologically, the member is predominantly composed of vesicular, porphyritic olivine basalt to basaltic andesite flows and massive, greenish-gray to brown volcanic breccias (Nolf and Nolf 1969). The member is conformably situated between the overlying Stanton Ranch Member of the Santa Cruz Island Volcanics and underlying San Onofre Breccia.

The Stanton Ranch Member of the Santa Cruz Island Volcanics was designated by Nolf and Nolf (1969) for its type locality exposures on the steep slopes northwest of the Stanton Ranch, Santa Cruz Island, CHIS (Figure 17; Table 2). The member is characterized as consisting predominantly of reddish-brown and gray andesite flows and flow breccias, with minor tuff breccias that crop out along the full length of the volcanic belt on the north side of Santa Cruz Island (Nolf and Nolf 1969). Exposure thicknesses of the Stanton Ranch Member range from approximately 400 m (1,300 ft) east of the volcanic centers to 140 m (450 ft) on western end of the island. The member conformably overlies the Griffith Canyon Member and discordantly underlies the Devils Peak Member of the Santa Cruz Island Volcanics.

The Devils Peak Member of the Santa Cruz Island Volcanics was named by Nolf and Nolf (1969) for a variety of andesite flows, flow breccias, reworked pyroclastics, and dark scoriaceous breccias exposed at the type locality on the south and east slopes of Devils Peak on Santa Cruz Island, CHIS (Figures 17 and 20; Table 2). The member is characterized by very thick, wedge or tongue-shaped units of dark gray to black, monolithologic, scoriaceous breccias that contain andesitic flows that commonly weather to a pale yellowish-orange or yellowish-brown (Norf and Norf 1969). The thickest exposures of the member are ~730 m (2,400 ft). The Devils Peak Member occurs discordantly between the overlying Prisoners Harbor Member and underlying Stanton Ranch Member of the Santa Cruz Island Volcanics.

The Prisoners Harbor Member of the Santa Cruz Island Volcanics was designated by Nolf and Nolf (1969) for its type locality exposures in the quarry and sea cliffs at Prisoners Harbor, Santa Cruz Island, CHIS (Figures 17 and 21; Table 2). Type locality exposures consist of flows that are dark gray, very fine-grained to glassy, and commonly develop a yellowish weathering rind (Nolf and Nolf 1969). Many of the flows at Prisoners Harbor are extensively brecciated and contain sharp, angular clasts of varying sizes (Nolf and Nolf 1969). Exposures of the member are typically less than ~30 m (100 ft) thick with a maximum thickness of 180 m (600 m) measured northwest of Cañada Del Puerto. Stratigraphically, the Prisoners Harbor Member discordantly overlies the Devils Peak Member of the Santa Cruz Island Volcanics and unconformably underlies the Monterey Formation.

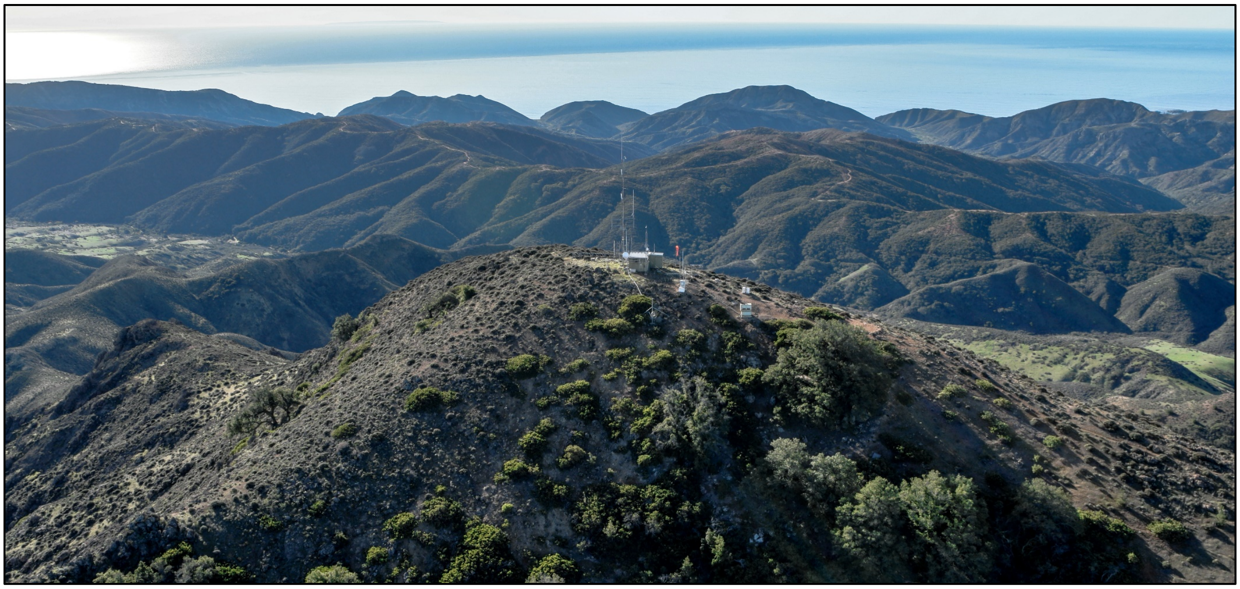


Figure 20. Telecommunication array atop type locality exposures of the Devils Peak Member of the Santa Cruz Island Volcanics at Devils Peak, Santa Cruz Island, CHIS. Photograph by user "Lee317" available via Wikimedia Commons https://commons.wikimedia.org/wiki/File:Devils_Peak_-_Mount_Diablo.jpg (Creative Commons Attribution-Share Alike 4.0 International [CC BY-SA 4.0]; https://creativecommons.org/licenses/by-sa/4.0/deed.en).

Figure 21. Type locality sea cliff exposures of the Prisoner's Harbor Member of the Santa Cruz Island Volcanics at Prisoners Harbor, Santa Cruz Island, CHIS (NPS).

The Miocene Beechers Bay Member of the Monterey Shale (frequently raised to a formation) was named by Avila and Weaver (1969) after its type locality exposures at Bechers Bay on eastern Santa Rosa Island, CHIS (Figure 19; Table 2). At the type locality, the member is well exposed in the canyons draining into Bechers Bay as well as the bordering sea cliffs (Figure 22). The member is subdivided into three distinct lithofacies that are all represented at the type locality, and include: 1) a basal whitish-gray, well-indurated, resistant, fine-grained vitric ash-tuff and interbedded tuffaceous siltstone measuring ~120 m (400 ft); 2) a middle sequence of tuffaceous, brown, fine-grained sandstone, siltstone, and platy siliceous shale measuring 360 m (1,200 ft) thick; and 3) an upper conglomerate composed of conglomerate breccia and interbedded pebbly sandstone and lithic tuff (Avila and Weaver 1969). The Beechers Bay Member conformably overlies the San Miguel Volcanics and underlies shale of the Monterey Formation.

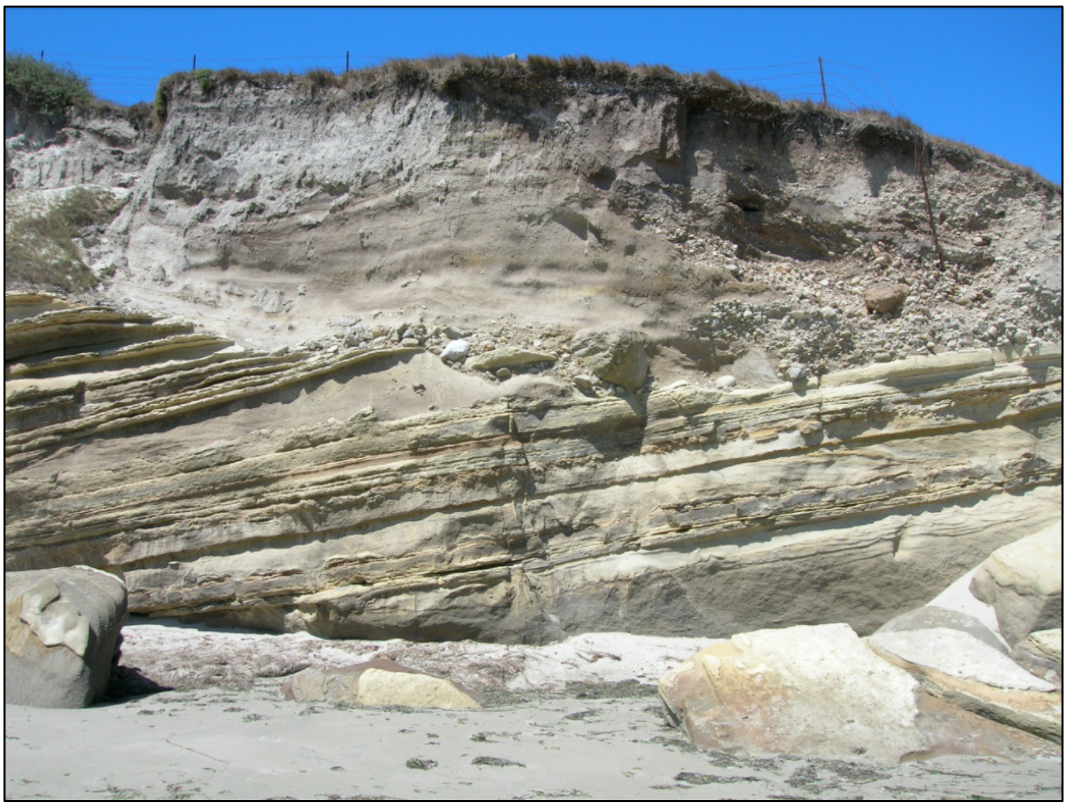


Figure 22. Close-up photograph of type locality sea cliff exposures of the Beechers Bay Member of the Monterey Shale located along Bechers Bay, Santa Rosa Island, CHIS (NPS). The tilted lithified beds pertain to the Beechers Bay Member, while the unlithified deposits above are Quaternary sediments.

The Pleistocene Potato Harbor Formation was designated by Weaver and Meyer (1969) for the type locality exposures at Potato Harbor on the northeast shore of Santa Cruz Island, CHIS (Figures 17 and 23; Table 2). At the type locality the formation is approximately 26 m (85 ft) thick and consists of massive to thinly-bedded sandy biomicrite, sandy biomicrosparite, and sandy limestone that caps the erosional surface of the cliffs above the northern shore. Type locality exposures can be divided into several lenticular subunits that are capped by a massive, friable, brown sandy biomicrite and biosparite up to nearly 2 m (6 ft) thick, standing in contrast to the bluish-gray, cross-bedded sandy biomicrosparites (Weaver and Meyer 1969). The Potato Harbor Formation unconformably overlies the Santa Cruz Island Volcanics or Monterey Shale and is capped by the weathered sandy biomicrite and carbonate-volcanic sand of the Middle Anchorage Alluvium (Weaver and Meyer 1969).

Figure 23. Type locality exposures of the Potato Harbor Formation at Potato Harbor on the northeast shore of Santa Cruz Island, CHIS. Note the boat for scale. Photograph by user "oliver.dodd" available via Flickr https://www.flickr.com/photos/oliverdodd (Creative Commons Attribution 4.0 International [CC BY 4.0]; https://creativecommons.org/licenses/by/4.0/).

In addition to the designated stratotypes located within CHIS, a list of stratotypes located within 48 km (30 mi) of park boundaries is included here for reference. These nearby stratotypes include the Oligocene–Miocene Rincon Shale (type section).

Santa Monica Mountains National Recreation Area

Santa Monica Mountains National Recreation Area (SAMO) is located near the greater Los Angeles metropolitan area in Los Angeles and Ventura Counties, coastal southern California (Figure 24). The recreation area includes a vast and varied California landscape that includes rugged mountains, chaparral-blanketed canyons, abundant wildlife, and 64 km (40 mi) of coastline with sandy beaches and rocky shores. Established on November 10, 1978, SAMO encompasses 63,402 hectares (156,670 acres) and preserves the rare Mediterranean ecosystem while also protecting historical sites (Anderson 2017). The Santa Monica Mountains are ~74 km (46 mi) long and 13 km (8 mi) wide (KellerLynn 2016). They represent part of the Western Transverse Ranges Province, which is bordered on the north by the Southern Coast Ranges and Mojave Desert Provinces, on the east by the Eastern Transverse Ranges Province, and on the south by the Peninsular Ranges Province (Lander 2011; Lander et al. 2013). The nearby northern Channel Islands situated off the southern California coast belong to a largely submerged portion of the Western Transverse Ranges Province (originally the southern part, before rotation) and in turn share the complex geologic history (see the "Channel Islands National Park" chapter above for more information).

The Santa Monica Mountains are a complex and dynamic place that includes active faults, fossils, remnant volcanoes, and stratigraphic units of continental and marine origin, the latter units comprising sediments originally deposited underwater and now often found at the tops of ridgelines. SAMO is underlain primarily by rocks of Miocene age, but the oldest rocks date back ~162 to 143 million years ago to the Late Jurassic Period (Figure 25). The rocks of SAMO record the complicated geologic history of coastal southern California. Significant events include: the subduction and breakup of the former oceanic Farallon Plate beneath the converging western margin of the continental North American Plate; partial subduction of the East Pacific Rise, followed by extension and resulting subsidence and accompanying faulting of the margin of the North American Plate, with capture of some fragments by the Pacific Plate; subsequent rotation of crustal tectonic blocks (including the Western Transverse Ranges Province) constituting the margin; and the corresponding development of a transform boundary between the North American and Pacific Plates along the modern-day San Andreas Fault System (Lander 1994, 1997, 2011; Fritsche 1998; Hillhouse 2010; Lander et al. 2013; KellerLynn 2016). Those tectonic events, along with global glacioeustatic changes in sea level resulting from fluctuations in size of the Antarctic ice cap, are reflected in a succession of alternating marine and continental units in the Santa Monica Mountains. Unlike mountain ranges in other areas of California, in which major linear geologic structures (e.g., faults and folds) and the resulting geographic features (e.g., mountains and valleys) are oriented in dominantly northwest–southeast directions, those in the Transverse Ranges Province are principally oriented in east–west directions. They were originally oriented roughly north–south but rotated up to roughly 70°–110° clockwise away from the northern Peninsular Ranges Province as a result of complex tectonic interactions between adjacent plate margins (Lander 1997, 2011; Fritsche 1998; Calvano et al. 2008; Hillhouse 2010; Lander et al. 2013; KellerLynn 2016).

Figure 24. Park map of SAMO (NPS).

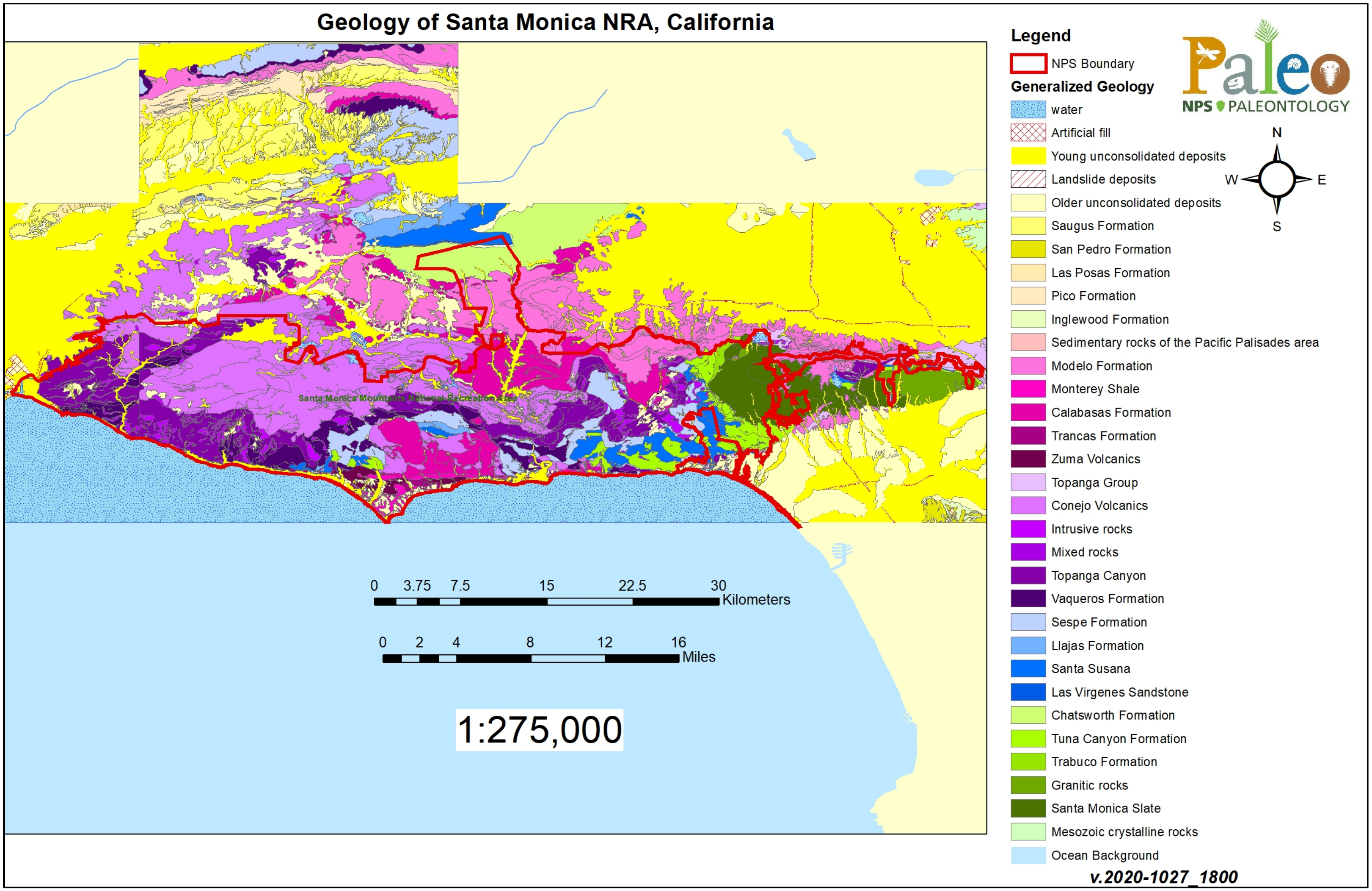


Figure 25. Bedrock geologic map of SAMO, California.

SAMO contains 25 identified stratotypes that are subdivided into 17 type localities and 8 type areas (Figures 26 and 27; Table 3). It should be noted that the stratigraphic nomenclature of the Santa Monica Mountains is contentious, with several different systems proposed (e.g., the USGS system proposed in Yerkes and Campbell [1979] versus systems used by Thomas Dibblee and Eugene Fritsche). These systems differ on names of units, assignments of members to formations, field identifications of outcrops, and placements of contacts. It is beyond the scope of this document to make an exhaustive review of the various alternatives, or to determine the best usage. Anyone studying these rocks is advised to pay careful attention to usage when dealing with the literature. Because almost of the formations named from SAMO were defined in Yerkes and Campbell (1979), this work is most frequently cited in this section. Readers seeking more information on alternative interpretations should seek out the various maps and publications by Dibblee (Dibblee 1991a, 1991b, 1992a, 1992b, 1993; Dibblee and Ehrenspeck 1990a, 1990b, 1993); Fritsche (1993), which attempted to reconcile the USGS and Dibblee systems with the North American Stratigraphic Code; Campbell et al. (2007); and Lander (2011) and Lander et al. (2013).

Table 3. List of SAMO stratotype units sorted by age with associated reference publications and locations.

Unit Name (map symbol)	Reference	Stratotype Location	Age
Calabasas Formation (Tcb)	Yerkes and Campbell 1979	Type locality: Stokes Canyon approximately 3 km (2 mi) west of Calabasas Peak	Miocene
Stokes Canyon Breccia Member, Calabasas Formation (Tcbs)	Yerkes and Campbell 1979	Type locality: exposures in Stokes Canyon	Miocene
Mesa Peak Breccia Member, Calabasas Formation (Tcbmp)	Yerkes and Campbell 1979	Type area: exposures near Mesa Peak	Miocene
Newell Sandstone Member, Calabasas Formation (Tcbn)	Yerkes and Campbell 1979	Type area: exposures near Newell Road	Miocene
Latigo Canyon Breccia Member, Calabasas Formation (Tcbl)	Yerkes and Campbell 1979	Type area: exposures in Latigo Canyon	Miocene
Escondido Canyon Shale Member, Calabasas Formation (Tcbe)	Yerkes and Campbell 1979	Type area: exposures in Escondido Canyon	Miocene
Dry Canyon Sandstone Member, Calabasas Formation (Tcbd)	Yerkes and Campbell 1979	Type area: exposures in Dry Canyon	Miocene
Trancas Formation (Tr)	Yerkes and Campbell 1979	Type locality: near the mouth of Trancas Canyon	Miocene
Zuma Volcanics (Tz)	Yerkes and Campbell 1979	Type locality: on the west side of Zuma Canyon	Miocene
Topanga Group (Tt)	Kew 1923, 1924	Type locality: Topanga Canyon, ~16 km (10 mi) northwest of Santa Monica	Miocene

Table 3 (continued). List of SAMO stratotype units sorted by age with associated reference publications and locations.

Unit Name (map symbol)	Reference	Stratotype Location	Age
Conejo Volcanics (Tco)	Taliaferro 1924, Yerkes and Campbell 1979	Type locality: exposures in the western Santa Monica Mountains (“Conejo Mountains”)	Miocene
Malibu Bowl Tongue, Conejo Volcanics (Tcom)	Yerkes and Campbell 1979	Type area: near the Malibu Bowl Fault	Miocene
Solstice Canyon Tongue, Conejo Volcanics (Tcos)	Yerkes and Campbell 1979	Type area: in Solstice Canyon	Miocene
Ramera Canyon Tongue, Conejo Volcanics (Tcor)	Yerkes and Campbell 1979	Type area: in Ramera Canyon	Miocene
Topanga Canyon Formation (Ttc)	Kew 1924	Type locality: in the roadcuts of Old Topanga Road	Miocene
Cold Creek Member, Topanga Canyon Formation (Ttcc)	Yerkes and Campbell 1979	Type locality: exposures in the Cold Creek–Old Topanga Canyon area	Miocene
Fernwood Member, Topanga Canyon Formation (Ttcf)	Yerkes and Campbell 1979	Type locality: in the vicinity of Fernwood of the west-central Topanga Quadrangle	Miocene
Saddle Peak Member, Topanga Canyon Formation (Ttcs)	Yerkes and Campbell 1979	Type locality: on the west shoulder of Saddle Peak	Miocene
Encinal Member, Topanga Canyon Formation (Ttce)	Yerkes and Campbell 1979	Type locality: on Encinal Canyon Road	Miocene
San Nicholas Member, Vaqueros Formation (Tvn)	Yerkes and Campbell 1979	Type locality: in San Nicholas Canyon	Miocene
Danielson Member, Vaqueros Formation (Tvd)	Yerkes and Campbell 1979	Type locality: exposures on Danielson Ranch in Big Sycamore Canyon	Miocene
Piuma Member, Sespe Formation (Tsp)	Yerkes and Campbell 1979	Type locality: along Piuma Road and at the head of Carbon Canyon	Oligocene–Miocene
Coal Canyon Formation (now generally included in the Santa Susana Formation) (Tss)	Yerkes and Campbell 1979	Type locality: in Carbon (formerly Coal) Canyon	Paleocene –Eocene
Tuna Canyon Formation (Kt)	Yerkes and Campbell 1979	Type locality: in Tuna Canyon	Cretaceous
Santa Monica Slate (Jsm)	Hoots 1931	Type locality: in the central area of the Santa Monica Mountains east of Topanga Canyon	Jurassic

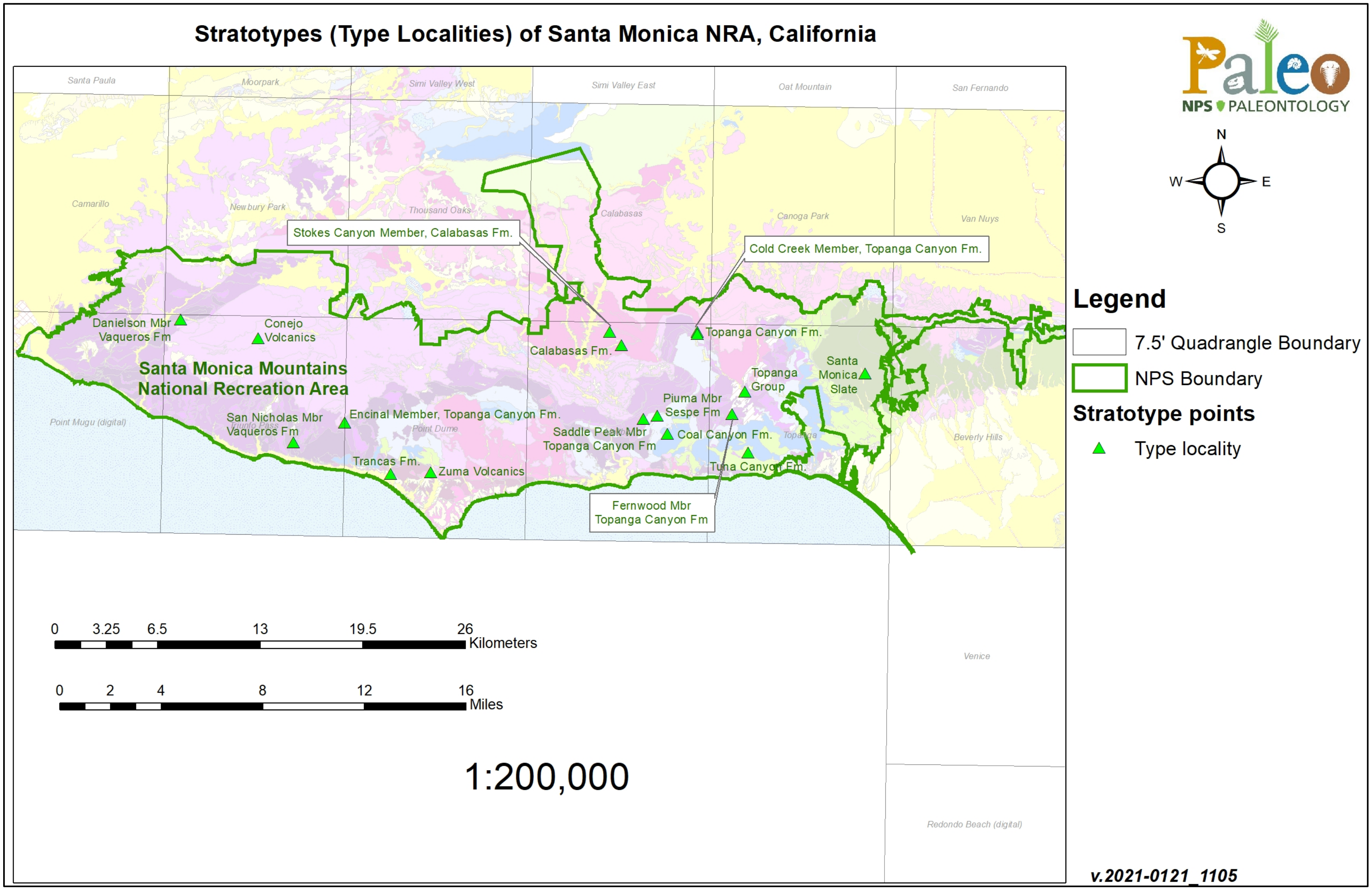


Figure 26. Modified geologic map of SAMO showing type locality designations. The transparency of geologic units has been increased.

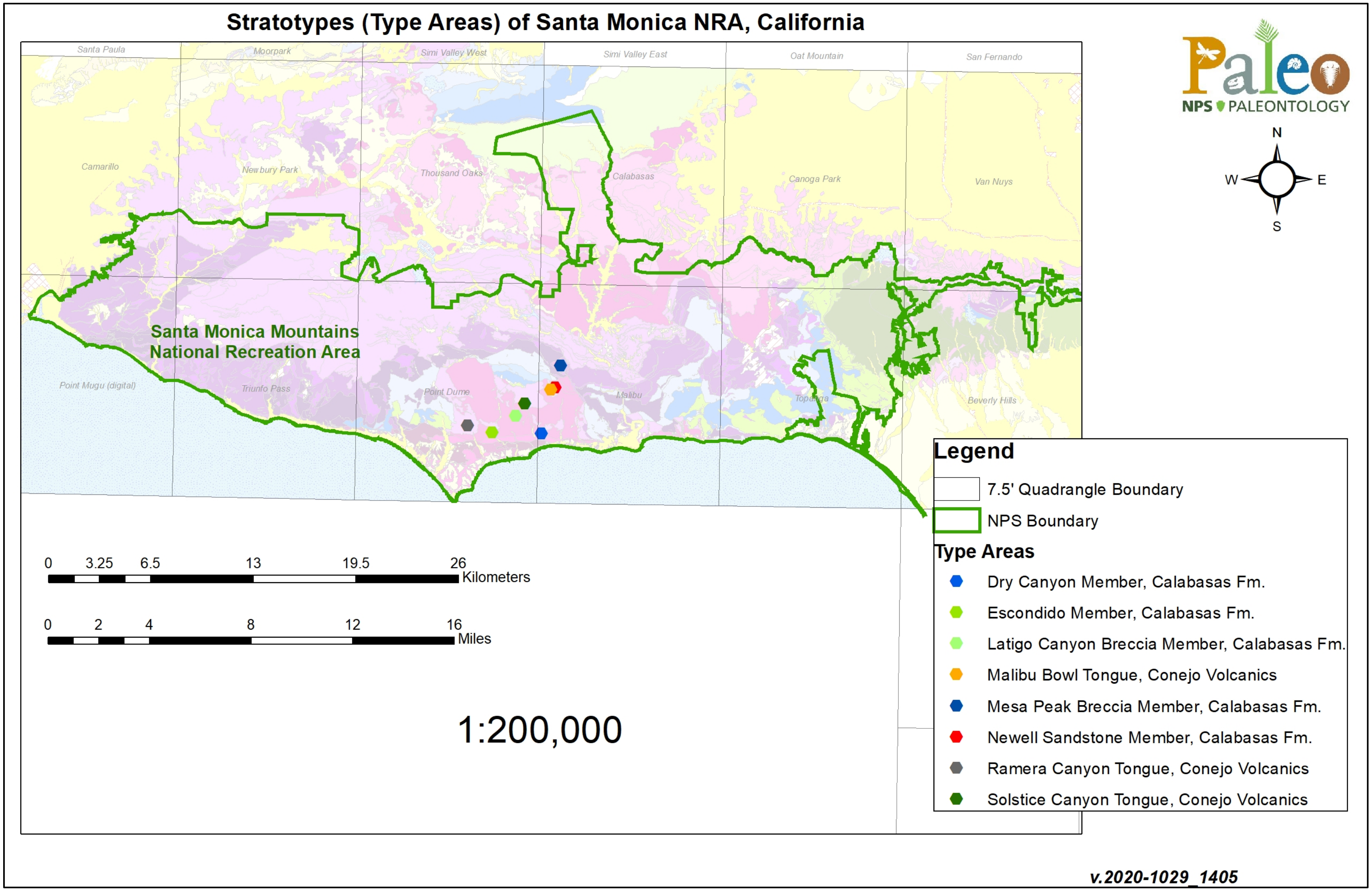


Figure 27. Modified geologic map of SAMO showing type area locations. The transparency of geologic units has been increased.

The Santa Monica Slate (or Formation), of Late Jurassic age, was named by Hoots (1931) after the extensive exposures of the formation located in the Santa Monica Mountains. The type locality of the formation is in the central area of the Santa Monica Mountains east of Topanga Canyon (Figure 26; Table 3). Lithologically, the formation consists of hard dark-gray slate with a few thin beds of light-gray siltstone and fine to coarse-grained quartzite. The shale surfaces weather brown and display well-developed slaty cleavage and bedding that is parallel to the original bedding plane of the rock (Hoots 1931). The true thickness of the Santa Monica Slate is not known because the base is not exposed. Hoots (1931) estimated the exposed thickness to be between 1,500 and 2,100 m (5,000–7,000 ft). The Late Jurassic age of the formation is based on the presence of the bivalve *Buchia* cf. *B. concentrica* (Imlay 1963). The upper contact with the Late Cretaceous Trabuco Formation is nonconformable (Campbell et al. 2014).

The Late Cretaceous marine Tuna Canyon Formation was named by Yerkes and Campbell (1979) to describe a thick marine sequence of sandstone, siltstone, and conglomerate restricted to the area north of the Malibu Coast fault. The formation was named after its type locality designation in Tuna Canyon, where exposures consist of fossiliferous, thick-bedded, graded, laminated beds of coarse-grained, arkosic sandstone, siltstone, and conglomerate (Figure 26; Table 3) (Yerkes and Campbell 1979, 1980; Campbell et al. 2014). Some of the beds exhibit convolute lamination, load casts, cross-lamination, or carbonized plant fragments (Yerkes and Campbell 1979). The maximum approximate thickness of the formation at the type locality is 800 m (2,600 ft) (Yerkes and Campbell 1979). The Late Cretaceous age of the Tuna Canyon Formation is based on occurrences of age-diagnostic marine foraminifer (“amoebas with shells”) and mollusk species reported by Yerkes and Campbell (1979, 1980), Saul (1983), and Campbell et al. (1996, 2014).

The early Paleocene–early Eocene marine Coal Canyon Formation (considered by some workers to be a facies of the Santa Susana Formation) was designated by Yerkes and Campbell (1979) after its type locality exposures in Carbon (formerly Coal) Canyon, SAMO (Figure 26; Table 3). At the type locality, the formation consists of sandstone and siltstone as well as pebble and cobble conglomerates that form steep, resistant slopes with beds as much as 7 m (23 ft) thick. Conglomerates consist of subrounded to well-rounded pebbles of light-colored granitic and gneissic rocks, brown and gray quartzite, and a diagnostic brick-red or lavender quartz-bearing porphyry (Yerkes and Campbell 1979). A minimum thickness from incomplete composite sections at the type locality is approximately 450 m (1,500 ft). The Coal Canyon Formation conformably or disconformably overlies the Tuna Canyon Formation, and west of Point Dume in the western Santa Monica Mountains it conformably underlies the early–early middle Eocene marine Llajas(?) Formation (Yerkes and Campbell 1979, 1980; Campbell et al. 2014). The age of the formation is based on marine mollusks (Yerkes and Campbell 1979, 1980; Saul 1983; Strathearn et al. 1988; Squires and Kennedy 1998; Campbell et al. 2014). Following some other workers, the Coal Canyon Formation was included in the Santa Susana Formation by Campbell et al. (2014), with the latter unit interfingering with and overlying the Las Virgenes Sandstone, which, in turn, was included in the continental Simi Conglomerate.

The early Oligocene–late early Miocene Piuma Member of the continental Sespe Formation was named by Yerkes and Campbell (1979) for type locality exposures along Piuma Road and at the head of Carbon Canyon, SAMO (Figure 26; Table 3). At its type locality, the Piuma Member consists of lower and upper units separated by a tongue of the marine Vaqueros Formation (Yerkes and Campbell 1979, 1980; Campbell et al. 2014). As reported by Yerkes and Campbell (1979), the lower unit was about 60 m (200 ft) thick and composed of grayish-red sandstone beds and spare pebble stringers; the marine tongue was approximately 45 m (148 ft) thick and composed of beds of medium- to coarse-grained sandstone interbedded with some layers of olive-gray mudstone or shale; and the upper unit was about 282 m (925 ft) thick and made up of gray, grayish-red, and olive-gray mudstone, medium- to coarse-grained sandstone, and pebbly sandstone. Therefore, the Piuma Member would be approximately 342 m (1,120 ft) thick, although there are different interpretations of the placements of the contacts and thus the thickness (Lander 2011; Lander et al. 2013). Unlike the underlying undivided Sespe Formation, which is rather uniform, relatively light-colored, and comparatively thick bedded, the Piuma Member consists of numerous superposed couplets. Each couplet consists of a relatively thin, tan, light purplish-gray to light brown, or reddish-brown, medium- to coarse-grained sandstone bed that is capped by a similarly thin, light greenish-blue or reddish-brown, fine-grained sandstone to mudstone layer (Lander 2011; Lander et al. 2013). As described by Yerkes and Campbell (1979), the Piuma Member conformably underlies the Saddle Peak Member of the Topanga Canyon Formation, intertongues with the Vaqueros Formation, and overlies the undivided Sespe Formation. However, the contact with the Saddle Peak Member was later found to be a disconformity (Lander 2011; Lander et al. 2013). Lander (2011) and Lander et al. (2013) regarded the Piuma Member as dating to between 28.141 and approximately 20 million years old based on magnetostratigraphy, radiometric dates in related beds, and land mammal biostratigraphy.

The early Oligocene–earliest Miocene Danielson Member of the Vaqueros Formation was originally termed the Danielson Formation by Sonneman (1956) and renamed by Yerkes and Campbell (1979) for its type locality exposures on Danielson Ranch in upper Big Sycamore Canyon, SAMO (Figure 26; Table 3). It is the lower of two members of the Vaqueros Formation formally described by Yerkes and Campbell (1979). A reference locality for the member occurs in upper Trancas Canyon (Yerkes and Campbell 1979). Yerkes and Campbell (1979) and Campbell et al. (2014) characterized the Danielson Member as consisting predominantly of grayish-black sandy siltstone and mudstone, forming thin to medium beds with indistinct parallel lamination. The mudstone and siltstone intervals sometimes contain mollusk shells, weathered foraminifers, and fish scales, with a characteristic *Turritella inezana* fauna (Yerkes and Campbell 1979). Per Yerkes and Campbell (1979), the Danielson Member conformably underlies the San Nicholas Member of the Vaqueros Formation and rests conformably on the Sespe Formation. Its age is known from benthic foraminifers (Yerkes and Campbell 1979; California foraminifer biostratigraphy after McDougall 2007). Flack (1993) and Fritsche (1993) identified the Danielson Member as the Danielson Tongue of the Rincon Shale, while Dibblee and Ehrenspeck (1990a, 1993) did not use the name.

The late Oligocene–late early Miocene San Nicholas Member is the upper of two members of the Vaqueros Formation formally described by Yerkes and Campbell (1979). The San Nicholas Member is named after its type locality exposures in San Nicholas Canyon, SAMO (Figure 26; Table 3). Exposures in the type locality consist of very thick-bedded to massive cliff and ledge-forming sandstone that are light gray to pale bluish gray and measure approximately 150 m (490 ft) thick (Yerkes and Campbell 1979; Campbell et al. 2014). Sandstones range from very fine- to very coarse-grained, typically display cross lamination and parallel lamination, and contain abundant fossil fragments (Yerkes and Campbell 1979; Campbell et al. 2014). Stratigraphically, the San Nicholas Member conformably overlies the lower Danielson Member of the Vaqueros Formation and conformably underlies the Encinal Member of the Topanga Canyon Formation (Yerkes and Campbell 1979; Campbell et al. 2014). The age of the San Nicholas Member is shown by benthic foraminifers (Yerkes and Campbell 1979). Fritsche (1993) identified the San Nicholas Member as the San Nicholas Tongue of an unnamed sandstone including the Vaqueros and Topanga Canyon Formations, while Dibblee and Ehrenspeck (1990a, 1993) did not use the name.

The dominantly marine Topanga Group of late early–early late Miocene age was proposed by Yerkes and Campbell (1979). This unit was originally named the Topanga Formation by Kew (1923, 1924) to include strata in the Santa Monica Mountains lying above the Vaqueros Formation and below the Modelo Formation. Kew (1923) named the Topanga Formation for its type locality exposures in Topanga Canyon, SAMO, approximately 16 km (10 mi) northwest of Santa Monica (Figure 26; Table 3). As mapped by Kew (1924) west of Old Topanga Canyon Road in Dry Canyon of the east-central Santa Monica Mountains, the formation included thick lower and upper sedimentary units that bracketed a thin volcanic flow unit. The three units were subsequently identified as the Lower, Middle, and Upper Topanga Formations, respectively, by Soper (1938) and Durrell (1954) (see Campbell et al. 2007). The middle Topanga Formation included the Conejo Volcanics of Taliaferro (1924) and interbedded sedimentary units. The Lower, Middle, and Upper Topanga Formations of Soper (1938) and Durrell (1954) became the Topanga Canyon Formation, Conejo Volcanics, and Calabasas Formation of the Topanga Group, respectively (see Campbell et al. 2007). Lithologically, the Topanga Formation of Kew (1924) consisted predominantly of tan, brown, and gray coarse-grained and conglomeratic sandstone beds with thin layers of light-colored shaly sandstone. He stated that the best exposures of the formation occurred at the nose of Topanga anticline just west of Old Topanga Canyon. Per Yerkes and Campbell (1979), the Topanga Group is 2,680 m (8,790 ft) thick, but usage of other definitions (Dibblee and Ehrenspeck 1990b, 1993; Dibblee 1993; Fritsche 1993) would change this figure.

The late early Miocene, dominantly marine Topanga Canyon Formation was named by Yerkes and Campbell (1979) for widespread exposures of marine and continental sandstone, shaly siltstone, and silty mudstone beds found above the Vaqueros Formation and below the Conejo Volcanics. The formation was named after its type locality exposures in roadcuts along Old Topanga Canyon Road (Figure 26; Table 3). Type locality exposures of the Topanga Canyon Formation contain the Topanga Canyon Fauna described by Arnold (1907) and named by Kew (1924). The formation has been divided into several members in some areas on the basis of well-developed facies that include non-marine, nearshore marine, and shallow marine. As defined by Yerkes and Campbell (1979), the formation included the marine Saddle Peak Member and the successively overlying continental Fernwood and marine Cold Creek Members in the east-central Santa Monica Mountains east of

Malibu Canyon, and the marine Encinal Member in the western portion of the range west of Point Dume. Where undivided, the Topanga Canyon Formation has an approximate maximum thickness of 675 m (2,220 ft) (Yerkes and Campbell 1979). Dibblee (Dibblee and Ehrenspeck 1990b, 1993; Dibblee 1993) and Fritsche (1993) both proposed including rocks of the Vaqueros Formation with Yerkes and Campbell's Topanga Canyon Formation because the two formations are only distinguishable by fossils, but differed on what name to use and which subunits of the two formations to include.

The late early–early middle(?) Miocene Encinal Member of the Topanga Canyon Formation was designated by Yerkes and Campbell (1979) for its type locality exposures along Encinal Canyon Road, SAMO (Figure 26; Table 3). Type locality exposures of the Encinal Member are approximately 430 m (1,400 ft) thick and consist mostly of platy to shaly, dark gray siltstone and silty mudstone with large lenticular dolomitic concretions (Yerkes and Campbell 1979; Campbell et al. 2014). The Encinal Member rests conformably on the San Nicholas Member of the Vaqueros Formation and is unconformably overlain by the Conejo Volcanics (Yerkes and Campbell 1979). Its age is based on benthic foraminifers (Yerkes and Campbell 1979; Flack 1993; Campbell et al. 2014). Flack (1993) and Fritsche (1993) identified the Encinal Member as the Encinal Tongue of the Rincon Shale, while Dibblee and Ehrenspeck (1993) did not recognize the Encinal Member as a named part of their Lower Topanga Formation (=Topanga Canyon Formation).

The late early Miocene marine Saddle Peak Member of the Topanga Canyon Formation was named by Yerkes and Campbell (1979) for exposures on the west shoulder of Saddle Peak, SAMO, on the divide situated between Dark and Carbon Canyons and extending in a southwesterly direction from the airway beacon/benchmark on the peak (B. Lander, pers. comm., December 2020). Roadcuts along Piuma Road southwest of Saddle Peak where it crosses the divide at the head of Dark Canyon are designated the type locality for the member (Figures 26 and 28; Table 3). Type locality exposures are approximately 220 m (720 ft) and consist of thick-bedded to massive, medium- to coarse-grained sandstone, pebbly sandstone, and sandy siltstone resting on a 0.5 m (1.6 ft) thick basal pebbly conglomerate (Yerkes and Campbell 1979, 1980; Campbell et al. 2014). The member is incomplete at the type locality due to faulting, so its thickness may be greater (Alderson 2013). The Saddle Peak Member was described by Yerkes and Campbell as resting conformably on the Piuma Member of the Sespe Formation and conformably underlying the Fernwood Member of the Topanga Canyon Formation; as noted above, the contact with the Piuma Member is now known to be disconformable (Lander 2011; Lander et al. 2013).

Figure 28. Saddle Peak, SAMO; the type locality exposures of the Saddle Peak Member of the Topanga Canyon Formation are on the southwest slope of the peak. Photograph by user “MiniHolland” available via Wikimedia Commons https://commons.wikimedia.org/wiki/File:Saddle_Peak,_California.JPG (Creative Commons Attribution-Share Alike 3.0 Unported [CC BY-SA 3.0]; https://creativecommons.org/licenses/by-sa/3.0/deed.en).

The late early Miocene continental Fernwood Member of the Topanga Canyon Formation was designated by Yerkes and Campbell (1979) for the type locality exposures in the vicinity of Fernwood on the lower western slope of Topanga Canyon in the west-central Topanga Quadrangle (Figure 26; Table 3). Type locality exposures are approximately 375 m (1,230 ft) thick and consist primarily of pebbly sandstone that forms thick, lenticular, ledge-forming beds that are complexly channeled and cross-bedded (Yerkes and Campbell 1979). Interbedded with the sandstone is abundant grayish-red or olive-gray mudstone with minor amounts of tuff and limestone (Yerkes and Campbell 1979). The Fernwood Member conformably overlies and intertongues with the Saddle Peak Member of the Topanga Canyon Formation, or locally overlies the Sespe Formation, and conformably underlies and intertongues with the Cold Creek Member of the Topanga Canyon Formation (Yerkes and Campbell 1979). Flack (1993) and Fritsche (1993) identified it as the Fernwood Tongue of the Sespe Formation, whereas Dibblee (1992b) did not use the name. The age of the Fernwood Member is based on mammal biostratigraphy (Lander 2020).

The late early–early middle Miocene marine Cold Creek Member of the Topanga Canyon Formation was designated by Yerkes and Campbell (1979) for the type locality exposures in the Cold Creek–Old Topanga Canyon area, SAMO (Figure 26; Table 3). Type locality exposures are approximately 707 m (2,320 ft) thick and consist of marine sandstone, silty sandstone, and minor amounts of pebbly sandstone (Yerkes and Campbell 1979). The Topanga Canyon fauna of Arnold (1907) and Kew (1924) occurs in the lower part of the Cold Creek Member and includes more than 120 species of mollusks (Alderson 2012). The sandstone is commonly medium-grained, moderately- to well-sorted, and occurs in laminated or graded beds up to 2 m (7 ft) thick (Yerkes and Campbell 1979). The Cold Creek Member conformably overlies the Fernwood Member of the Topanga Canyon Formation and is overlain by the Calabasas Formation at the type locality where the Conejo Volcanics are absent or extremely thin (Yerkes and Campbell 1979). Its age is based on benthic foraminifers (Campbell et al. 2014).

The late early–early middle Miocene, dominantly marine Conejo Volcanics were named by Taliaferro (1924) for volcanic rocks exposed at the type locality in the western Santa Monica Mountains ("Conejo Mountains") (Figures 27 and 29; Table 3). Taliaferro (1924) estimated that the volcanic rocks and interbedded Miocene sedimentary strata of the Conejo Volcanics were as much as 4,600 m (15,000 ft) thick. The main sequence of the Conejo Volcanics consists of andesitic and basaltic breccias, flows, pillow breccias, and aquagene tuffs (formed by basalt flowing beneath water or ice) with minor interbeds of fossiliferous volcanic sandstone and siltstone, limestone, and tuff (Yerkes and Campbell 1979). A basal black shaly marine siltstone measuring up to 90 m (300 ft) and containing abundant fish scales is present in some areas (Yerkes and Campbell 1979). The unit contains three distinct tongues (Malibu Bowl, Solstice Canyon, and Ramera Canyon) of volcanic rock that are complexly interbedded with marine sedimentary members of the Calabasas Formation. The age of the formation is based on radiometric dates (Yerkes and Campbell 1979; Fritsche et al. 2001). The Conejo Volcanics have also been identified as the Middle Topanga Formation (Soper 1938; Durrell 1954). This name was reused in part by Dibblee (1993) and Dibblee and Ehrenspeck (1993), who limited it to sedimentary units they removed from the Conejo Volcanics, specifically the Latigo (Canyon) Breccia Member of Yerkes and Campbell (1979).

The Ramera Canyon Tongue was designated by Yerkes and Campbell (1979) as the lowermost formally named tongue of the Conejo Volcanics recognized in the upper plate of the Malibu Bowl detachment fault. The tongue is named after its type area exposures in Ramera Canyon, SAMO (Figure 27; Table 3). Type area exposures consist of basaltic and andesitic breccias, tuff-breccias, and flows with minor amounts of volcanic sandstone that together are approximately 518 m (1,700 ft) thick (Yerkes and Campbell 1979). The upper part of the unit tongues eastward into the lower part of the Escondido Canyon Shale Member of the Calabasas Formation. The Ramera Canyon Tongue overlies the Topanga Canyon Formation and underlies and interfingers with the Escondido Canyon Shale and Dry Canyon Sandstone Members of the Calabasas Formation.

The Solstice Canyon Tongue of the Conejo Volcanics was named by Yerkes and Campbell (1979) for its type area exposures in Solstice Canyon, SAMO (Figure 27; Table 3). Type area exposures have an approximate maximum thickness of 244 m (800 ft) and are composed of basaltic and andesitic flows, breccias, and tuffs with local volcanic sandstone (Yerkes and Campbell 1979). The Solstice Canyon Tongue overlies the Latigo Canyon Breccia Member of the Calabasas Formation, intertongues with the Dry Canyon Sandstone Member of the Calabasas Formation, and underlies the Malibu Bowl Tongue of the Conejo Volcanics.

Figure 29. Southwest view from the top of Sandstone Peak looking towards Boney Peak, both of which consist of the Conejo Volcanics in the western Santa Monica Mountains, SAMO (NPS).

The Malibu Bowl Tongue of the Conejo Volcanics was designated by Yerkes and Campbell (1979) for its type area exposures near the Malibu Bowl Fault, SAMO (Figure 27; Table 3). The approximate maximum thickness of the tongue is 143 m (469 ft). It consists of andesitic and basaltic flows and flow breccias that tongue eastward into the Newell Sandstone Member of the Calabasas Formation (Yerkes and Campbell 1979). The Malibu Bowl Tongue overlies the Dry Canyon Sandstone Member of the Calabasas Formation or the Solstice Canyon Tongue of the Conejo Volcanics, and underlies and intertongues with the Newell Sandstone Member of the Calabasas Formation.

The Miocene Calabasas Formation was designated by Yerkes and Campbell (1979) for exposures in the Calabasas Peak area, SAMO. The type locality of the formation is in Stokes Canyon approximately 3 km (2 mi) west of the peak (Figure 26; Table 3; Yerkes and Campbell 1979). The Calabasas Formation consists of thick-bedded, medium- to coarse-grained sandstone, interbedded silty shale, and sedimentary breccia. Silty shale intervals of the formation contain large dolomitic concretions and locally abundant rust-colored plant casts and fish scales (Yerkes and Campbell 1979). Type locality exposures contain a prominent interbed of the Stokes Canyon Breccia Member that measures up to 60 m (200 ft) thick (Yerkes and Campbell 1979). Stratigraphically, the Calabasas Formation variously intertongues with, conformably overlies, or has an unconformable contact with the Conejo Volcanics, and is unconformably overlain by the Modelo Formation (Yerkes and Campbell 1979). The rocks of the Calabasas Formation were identified as the Upper Topanga Formation in some earlier works, and the name was reused in Dibblee (1993).

The Dry Canyon Sandstone Member is the oldest designated member of the Calabasas Formation by Yerkes and Campbell (1979). The member is named for its type area exposures in Dry Canyon of the Santa Monica Mountains, SAMO (Figure 27; Table 3). Exposures in the type area measure approximately 686 m (2,250 ft) thick and consist of many thin turbidite (deposits of gravity flows) sequences of sandstone and siltstone that tongue westward into the Escondido Canyon Shale Member (Yerkes and Campbell 1979). Siltstone intervals contain locally prominent dolomitic concretions. Yerkes and Campbell (1979) collected Miocene mollusk fossils from a coarse-grained arkosic arenite of the Dry Canyon Sandstone in the upper plate of the Malibu Bowl fault.

The Escondido Canyon Shale Member of the Calabasas Formation was designated by Yerkes and Campbell (1979) for its type area in Escondido Canyon, SAMO (Figure 27; Table 3). Type area exposures are approximately 276 m (906 ft) thick and consist of siltstone, mudstone, shale, and minor interbedded thin sandstone turbidites (Yerkes and Campbell 1979). Siltstone intervals contain locally prominent dolomitic concretions. Exposures of the member tongue eastward into the Dry Canyon Sandstone Member. The Escondido Canyon Shale Member overlies the Ramera Canyon Tongue of the Conejo Volcanics, intertongues with the Dry Canyon Sandstone Member of the Calabasas Formation, and underlies the Latigo Canyon Breccia Member of the Calabasas Formation.

The Latigo Canyon Breccia Member of the Calabasas Formation was named by Yerkes and Campbell (1979) for its type area exposures in Latigo Canyon, SAMO (Figure 27; Table 3). Type area exposures consist of sedimentary breccia that contains large redbed sandstone clasts derived from the Sespe Formation, and fossiliferous sandstone clasts of the Vaqueros Formation in sandy, tuffaceous, or volcanic breccia (Yerkes and Campbell 1979). The Latigo Canyon Breccia Member intertongues with an unnamed volcanic breccia. Maximum measured thickness of the member is approximately 91 m (300 ft). The Latigo Canyon overlies the Escondido Canyon Shale Member of the Calabasas Formation and underlies the Solstice Canyon Tongue of the Conejo Volcanics.

The Newell Sandstone Member of the Calabasas Formation was designated by Yerkes and Campbell (1979) for its type area near Newell Road, SAMO (Figure 27; Table 3). Type area exposures consist of poorly sorted, turbiditic sandstone and shaly siltstones with large dolomitic concretions. The unit tongues westward into the Malibu Bowl Tongue of the Conejo Volcanics (Yerkes and Campbell 1979). Maximum measured thickness of type area exposures is approximately 244 m (800 ft). The Newell Sandstone Member rests conformably between the overlying Mesa Peak Breccia Member and underlying Dry Canyon Sandstone Member.

The Mesa Peak Breccia Member of the Calabasas Formation was named by Yerkes and Campbell (1979) for its type area near Mesa Peak, SAMO (Figure 27; Table 3). Type area exposures consist of angular fragments of volcanic rock and very coarse-grained sandstone that together have a maximum thickness of 288 m (945 ft) (Yerkes and Campbell 1979). The Mesa Peak Breccia conformably overlies the Newell Sandstone Member and lacks adequate upper contact exposures.

The Stokes Canyon Breccia Member of the Calabasas Formation was named by Yerkes and Campbell (1979) for its type locality exposures in Stokes Canyon, SAMO (Figure 26; Table 3). Type locality exposures occur as interbeds with the Calabasas Formation that measure 60 m (200 ft) thick and consist of angular fragments of redeposited sandstone that contain Paleocene and Eocene mollusks (Yerkes and Campbell 1979).

The Miocene Trancas Formation was named by Yerkes and Campbell (1979) for its type locality exposures near the mouth of Trancas Canyon south of the Malibu Coast fault, SAMO (Figure 26; Table 3). The type locality includes scattered exposures of an incomplete stratigraphic section and consist of marine sandstone, mudstone, silty shale, claystone, and locally prominent sedimentary breccia (Yerkes and Campbell 1979). A complete section of the Trancas Formation is not available due to the intensely folded and faulted nature of the unit. The formation unconformably underlies and locally intertongues with the Monterey Shale. The basal contact is not exposed but is inferred to rest unconformably on the Catalina Schist (Yerkes and Campbell 1979).

The Miocene Zuma Volcanics were designated by Yerkes and Campbell (1979) for a series of volcanic rocks that underlie the Monterey Shale and contain interbedded sedimentary rocks of the Trancas Formation and Monterey Shale. Yerkes and Campbell (1979) named the unit after its type locality exposures on the west side of Zuma Canyon, south of the Malibu Coast fault, SAMO. These exposures consist of basaltic and andesitic flows, breccias, pillow lavas, mudflow breccias, aquagene tuffs, minor amounts of volcanic sediment, and localized interbeds of mudstone and siltstone (Figure 26; Table 3). The thickest section of the unit is exposed in a synclinal sequence (concave-up fold) ~2.5 km (1.5 mi) north of Point Dume and has an approximate thickness of 800–1,000 m (2,600–3,300 ft).

In addition to the designated stratotypes located within SAMO, a list of stratotypes located within 48 km (30 mi) of park boundaries is included here for reference. These nearby stratotypes include the Pleistocene units of the Pico Formation (type locality) and Saugus Formation (type locality), Pliocene–Pleistocene San Pedro Formation (type locality), Eocene units of the Llajas Formation (type locality) and Cozy Dell Shale (type section), Miocene Modelo Formation (type section and type locality), Oligocene–Miocene Rincon Shale (type section), Eocene–Miocene Sespe Formation (type section), and Cretaceous Chatsworth Formation (type section and type locality).

Recommendations

1. The NPS Geologic Resources Division should work with park and network staff to increase their awareness and understanding about the scientific, historic and geologic heritage significance of geologic stratotypes (type sections/localities/areas, reference sections, lithodemes).
2. Once the MEDN Geologic Type Section Inventory report is finalized, the NPS Geologic Resources Division will schedule a briefing for the staff of the MEDN and respective network parks.
3. There are several units in local use on the Channel Islands that do not have formal stratotypes. Two were named from San Miguel Island, the San Miguel Volcanics and the South Point Formation or Sandstone. Six were named from Santa Cruz Island: the Blanca Formation, Cañada Formation, Jolla Vieja Formation, Middle Anchorage Alluvium, Pozo Formation, and the Santa Cruz Island Formation. Finally, two units, one with three members, were named from Santa Rosa Island: the Santa Rosa Island Formation (including the Fox, Garañon, and Tecolote members) and the Santa Rosa Island Volcanics. It also appears that the unit identified as the Vaqueros Formation on Santa Cruz and Santa Rosa islands represents a distinct and yet-to-be-named formation (Powell and Geiger 2019). Therefore, we recommend formal type sections be designated in order to A) provide standard references for scientific research; B) educate park staff and visitors about the geoheritage significance of these units; and C) help safeguard the exposures.
4. The NPS Geologic Resources Division should work with park and network staff to ensure they are aware of the location of stratotypes in park areas. This information would be important to ensure that proposed park activities or development would not adversely impact the stability and condition of these geologic exposures.
5. The NPS Geologic Resources Division should work with park and network staff, the U.S. Geological Survey, State Geological Surveys, academic geologists and other partners to formally assess potential new stratotypes as to their significance (international, national, or state-wide), based on lithology, stratigraphy, fossils or notable features using procedural code outlined by the North American Commission on Stratigraphic Nomenclature.
6. From the assessment in (5), NPS staff should focus on registering new stratotypes at State and Local government levels where current legislation allows, followed by a focus on registering at Federal and State levels where current legislation allows.
7. The NPS Geologic Resources Division should work with park and network staff to compile and update a central inventory of all designated stratotypes and potential future nominations.
8. The NPS Geologic Resources Division should ensure the park-specific Geologic Type Section Inventory Reports are widely distributed and available online.
9. The NPS Geologic Resources Division should work with park and network staff to regularly monitor geologic type sections to identify any threats or impacts to these geologic heritage features in parks.

10. The NPS Geologic Resources Division should work with park and network staff to obtain good photographs of each geologic type section within the parks. In some cases, where there may be active geologic processes (rock falls, landslides, coastal erosion, etc.), the use of photogrammetry may be considered for monitoring of geologic type sections. GPS locations should also be recorded and kept in a database when the photographs are taken.
11. The NPS Geologic Resources Division should work with park and network staff to utilize selected robust internationally and nationally significant type sections as formal teaching/education sites and for geotourism so that the importance of the national- and international-level assets are more widely (and publicly) known, using information boards and walkways.
12. The NPS Geologic Resources Division should work with park and network staff in developing conservation protocols of significant type sections, either by appropriate fencing, walkways, and information boards or other means (e.g., phone apps).
13. There are numerous formations in use on CHIS that do not have stratotypes. We recommend that formal type sections be designated in order to A) provide a standard reference for scientific research; B) educate park staff and visitors about the geoheritage significance of the units; and C) help safeguard the most characteristic exposures.

Literature Cited

Alderson, J. 2012. Topanga fossils. *In* M. Johnson, editor. The Topanga Story, 2nd edition. Topanga Historical Society, Topanga, California.

Alderson, J. M. 2013. Updated geologic maps of Saddle Peak and Calabasas Peak areas of east-central Santa Monica Mountains, Los Angeles County, southern California. Appendix A, pages 39–41 *in* E. B. Lander, V. L. Santucci, and J. Tweet, compilers. 2013. Society of Vertebrate Paleontology 73rd annual meeting field trip volume and guidebook on Arikareean and Hemingfordian vertebrate paleontology of the Santa Monica Mountains National Recreation Area, Los Angeles County, southern California. Society of Vertebrate Paleontology, Natural History Museum of Los Angeles County Department of Vertebrate Paleontology [LACM], National Park Service Santa Monica Mountains National Recreation Area, Paleo Environmental Associates, Inc., and Tweet Paleo-Consulting (on file at LACM).

Anderson, M. 2017. National Parks Index: 2012–2016. Official Index of the National Park Service.

Arnold, R. 1907. New and characteristic species of fossil mollusks from the oil-bearing Tertiary formations of southern California. U.S. National Museum Proceedings 32(1545):525–546.

Avila, F. A., and D. W. Weaver. 1969. Mid-Tertiary stratigraphy, Santa Rosa Island. Pages 48–67 *in* D. W. Weaver, D. P. Doerner, and B. Nolf, editors. Geology of the northern Channel Islands, southern California borderland. American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Section, Upland, California.

Bailey, R. G. 1976. Ecoregions of the United States (map). US Department of Agriculture, US Forest Service, Intermountain Region, Ogden, Utah.

Bartling, W. A., and P. L. Abbott. 1983. Upper Cretaceous sedimentation and tectonics with reference to the Eocene, San Miguel Island, and San Diego area, California. Pages 133–150 *in* D. K. Larue and R. J. Steel, editors. Cenozoic marine sedimentation: Pacific margin, U.S.A. Society of Economic Paleontologists and Mineralogists, Pacific Section, Los Angeles, California.

Brocx, M., C. Brown, and V. Semeniuk. 2019. Geoheritage importance of stratigraphic type sections, type localities and reference sites—review, discussion and protocols for geoconservation. Australian Journal of Earth Sciences 66(6):823–836.

Calvano, G., D. R. Prothero, J. A. Ludtke, and E. B. Lander. 2008. Magnetic stratigraphy of the Eocene to Miocene Sespe–Vaqueros Formations, Los Angeles and Orange Counties, California. Pages 43–61 *in* X. Wang and L. G. Barnes, editors. Geology and vertebrate paleontology of western and southern North America. Natural History Museum of Los Angeles County, Los Angeles, California. Science Series 41.

Campbell, R. H., B. A. Blackerby, R. F. Yerkes, J. E. Schoelhamer, P. W. Birkeland, and C. M. Wentworth. 1996. Geologic map of the Point Dume Quadrangle, Los Angeles County, California. U.S. Geological Survey, Reston, Virginia. Geologic Quadrangle Map 1747. Scale 1:24,000. Available at: https://ngmdb.usgs.gov/Prodesc/proddesc_61691.htm (accessed January 20, 2021).

Campbell, R. H., T. H. McCulloh, and J. G. Vedder. 2007. The Miocene Topanga Group of southern California—A 100-year history of changes in stratigraphic nomenclature. U.S. Geological Survey, Reston, Virginia. Open-File Report 2007-1385. Available at: https://pubs.usgs.gov/of/2007/1385/ (accessed January 20, 2021).

Campbell, R. H., C. J. Willis, P. J. Irvine, and B. J. Swanson, compilers. 2014. Preliminary geologic map of the Los Angeles 30' x 60' Quadrangle, California, Version 2.1. California Geological Survey, Sacramento, California. Scale 1:100,000.

Dibblee, T. W., Jr. 1991a. Geologic map of the Hollywood and Burbank (south ½) Quadrangles, Los Angeles County, California. Dibblee Geological Foundation, Santa Barbara, California. Map DF-30. Scale 1:24,000.

Dibblee, T. W., Jr. 1991b. Geologic map of the Beverly Hills and Van Nuys (south ½) Quadrangles, Los Angeles County, California. Dibblee Geological Foundation, Santa Barbara, California. Map DF-31. Scale 1:24,000.

Dibblee, T. W., Jr. 1992a. Geologic map of the Calabasas Quadrangle, Los Angeles and Ventura Counties, California. Dibblee Geological Foundation, Santa Barbara, California. Map DF-37. Scale 1:24,000.

Dibblee, T. W., Jr. 1992b. Geologic map of the Topanga and Canoga Park (south ½) Quadrangles, Los Angeles County, California. Dibblee Geological Foundation, Santa Barbara, California. Map DF-35. Scale 1:24,000.

Dibblee, T. W., Jr. 1993. Geologic map of the Malibu Beach Quadrangle, Los Angeles County, California. Dibblee Geological Foundation, Santa Barbara, California. Map DF-47. Scale 1:24,000.

Dibblee, T. W., Jr., and H. E. Ehrenspeck. 1990a. Geologic map of the Camarillo and Newbury Park Quadrangles, Ventura County, California. Dibblee Geological Foundation, Santa Barbara, California. Map DF-28. Scale 1:24,000.

Dibblee, T. W., Jr., and H. E. Ehrenspeck. 1990b. Geologic map of the Point Mugu and Triunfo Pass Quadrangles, Ventura and Los Angeles Counties, California. Dibblee Geological Foundation, Santa Barbara, California. Map DF-29. Scale 1:24,000.

Dibblee, T. W., Jr., and H. E. Ehrenspeck. 1993. Field relations of Miocene volcanic and sedimentary rocks of the western Santa Monica Mountains, California. Pages 75–92 *in* P. W. Weigand, E. A. Fritsche, and G. E. Davis, editors. Depositional and volcanic environments of middle Tertiary rocks in the Santa Monica Mountains, southern California. Pacific Section, Society for Sedimentary Geology, Bakersfield, California. Book 72.

Dibblee, T. W., Jr., and H. E. Ehrenspeck. 2001. Geologic map of San Miguel Island, Santa Barbara County, California. Dibblee Geological Foundation, Santa Barbara, California. Map 72. Scale 1:24,000.

Durrell, C. 1954. Geology of the Santa Monica Mountains, Los Angeles and Ventura Counties. Map Sheet 8 *in* R. H. Jahns, editor. Geology of southern California. California Division of Mines Bulletin 170.

Evans, T. J. 2016. General standards for geologic maps. Section 3.1 *in* M. B. Carpenter and C. M. Keane, compilers. The geoscience handbook 2016. AGI Data Sheets, 5th Edition. American Geosciences Institute, Alexandria, Virginia.

Fenneman, N. M. 1946. Physical divisions of the United States (map). U.S. Geological Survey, Washington, D.C. Unnumbered. Available at: https://pubs.er.usgs.gov/publication/70207506 (accessed January 20, 2021).

Flack, M. E. 1993. Depositional environments of the "Topanga Canyon" Formation, the Encinal Tongue of the Rincon Shale, and the Fernwood Tongue of the Sespe Formation, central Santa Monica Mountains, California. Pages 45–74 *in* P. W. Weigand, E. A. Fritsche, and G. E. Davis, editors. Depositional and volcanic environments of middle Tertiary rocks in the Santa Monica Mountains, southern California. Pacific Section, Society for Sedimentary Geology, Bakersfield, California. Book 72.

Fritsche, E. A. 1993. Middle Tertiary stratigraphic terminology for the Santa Monica Mountains, southern California. Pages 1–12 *in* P. W. Weigand, E. A. Fritsche, and G. E. Davis, editors. Depositional and volcanic environments of middle Tertiary rocks in the Santa Monica Mountains, southern California. Pacific Section, Society for Sedimentary Geology, Bakersfield, California. Book 72.

Fritsche, A. E. 1998. Miocene paleogeography of southern California and its implications regarding basin terminology. International Geology Review 40:452–470; and Pages 484–502 *in* W. G. Ernst and C. A. Nelson, editors. Integrated earth and environmental evolution of the southwestern United States. Bellwether Publishing, Ltd., Columbia, Maryland.

Fritsche, A. E., P. W. Weigand, I. P. Colburn, and R. L. Harma. 2001. Transverse/Peninsular Ranges connections—Evidence for the incredible Miocene rotation. Pages 101–146 *in* G. C. Dunne and J. D. Cooper, compilers. Geologic excursions in southwestern California. Pacific Section, Society for Sedimentary Geology, Bakersfield, California. Book 89.

Gradstein, F. M., J. G. Ogg, M. D. Schmitz, and G. M. Ogg, editors. 2020. Geologic time scale 2020. Elsevier, Amsterdam, Netherlands.

Henderson, T., V. L. Santucci, T. Connors, and J. S. Tweet. 2020. National Park Service geologic type section inventory: Greater Yellowstone Inventory & Monitoring Network. Natural Resource Report NPS/GRYN/NRR—2020/2198. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2280034 (accessed January 20, 2021).

Hillhouse, J. W. 2010. Clockwise rotation and implications for northward drift of the western Transverse Ranges from paleomagnetism of the Piuma Member, Sespe Formation, near Malibu, California. Geochemistry, Geophysics, Geosystems 11(7):1–27.

Hoots, H. W. 1931. Geology of the eastern part of the Santa Monica Mountains, Los Angeles County, California. Pages 83–134 *in* Shorter contributions to general geology, 1930. U.S. Geological Survey, Washington, D.C. Professional Paper 165. Available at: https://pubs.er.usgs.gov/publication/pp165 (accessed January 20, 2021).

Imlay, R.W. 1963. Jurassic fossils from southern California. Journal of Paleontology 37(1):97–107.

KellerLynn, K. 2016. Santa Monica Mountains National Recreation Area: Geologic Resources Inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2016/1297. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2233234 (accessed January 20, 2021).

KellerLynn, K. 2018. Cabrillo National Monument: Geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2018/1666. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2253757 (accessed January 20, 2021).

Kennedy, M. P. and G. W. Moore. 1971. Stratigraphic relations of Upper Cretaceous and Eocene formations, San Diego coastal area, California. American Association of Petroleum Geologists Bulletin 55(5):709–722.

Keroher, G. C., and others. 1966. Lexicon of geologic names of the United States for 1936–1960. U.S. Geological Survey, Washington, D.C. Bulletin 1200. Available at: https://pubs.er.usgs.gov/publication/b1200 (accessed January 20, 2021).

Kew, W. S. W. 1923. Geologic formations of a part of southern California and their correlation. American Association of Petroleum Geologists Bulletin 7(4):411–420.

Kew, W. S. W. 1924. Geology and oil resources of a part of Los Angeles and Ventura Counties, California. U.S. Geological Survey, Washington, D.C. Bulletin 753. Available at: https://pubs.er.usgs.gov/publication/b753 (accessed January 20, 2021).

Lander, E. B. 1994. Recalibration and causes of marine regressive-transgressive cycle recorded by middle Eocene to lower Miocene nonmarine Sespe Formation, southern California continental plate margin. Pages 79–88 *in* A. E. Fritsche, editor. Sedimentology and paleontology of Eocene rocks in the Sespe Creek area, Ventura County, California. Pacific Section, Society for Sedimentary Geology, Bakersfield, California. Book 74.

Lander, E. B. 1997. Geology and vertebrate paleontology of Cenozoic nonmarine rock units, Simi Valley, Ventura County, California. Pages 302–319 *in* P. Havens, and B. Appleton, editors. Simi Valley, a journey through time. Simi Valley Historical Society and Museum, Simi Valley, California.

Lander, E. B., compiler. 2011. Western Association of Vertebrate Paleontologists 2011 annual meeting field trip volume and guidebook—Stratigraphy, biostratigraphy, biochronology, geochronology, magnetostratigraphy, and plate tectonic history of the early middle Eocene to late early Miocene Sespe, Vaqueros, and Lower Topanga Formation, east-central Santa Monica Mountains, Los Angeles County, southern California. Natural History Museum of Los Angeles County Department of Vertebrate Paleontology [LACM] and Paleo Environmental Associates, Inc. (on file at LACM).

Lander, E. B. 2020. Geomagnetic polarity recalibration, upper unit of continental Hector Formation, northeastern Cady Mountains, San Bernardino County, southern California—Implications regarding refined correlations and North American land mammal subage assignments for Hemingfordian Upper Cady Mountains Local Faunas and correlative assemblages containing earlier records of *Parapliohippus carrizoensis* (Mammalia, Perissodactyla, Equidae). Pages 239–241 *in* D. M. Miller, editor. Changing facies. 2020 Desert Symposium field guide and proceedings. Desert Symposium, Inc., Yucca Valley, California.

Lander, E. B., V. L. Santucci, and J. Tweet, compilers. 2013. Society of Vertebrate Paleontology 73rd annual meeting field trip volume and guidebook on Arikareean and Hemingfordian vertebrate paleontology of the Santa Monica Mountains National Recreation Area, Los Angeles County, southern California. Society of Vertebrate Paleontology, Natural History Museum of Los Angeles County Department of Vertebrate Paleontology [LACM], National Park Service Santa Monica Mountains National Recreation Area, Paleo Environmental Associates, Inc., and Tweet Paleo-Consulting (on file at LACM).

Mattinson, J. M., and D. J. Hill. 1976. Age of plutonic basement rocks, Santa Cruz Island, California. Pages 53–58 *in* D. G. Howell, editor. Aspects of the geologic history of the California continental borderland. American Association of Petroleum Geologists, Pacific Section, Bakersfield, California. Miscellaneous Publication 24.

McDougall, K. 2007. California Cenozoic biostratigraphy—Paleogene. Pages 1–56 *in* A. H. Scheirer, editor. Petroleum systems and geologic assessment of oil and gas in the San Joaquin Basin Province, California. U.S. Geological Survey, Reston, Virginia. Professional Paper 1713. Available at: https://pubs.usgs.gov/pp/pp1713/ (accessed January 20, 2021).

Nolf, B., and P. Nolf. 1969. Santa Cruz Island volcanics. Pages 91–94 *in* D. W. Weaver, D. P. Doerner, and B. Nolf, editors. Geology of the northern Channel Islands, southern California borderland. American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Section, Upland, California.

North American Commission on Stratigraphic Nomenclature, 2005. North American stratigraphic code. AAPG Bulletin 89(11):1547–1591.

Omernik, J. M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers 77(1):118–125.

Powell, C. L., II, and D. L. Geiger. 2019. Two new Miocene limpets (Fissurellidae) from southern California, with notes on other fossil occurrences of the family in northwestern North America. PaleoBios 36:1–7.

Saul, L. R. 1983. *Turritella* zonation across the Cretaceous–Tertiary boundary, California. University of California Publications in Geological Sciences 125:1–149.

Sonneman, H. S. 1956. Geology of the Boney Mountain area, Santa Monica Mountains, California. Thesis. University of California, Los Angeles, Los Angeles, California.

Soper, E. K. 1938. Geology of the central Santa Monica Mountains, Los Angeles County, California. California Journal of Mines and Geology 34(2):131–180.

Squires, R. L., and G. L. Kennedy. 1998. Additions to the late Paleocene molluscan fauna from the Santa Monica Mountains, Los Angeles County, southern California. The Veliger 41(2):157–171.

Strathearn, G. E., K. Griffis, and B. L. Ingram. 1988. Palynomorphs and benthic foraminifera from a portion of the Coal Canyon Formation (Paleocene–Eocene). Pages 73–82 *in* M. V. Filewicz and R. L. Squires, editors. Paleogene stratigraphy, west coast of North America. Pacific Section, Society of Economic Paleontologists and Mineralogists, Bakersfield, California. Book 58.

Taliaferro, N. L. 1924. Notes on the geology of Ventura County, California. Pages 789–810 *in* N. L. Taliaferro, F. S. Hudson, and W. N. Craddock. The oil fields of Ventura County, California. American Association of Petroleum Geologists Bulletin 8(6):789–829.

Tweet, J. S., V. L. Santucci, and T. Connors. 2012. Paleontological resource inventory and monitoring: Mediterranean Coast Network. Natural Resource Technical Report NPS/MEDN/NRTR—2012/640. National Park Service, Fort Collins, Colorado.

Tweet, J. S., V. L. Santucci, K. Convery, J. Hoffman, and L. Kirn. 2020. Channel Islands National Park: Paleontological resource inventory (public version). Natural Resource Report NPS/CHIS/NRR—2020/2171. National Park Service, Fort Collins, Colorado. https://doi.org/10.36967/nrr-2278664.

Weaver, D. W. 1969. The pre-Tertiary rocks. Pages 11–13 *in* D. W. Weaver, D. P. Doerner, and B. Nolf, editors. Geology of the northern Channel Islands, southern California borderland. American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Section, Upland, California.

Weaver, D. W., and G. L. Meyer. 1969. Stratigraphy of northeastern Santa Cruz Island. Pages 95–104 *in* D. W. Weaver, D. P. Doerner, and B. Nolf, editors. Geology of the northern Channel Islands, southern California borderland. American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Section, Upland, California.

Weigand, P. W., K. L. Savage, and C. Nicholson. 2002. The Conejo Volcanics and other Miocene volcanic suites in southwestern California. Pages 187–204 *in* A. Barth, editor. Contributions to crustal evolution of the southwestern United States. Geological Society of America, Boulder, Colorado. Special Paper 365.

Wilmarth, M. G. 1938. Lexicon of geologic names of the United States (including Alaska). U.S. Geological Survey, Washington, D.C. Bulletin 896. Available at: https://pubs.er.usgs.gov/publication/b896 (accessed January 20, 2021).

Yerkes, R. F., and R. H. Campbell. 1979. Stratigraphic nomenclature of the central Santa Monica Mountains, Los Angeles County, California. U.S. Geological Survey, Washington, D.C. Bulletin 1457-E. Available at: https://pubs.er.usgs.gov/publication/b1457E (accessed January 20, 2021).

Yerkes, R. F., and R. H. Campbell. 1980. Geologic map of east-central Santa Monica Mountains, Los Angeles County, California. U.S. Geological Survey, Washington, D.C. Miscellaneous Investigations Series Map 1146. Scale 1:24,000. Available at: https://ngmdb.usgs.gov/Prodesc/proddesc_541.htm (accessed January 20, 2021).

Appendix A: Source Information for GRI Maps of MEDN Parks

CABR

- GMAP 75029: Kennedy, M. P. and S. S. Tan. 2008. Geologic map of the San Diego 30' x 60' Quadrangle, California: A digital database (2005 version 1.0). California Geological Survey, Sacramento, California. Preliminary Geologic Map. Scale 1:100,000.
- GMAP 4879: Kennedy, M. P. 1975. Geology of the Point Loma 7.5' quadrangle, San Diego County, California. Map *in* Geology of the San Diego Metropolitan Area, California, Section A. Plate 3a: Western San Diego metropolitan area. California Geological Survey, Sacramento, California. Bulletin 200. Scale 1:24,000.
- GMAP 46614: Tan, S. S. 1995. Relative landslide susceptibility and landslide distribution map, Point Loma Quadrangle. California Geological Survey, Sacramento, California. Open-File Report 95-03. Scale 1:24,000.

CHIS

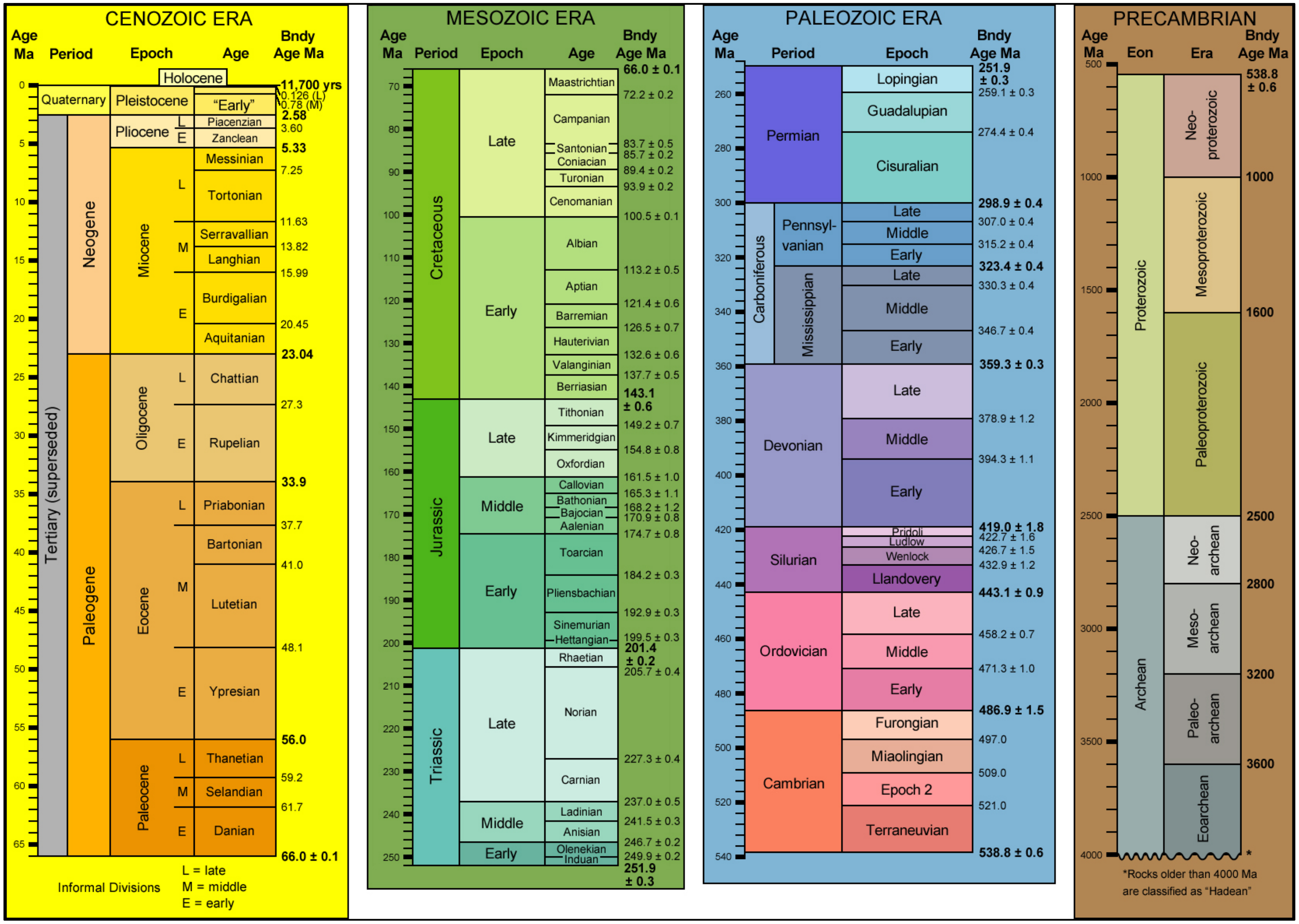
- GMAP 75157: Weaver, D. W., and D. P. Doerner. 1969c. Geologic map: San Miguel Island. Map *in* D. W. Weaver, D. P. Doerner, and B. Nolf, editors. Geology of the northern Channel Islands, southern California borderland. American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Section, Upland, California. Scale 1:24,000.
- GMAP 75158: Weaver, D. W., and B. Nolf. 1969. Geology of Santa Cruz Island. Map *in* D. W. Weaver, D. P. Doerner, and B. Nolf, editors. Geology of the northern Channel Islands, southern California borderland. American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Section, Upland, California. Scale 1:24,000.
- GMAP 75156: Sonneman, H., D. Weaver, D. Doerner, F. Avila, and anonymous authors. 1969. Geology of Santa Rosa Island. Map *in* D. W. Weaver, D. P. Doerner, and B. Nolf, editors. Geology of the northern Channel Islands, southern California borderland. American Association of Petroleum Geologists and Society of Economic Paleontologists and Mineralogists, Pacific Section, Upland, California. Scale 1:24,000.
- GMAP 76115: Schmidt, K. M., S. A. Minor, and D. R. Bedford. In prep. (2018 version). Quaternary surficial geologic map of Anacapa Island, Channel Islands National Park, California. U.S. Geological Survey, Reston, Virginia. Unpublished Scientific Investigations Map SIM-xxxx. Scale 1:12,000.
- GMAP 76283: Schmidt, K. M., S. A. Minor, and D. R. Bedford. In prep. (2020 version). Quaternary surficial geologic map of Santa Barbara Island, Channel Islands National Park, California. U.S. Geological Survey, Reston, Virginia. Unpublished Scientific Investigations Map SIM-xxxx. Scale 1:12,000.

- GMAP 76114: Schmidt, K. M., S. A. Minor, and D. R. Bedford. In prep. (2018 version). Quaternary surficial geologic map of Santa Barbara Island, Channel Islands National Park, California. U.S. Geological Survey, Reston, Virginia. Unpublished Scientific Investigations Map SIM-xxxx. Scale 1:12,000.
- GMAP 76115: Schmidt, K. M., S. A. Minor, and D. R. Bedford. In prep. (2019 version). Quaternary surficial geologic map of Santa Cruz Island, Channel Islands National Park, California. U.S. Geological Survey, Reston, Virginia. Unpublished Scientific Investigations Map SIM-xxxx. Scale 1:12,000. (GRI Source Map ID 76115).
- GMAP 76116: Schmidt, K. M., S. A. Minor, and D. R. Bedford. In prep. (2019 version). Quaternary surficial geologic map of Santa Rosa Island, Channel Islands National Park, California. U.S. Geological Survey, Reston, Virginia. Unpublished Scientific Investigations Map SIM-xxxx. Scale 1:12,000.

SAMO

- GMAP 76065: Campbell, R. H., C. J. Wills, P. J. Irvine, and B. J. Swanson. (digital preparation by C. I. Gutierrez and M. D. O'Neal). 2014. Preliminary geologic map of the Los Angeles 30' x 60' Quadrangle, California (version 2.0). California Geological Survey, Sacramento, California and the U.S. Geological Survey, Reston, Virginia. Scale 1:100,000.
- GMAP 74950: Tan, S. S., K. B. Clahan, C. S. Hitchcock, C. I. Gutierrez, and M. T. Mascorro. 2004. Geologic map of the Camarillo 7.5-minute Quadrangle, Ventura County, California (version 1.0). California Geological Survey, Sacramento, California. Preliminary Geologic Map. Scale 1:24,000.
- GMAP 75634: Wills, C. J., R. H. Campbell, and P. J. Irvine. 2012. Geologic map database of the Santa Monica Mountains region, Los Angeles and Ventura Counties, California. California Geological Survey, Sacramento, California. Unpublished. Scale 1:24,000.
- GMAP 75623: Irvine, P. J., and T. P. McCrink. 2012. Landslide inventory of the Santa Monica Mountains region, Los Angeles and Ventura Counties, California. California Geological Survey, Sacramento, California, Unpublished. Scale 1:24,000.

Appendix B: Geologic Time Scale



Ma=Millions of years old. **Bndy Age**=Boundary Age. Layout after 1999 Geological Society of America Time Scale (https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf). Dates after Gradstein et al. (2020).

NPS 963/176694, 342/176694, 159/176694, 638/176694, July 2021

National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science
1201 Oakridge Drive, Suite 150
Fort Collins, CO 80525