National Park Service
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Natural Resource Stewardship and Science

National Park Service Geologic Type Section Inventory

Mojave Desert Inventory & Monitoring Network

Natural Resource Report NPS/MOJN/NRR—2021/2340

ON THE COVER

Type locality exposures of the Bonanza King Formation located in Mojave National Preserve at the former Bonanza King mine (MICHAEL WOLF).

National Park Service Geologic Type Section Inventory

Mojave Desert Inventory & Monitoring Network

Natural Resource Report NPS/MOJN/NRR—2021/2340

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Executive Summary

A fundamental responsibility of the National Park Service (NPS) 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 may threaten or influence their stability and preservation.

There are several different categories of geologic or stratigraphic units (supergroup, group, formation, member, bed) that represent a hierarchical system of classification. The mapping of stratigraphic units involves the evaluation of lithologies, bedding properties, thickness, geographic distribution, and other factors. Mappable geologic units 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 or exposure area of the unit is designated as the type section or other category of stratotype (see "Definitions" below). The type section is an important reference exposure for a named geologic unit which presents a relatively complete and representative example for this unit. Geologic stratotypes are important both historically and scientifically, and should be available for other researchers to evaluate in the future.

The inventory of all geologic stratotypes throughout the 423 units of the NPS is an important effort in documenting these locations in order that NPS staff recognize and protect these areas for future studies. The focus adopted for completing the baseline inventories throughout the NPS was centered on the 32 inventory and monitoring networks (I&M) 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 (e.g., geology, hydrology, climate), biological resources (e.g., 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 such as inventory, monitoring, research, and 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 planning team from the NPS Geologic Resources Division who proposed and designed this inventory selected the Greater Yellowstone Inventory & Monitoring Network (GRYN) as the pilot network for initiating this project. Through the research undertaken to identify the geologic stratotypes within the parks of the GRYN methodologies for data mining and reporting on these resources were established. Methodologies and reporting adopted for the GRYN have been used in the development of this report for the Mojave Desert Inventory & Monitoring Network (MOJN).

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 MOJN shows there are currently no designated stratotypes for Joshua Tree National Park (JOTR) or Manzanar National Historic Site (MANZ); Death Valley National Park (DEVA) has 13 type sections, 23 type localities, two type areas, and seven reference sections; Great Basin National Park (GRBA) has one type section and five type localities; Lake Mead National Recreation Area (LAKE) has two type localities; Mojave National Preserve (MOJA) has two type localities; and the NPS-administered portion of Grand Canyon-Parashant National Monument (PARA) has two type sections.

This report ends 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.

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Dedication

This Mojave Desert Inventory & Monitoring Network Geologic Type Section Inventory is dedicated to Allen Calvert, Mojave Desert Network Program Manager. Allen has been a tremendous support to the NPS Paleontology Program and the NPS Geologic Resources Division on a number of network park projects and served as the peer review coordinator for various park resource inventory reports. We extend our appreciation to Allen for his many contributions to the National Park Service.

Allen Calvert, Mojave Desert Network Program Manager.

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 I&M 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 re-examined, and can serve as teaching sites for students (Brocx et al. 2019). The geoheritage significance of stratotypes is analogous to 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 mentioned in this report.

This geologic type section inventory for the parks of the Mojave Desert Inventory & Monitoring Network (MOJN) 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 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 whether a particular type section is geographically located within or outside NPS administered boundaries. Below are the primary considerations that warrant 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 topographic or geologic features and landmarks that are recognizable to park staff;
- Geologic stratotypes are both historically and scientifically important components of earth science investigations and mapping. Geologic stratotypes are similar in nature to type specimens in biology and paleontology, serving as the primary reference for defining distinctive characteristics and establishing accurate comparisons;
- Understanding and interpreting the geologic record depends upon 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 stratotypes within NPS areas have not been previously inventoried and there is a general absence of baseline information for this geologic resource category;
- NPS staff may not be aware of the concept of geologic stratotypes and therefore would not understand the significance or occurrence of these natural references in the parks;
- Given the importance of geologic type sections as geologic references 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 stratotypes within parks, the NPS would be unable to proactively monitor the stability, condition, or potential impacts to these locations during normal park operations or planning. This also prevents the protection of these localities from activities which may involve ground disturbance or construction.
- This inventory can inform important conversations on whether geologic stratotypes 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 which 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 stratotypes are preserved and available for future study.

Geology and Stratigraphy of the MOJN I&M Network Parks

The Mojave Desert Inventory & Monitoring Network (MOJN) consists of seven national park units in southern California, Nevada, and northwestern Arizona (Figure 1). These parks include: Death Valley National Park (DEVA), Great Basin National Park (GRBA), Joshua Tree National Park (JOTR), Lake Mead National Recreation Area (LAKE), Manzanar National Historic Site (MANZ), Mojave National Preserve (MOJA), and Grand Canyon-Parashant National Monument (PARA). Additionally, there are two units geographically within the MOJN that were established after the creation of the Inventory & Monitoring program: Castle Mountains National Monument (CAMO) and Tule Springs Fossil Beds National Monument (TUSK). We are including them in this report as appropriate, although they are not officially considered I&M parks.

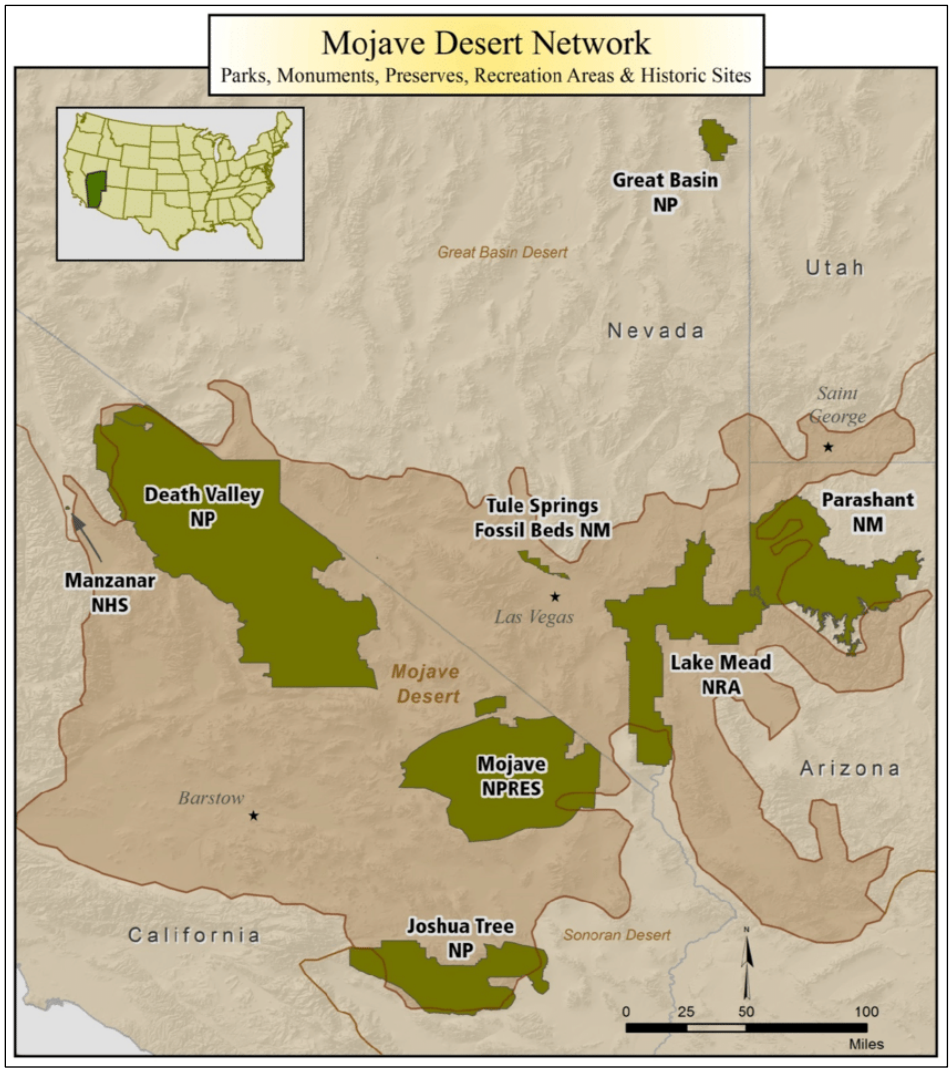


Figure 1. Map of Mojave Desert Network parks including: Death Valley National Park (DEVA), Great Basin National Park (GRBA), Joshua Tree National Park (JOTR), Lake Mead National Recreation Area (LAKE), Manzanar National Historic Site (MANZ), Mojave National Preserve (MOJA), Grand Canyon-Parashant National Monument (PARA), and Tule Springs Fossil Beds National Monument (TUSK) (NPS).

Most of the parks in the MOJN are located within or very near the Mojave Desert, hence the name of the network. GRBA is the major outlier. The Mojave Desert is related to the Great Basin physiographic province and the Basin and Range tectonic province. The desert overlaps the southern part of the Great Basin, known for its internal drainage. In turn, the Mojave Desert and Great Basin overlap a significant part but not all of the Basin and Range tectonic province. The Basin and Range tectonic province is characterized by high elevation fault-block mountain chains and intermountain flat-lying basins that began to develop during the early Miocene. Among these basins, the lowest elevation point in the United States is recorded at Badwater in DEVA. The MOJN also includes a small portion of the southwestern Colorado Plateau, where PARA is located.

Geologically, the MOJN parks collectively preserve an extensive rock record spanning from the Paleoproterozoic through the Holocene (see Appendix B for a geologic time scale). A complex geologic history includes marine and terrestrial sedimentary rocks, extrusive and intrusive igneous rocks and metamorphic rocks. The geologic features and processes of the Basin and Range province present iconic and scenic landscapes within the MOJN parks.

Precambrian

Rocks of Precambrian age (in the informal sense of "older than the Cambrian") are well exposed and documented within several parks of the MOJN and span much of the Proterozoic Eon. Paleoproterozoic and Mesoproterozoic igneous and metamorphic rocks occur at CAMO, DEVA, JOTR, LAKE and MOJA. The Neoproterozoic is represented in DEVA, from oldest to youngest, by the Pahrump Group, Johnnie Formation, Sterling Quartzite and the lower portion of the Wood Canyon Formation. At GRBA the Neoproterozoic units include the McCoy Creek Group and the lower portion of the Prospect Mountain Quartzite. At MOJA, pre-Johnnie Formation sedimentary rocks, Johnnie Formation, Stirling Quartzite and the lower portion of the Wood Canyon Formation are Neoproterozoic in age.

Paleozoic

The Paleozoic is well represented throughout the parks of the MOJN. The transition between Proterozoic and early Cambrian is preserved in several parks of the network. The Cambrian marks a worldwide event in the history of life referred to as the "Cambrian Explosion". This transition is marked by an abundant fossil record preserved with the first organisms incorporating calcium carbonate exoskeletons. The Waucoban Series in DEVA was studied and defined by paleontologist Charles Walcott during the late 1890s, and is the reference section for this earliest Cambrian diversification of life. A large number of early Cambrian units are mapped in DEVA, including the Wood Canyon Formation, Zabriskie Quartzite, Poleta Formation, and other units. The Wood Canyon Formation and Zabriskie Quartzite are also mapped in MOJA, along with the Latham Shale and other early Cambrian units. The Prospect Mountain Quartzite marks the Proterozoic–Cambrian transition at GRBA.

The early–middle Cambrian is preserved by the Tapeats Sandstone in LAKE. The middle Cambrian Bright Angel Shale and Muav Limestone are mapped in both LAKE and PARA. At DEVA, the middle Cambrian is represented by the Carrara and Bonanza King Formations. The Bonanza King Formation is also present in MOJA. The late Cambrian Nopah Formation is exposed in DEVA and

MOJA. At GRBA the late Cambrian is represented by several formations including the House Limestone which spans into the Early Ordovician.

At DEVA, GRBA, and LAKE the Early and Middle Ordovician are recorded in the Pogonip Group. The Eureka Quartzite dates to the Late Ordovician at DEVA and GRBA.

The Silurian is documented in the Ely Springs Dolomite and Hidden Valley Dolomite within DEVA. There are also some unnamed Silurian rocks on Bullfrog Mountain in DEVA.

The Hidden Valley Formation extends into the Early Devonian in DEVA. The Lost Burro Formation spans the Early to Late Devonian at DEVA. The Early Devonian at GRBA is marked by the Sevy Dolomite, overlain by the Simonson Dolomite and Guilmette Formation. Middle to Late Devonian units include the Sultan Formation, mapped in western LAKE and MOJA, and the Temple Butte Formation, mapped in eastern LAKE and PARA.

Mississippian-age rocks are preserved in DEVA, LAKE, MOJA and PARA. The Early Mississippian is mapped in DEVA with the Tin Mountain Limestone. The Early–Middle Redwall Limestone occurs within LAKE and PARA. At MOJA the Monte Cristo Formation represents the Early–Middle Mississippian. The Perdido Group, Learning Rock Formation and Mexican Spring Formation mark the Early and Middle Mississippian in DEVA, and the Rest Spring Shale and Indian Springs Formation mark the Late Mississippian. At LAKE and PARA several Late Mississippian formations of the Supai Group are mapped and extend into the Pennsylvanian. The Pennsylvanian at DEVA and MOJA is represented by the Bird Spring Formation.

The early Permian is exposed in four MOJN parks: DEVA, LAKE, MOJA, and PARA. The Bird Spring Formation spans from the Pennsylvanian into the early Permian in DEVA and MOJA. The Keeler Canyon Formation also extends from the Pennsylvanian into the Permian at DEVA. Additional early Permian units at DEVA include the Osborne Canyon Formation, Darwin Canyon Formation, Lone Pine Formation, Upland Valley Limestone, and Owens Valley Group. At LAKE and PARA the early Permian is represented by the Pakoon Limestone, Esplanade Sandstone, Hermit Shale, Coconino Sandstone, Toroweap Formation, and Kaibab Limestone.

Mesozoic

The oldest Mesozoic unit known in the MOJN parks is the Early–Middle Triassic Moenkopi Formation which is mapped in LAKE, MOJA and PARA. Unnamed Middle Triassic intrusive igneous rocks occur at JOTR. The Late Triassic Chinle Formation is exposed in LAKE and PARA.

The Butte Valley Formation at DEVA is an Early Jurassic marine unit. The Early Jurassic Moenave and Kayenta Formations are mapped in LAKE and PARA. The Early Jurassic Aztec Sandstone is mapped in two of the MOJN parks, LAKE and MOJA, while the time-equivalent Navajo Sandstone is mapped in PARA, the Colorado Plateau park. A variety of Jurassic intrusive rocks occur within GRBA, JOTR, and MOJA.

The McCoy Mountains Formation is a possible Early Cretaceous unit in JOTR. Late Cretaceous igneous rocks, both intrusive and extrusive, are mapped at DEVA, GRBA, JOTR, LAKE, and MOJA.

Cenozoic

The oldest Paleogene units in the MOJN include the late Eocene through early Oligocene Titus Canyon Formation at DEVA. At GRBA igneous dikes, sills and a biotite granite are referenced to be either Eocene or Oligocene in age. Additionally, rhyodacite flows and subvolcanic intrusive rocks at GRBA are reported to date to the early Oligocene. The Ubehebe Formation in DEVA spans from the late Oligocene to the early Miocene. Additionally, the Rainbow Gardens Formation in PARA is a late Oligocene to early Miocene unit.

The Miocene, especially the late Miocene, is well represented by rock units in the MOJN parks. The oldest known Miocene unit is the Horse Spring Formation at LAKE which spans the early to middle Miocene with several members. Early Miocene tuffs and unnamed sedimentary rocks are also found at MOJA. During the middle to late Miocene there was both extrusive and intrusive igneous activity as evidenced by rocks exposed within CAMO, LAKE, MOJA and PARA. A number of middle to late Miocene formations are mapped in DEVA including the Artist Drive, Eagle Mountain, and Furnace Creek Formations. The Hualapai Limestone and Muddy Creek Formation are mapped in LAKE. Additionally, the “Rocks of the Overton Arm” and the “Rocks of the Grand Wash Trough” span the middle and late Miocene at LAKE. The “Rocks of the Grand Wash Trough” also occur at PARA. The Cima volcanic field at MOJA became active during the late Miocene.

Pliocene rocks include a number of named formations in DEVA including the Greenwater Volcanics, Copper Canyon Formation, and Funeral Formation, along with a variety of volcanic units. At LAKE the Pliocene is represented by the Bouse Formation, along with the “Deposits of Hualapai Wash” and Deposits at Jumbo Pass”. A number of unnamed Pliocene units occur in MOJN parks.

Quaternary

Quaternary units, many currently unnamed, are found throughout the MOJN parks including DEVA, JOTR, LAKE, MOJA, and TUSK. The early Pleistocene Confidence Hills and Mormon Point formations occur within DEVA, along with various volcanic flows, tuffs, and unnamed or informally named units (e.g., Rogers Beds). Following a hiatus, the Cima volcanic field of MOJA resumed activity in the Pleistocene. The informal Pinto Formation at JOTR and Las Vegas Formation at TUSK are important sources of Pleistocene vertebrate fossils.

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 MOJN parks: DEVA on February 12, 2002; LAKE on February 13, 2002; PARA on April 28, 2003; MANZ on April 28–May 1, 2003, MOJA on April 30, 2003; JOTR on May 1, 2003; GRBA on September 17–19, 2003; and TUSK on July 14–15, 2015.

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 GRBA and MANZ. 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 MOJN 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 which 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 MOJN 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 dataset 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 MOJN 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 JOTR was compiled using data model version 2.3, which is available at https://www.nps.gov/articles/gri-geodatabase-model.htm; the DEVA, GRBA, LAKE, MANZ, MOJA, TUSK, and PARA data are based on older data models 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 DEVA, GRBA, JOTR, LAKE, MANZ, MOJA, PARA, or TUSK from the unit list.

The following components are part of the dataset:

- 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 upon 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 of the MOJN. 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 MOJN, but also to other inventory and monitoring networks and parks.

There are several considerations for 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 which limits the information contained within 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 which transcend state boundaries. Geologic formations and other units which cross state boundaries may be referenced with different names in each of the states the units are mapped. An example would be the Triassic Chugwater Formation in Wyoming, which is 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 the 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 may not have a background in geology. Therefore, this document is 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).

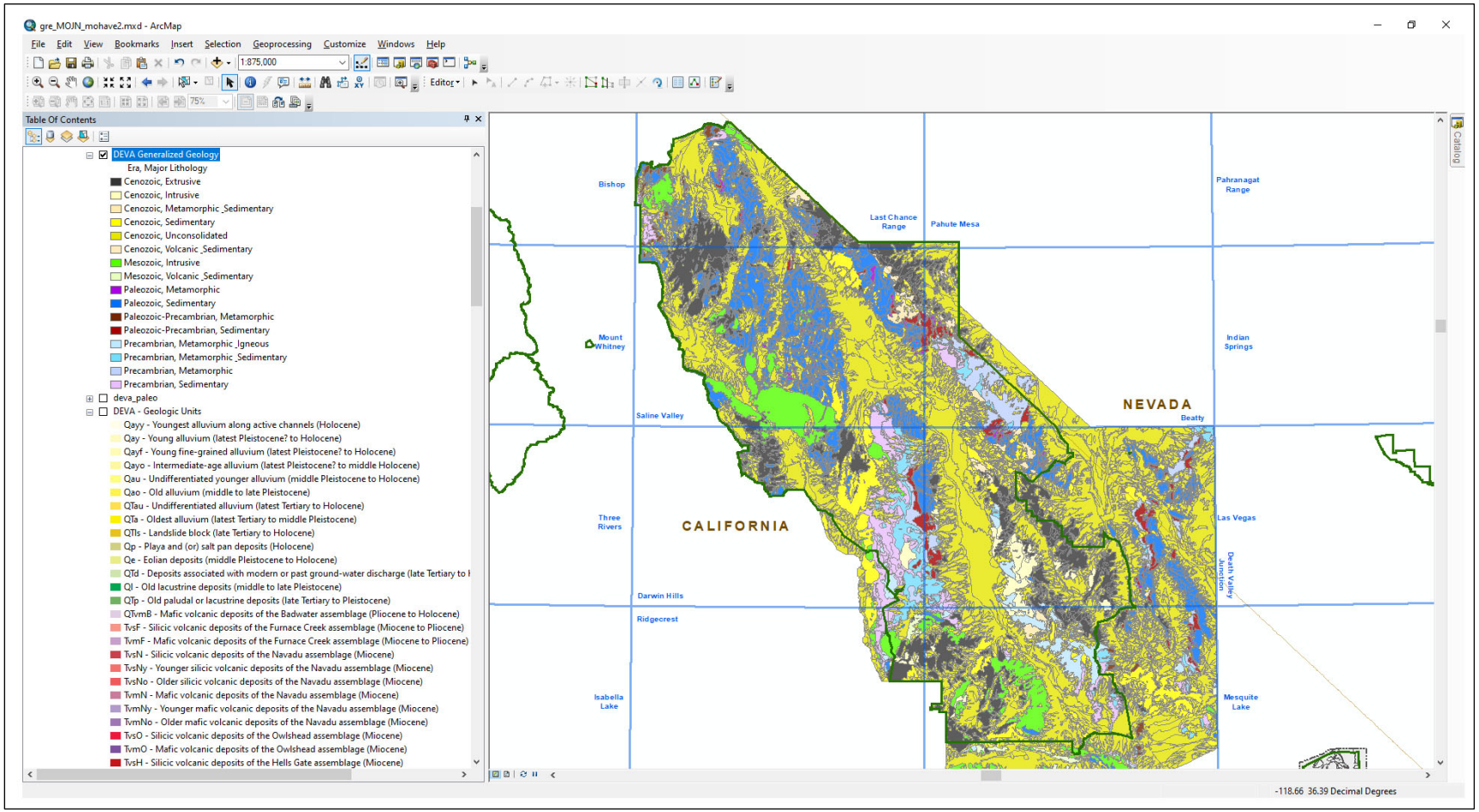


Figure 2. Screenshot of digital bedrock geologic map of Death Valley National Park showing mapped units.

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, and 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 Santa Rosa Hills Limestone.

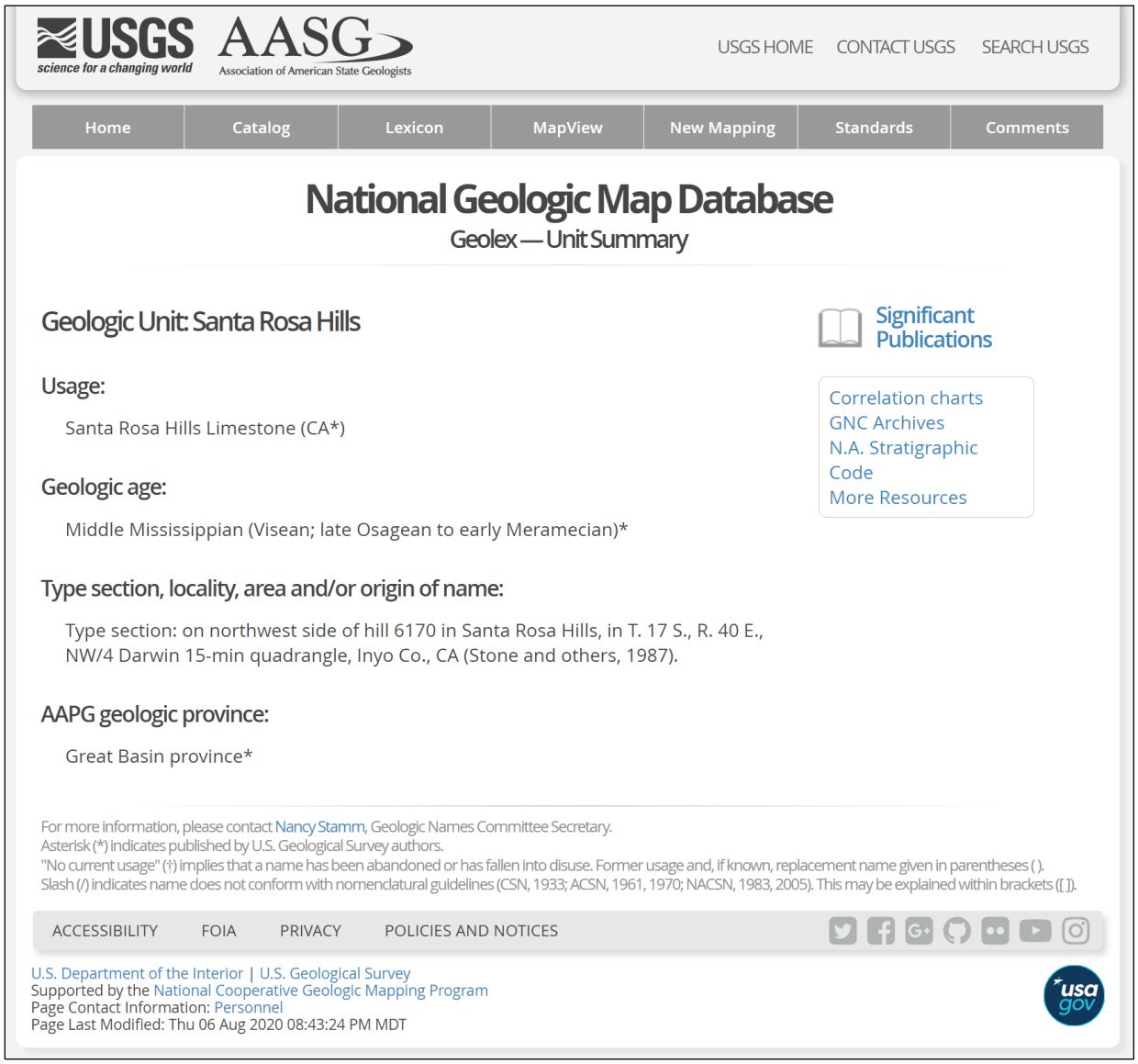
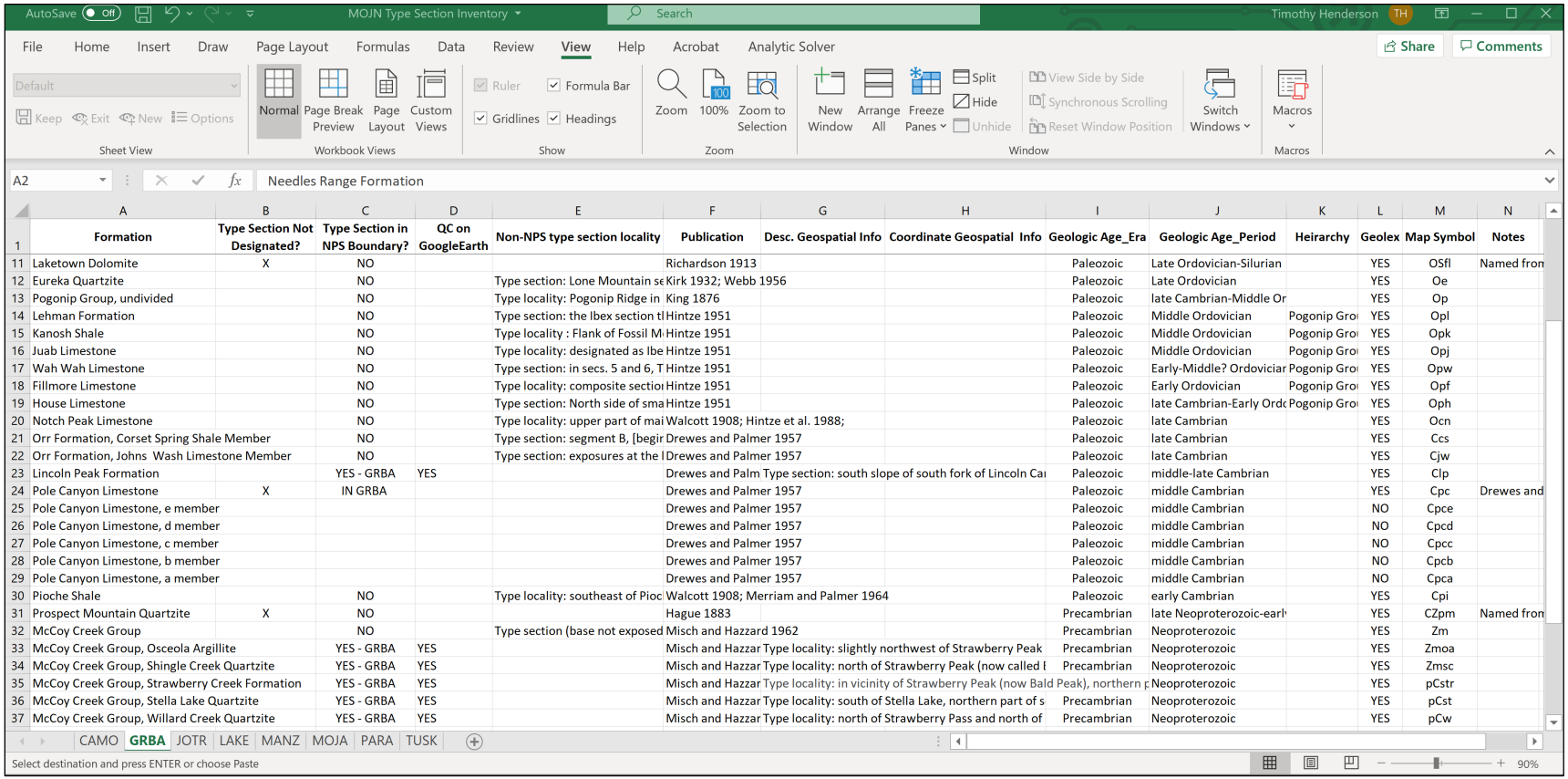


Figure 3. GEOLEX search result for Santa Rosa Hills Limestone unit.

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). They are typically presented in an abbreviated format such as "sec. [#], T. [#] [N. or S.], R. [#] [E. or W.]". 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.

Upon accurately identifying the stratotypes, 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) whether a stratotype is officially designated; (2) whether the stratotype is on NPS land; (3) whether the stratotype location has 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) whether the geologic unit was listed in GEOLEX; and (10) a generic notes field (Figure 4).



	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
11	Laketown Dolomite	X	NO			Richardson 1913			Paleozoic	Late Ordovician-Silurian		YES	OSfl	Named fron
12	Eureka Quartzite		NO		Type section: Lone Mountain se	Kirk 1932; Webb 1956			Paleozoic	Late Ordovician		YES	Oe	
13	Pogonip Group, undivided		NO		Type locality: Pogonip Ridge in	King 1876			Paleozoic	late Cambrian-Middle Or		YES	Op	
14	Lehman Formation		NO		Type section: the Ibex section tl	Hintze 1951			Paleozoic	Middle Ordovician	Pogonip Grou	YES	Opl	
15	Kanosh Shale		NO		Type locality : Flank of Fossil M	Hintze 1951			Paleozoic	Middle Ordovician	Pogonip Grou	YES	Opk	
16	Juab Limestone		NO		Type locality: designated as Ibe	Hintze 1951			Paleozoic	Middle Ordovician	Pogonip Grou	YES	Opj	
17	Wah Wah Limestone		NO		Type section: in secs. 5 and 6, T	Hintze 1951			Paleozoic	Early-Middle? Ordoviciar	Pogonip Grou	YES	Opw	
18	Fillmore Limestone		NO		Type locality: composite sectio	Hintze 1951			Paleozoic	Early Ordovician	Pogonip Grou	YES	Opf	
19	House Limestone		NO		Type section: North side of sma	Hintze 1951			Paleozoic	late Cambrian-Early Ordo	Pogonip Grou	YES	Oph	
20	Notch Peak Limestone		NO		Type locality: upper part of mai	Walcott 1908; Hintze et al. 1988;			Paleozoic	late Cambrian		YES	Ocn	
21	Orr Formation, Corset Spring Shale Member		NO		Type section: segment B, [begir	Drewes and Palmer 1957			Paleozoic	late Cambrian		YES	Ccs	
22	Orr Formation, Johns Wash Limestone Member		NO		Type section: exposures at the l	Drewes and Palmer 1957			Paleozoic	late Cambrian		YES	Cjw	
23	Lincoln Peak Formation		YES - GRBA	YES		Drewes and Palm	Type section: south slope of south fork of Lincoln Ca		Paleozoic	middle-late Cambrian		YES	Clp	
24	Pole Canyon Limestone	X	IN GRBA			Drewes and Palmer 1957			Paleozoic	middle Cambrian		YES	Cpc	Drewes and
25	Pole Canyon Limestone, e member					Drewes and Palmer 1957			Paleozoic	middle Cambrian		NO	Cpce	
26	Pole Canyon Limestone, d member					Drewes and Palmer 1957			Paleozoic	middle Cambrian		NO	Cpcd	
27	Pole Canyon Limestone, c member					Drewes and Palmer 1957			Paleozoic	middle Cambrian		NO	Cpcc	
28	Pole Canyon Limestone, b member					Drewes and Palmer 1957			Paleozoic	middle Cambrian		NO	Cpcb	
29	Pole Canyon Limestone, a member					Drewes and Palmer 1957			Paleozoic	middle Cambrian		NO	Cpca	
30	Pioche Shale		NO		Type locality: southeast of Pioc	Walcott 1908; Merriam and Palmer 1964			Paleozoic	early Cambrian		YES	Cpi	
31	Prospect Mountain Quartzite	X	NO			Hague 1883			Precambrian	late Neoproterozoic-earl		YES	CZpm	Named fron
32	McCoy Creek Group		NO		Type section (base not exposed	Misch and Hazzard 1962			Precambrian	Neoproterozoic		YES	Zm	
33	McCoy Creek Group, Osceola Argillite		YES - GRBA	YES		Misch and Hazzar	Type locality: slightly northwest of Strawberry Peak		Precambrian	Neoproterozoic		YES	Zmoa	
34	McCoy Creek Group, Shingle Creek Quartzite		YES - GRBA	YES		Misch and Hazzar	Type locality: north of Strawberry Peak (now called I		Precambrian	Neoproterozoic		YES	Zmsc	
35	McCoy Creek Group, Strawberry Creek Formation		YES - GRBA	YES		Misch and Hazzar	Type locality: in vicinity of Strawberry Peak (now Bald Peak), northern p		Neoproterozoic			YES	pCstr	
36	McCoy Creek Group, Stella Lake Quartzite		YES - GRBA	YES		Misch and Hazzar	Type locality: south of Stella Lake, northern part of s		Precambrian	Neoproterozoic		YES	pCst	
37	McCoy Creek Group, Willard Creek Quartzite		YES - GRBA	YES		Misch and Hazzar	Type locality: north of Strawberry Pass and north of		Precambrian	Neoproterozoic		YES	pCw	

Figure 4. Stratotype inventory spreadsheet of the MOJN 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 describes 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 that 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 follows:

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 principal 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 (igneous rock that solidified at great depth) or 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.

Death Valley National Park (DEVA)

Death Valley National Park (DEVA), the largest national park of the lower 48 states, is situated in the Great Basin province in California (Inyo and San Bernardino Counties) and Nevada (Esmeralda and Nye Counties) (Figure 5). The park was proclaimed a national monument on February 11, 1933 and was re-designated as a national park on October 31, 1994 (Anderson 2017). Encompassing approximately 1,365,030 hectares (3,373,063 acres), the landscape of DEVA is host to numerous mountain ranges, rock formations, sand dunes, dry lake playas, canyons, craters, desert springs, and a great diversity of life. DEVA is home to the endemic Devils Hole pupfish, a tiny desert fish protected in its desert spring habitat. The wildflower bloom is a spectacular draw for visitors to the park, especially in years where a superbloom creates carpets of flowers that decorate the horizon. The vast natural resources of DEVA are world-renowned, leading to the park being designated a Biosphere Reserve in 1984.

The geology of DEVA consists of some of the world's best surficial rock exposures that showcase complex, unique tectonics and diverse geologic resources. Contained within the boundaries of the park is an expansive rock record that stretches back over a billion years and records evidence of ancient depositional environments that include shallow seas, lakes, and volcanic fields. The vast geologic history of DEVA ranges from Mesoproterozoic (~1.8 billion years old) metamorphic rocks exposed in the Black Mountains to recent playa sediments found in the valley basins (Figure 6). Plate tectonic and erosional processes have played a major role in shaping the rugged topography of the park and continue to do so today. Badwater Basin is the lowest point in North America at 86 m (282 ft) below sea level, yet it sits adjacent to and within the shadow of Telescope Peak at 3,368 m (11,049 ft) due to regional extensional faulting that causes the basins to sink and mountains to rise.

DEVA contains 45 identified stratotypes (Table 1) that are subdivided into 13 type sections (Figure 7), 23 type localities (Figure 8), two type areas (Figure 9), and seven reference sections (Figure 10).

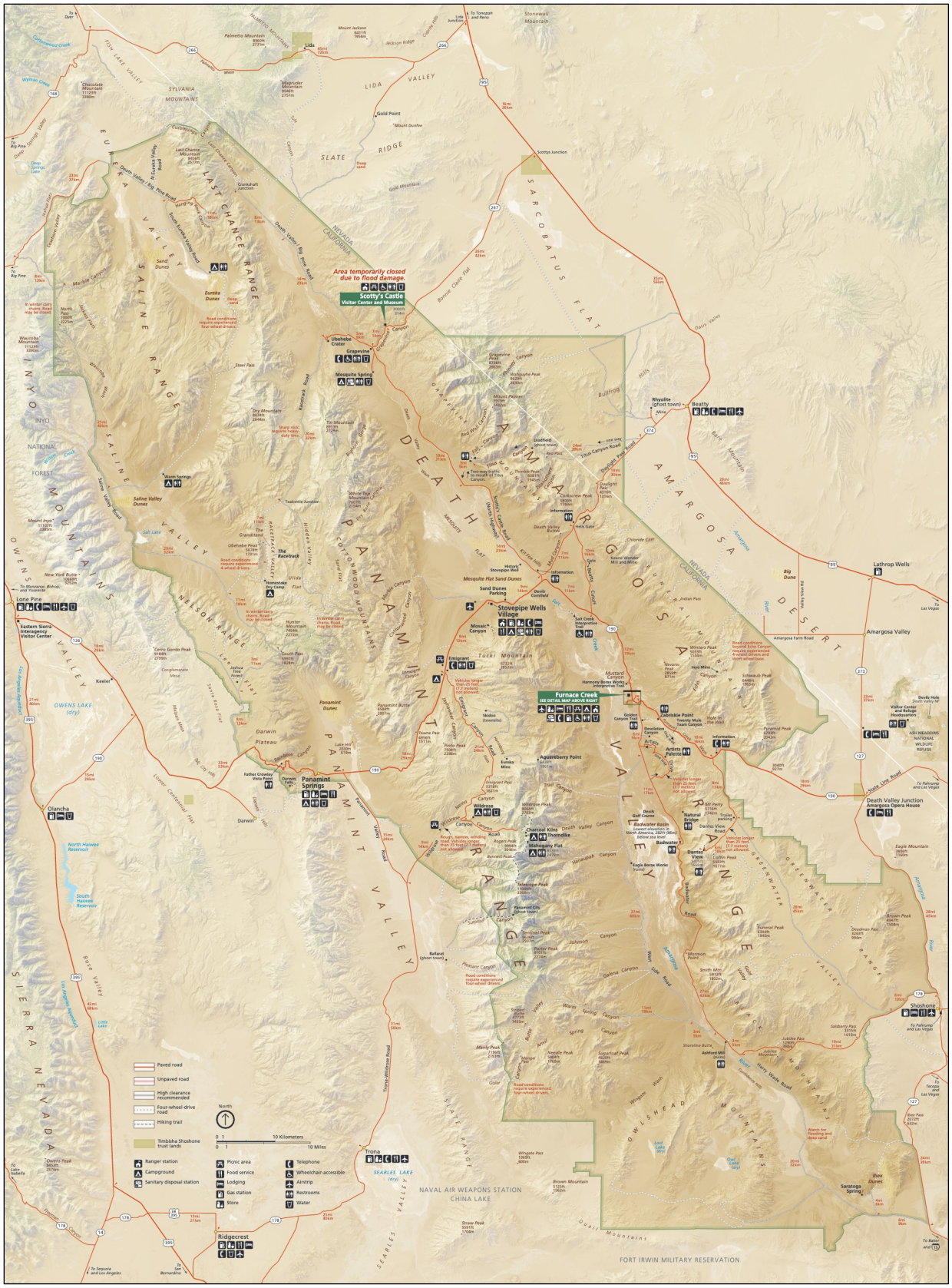


Figure 5. Park map of DEVA, California–Nevada (NPS).

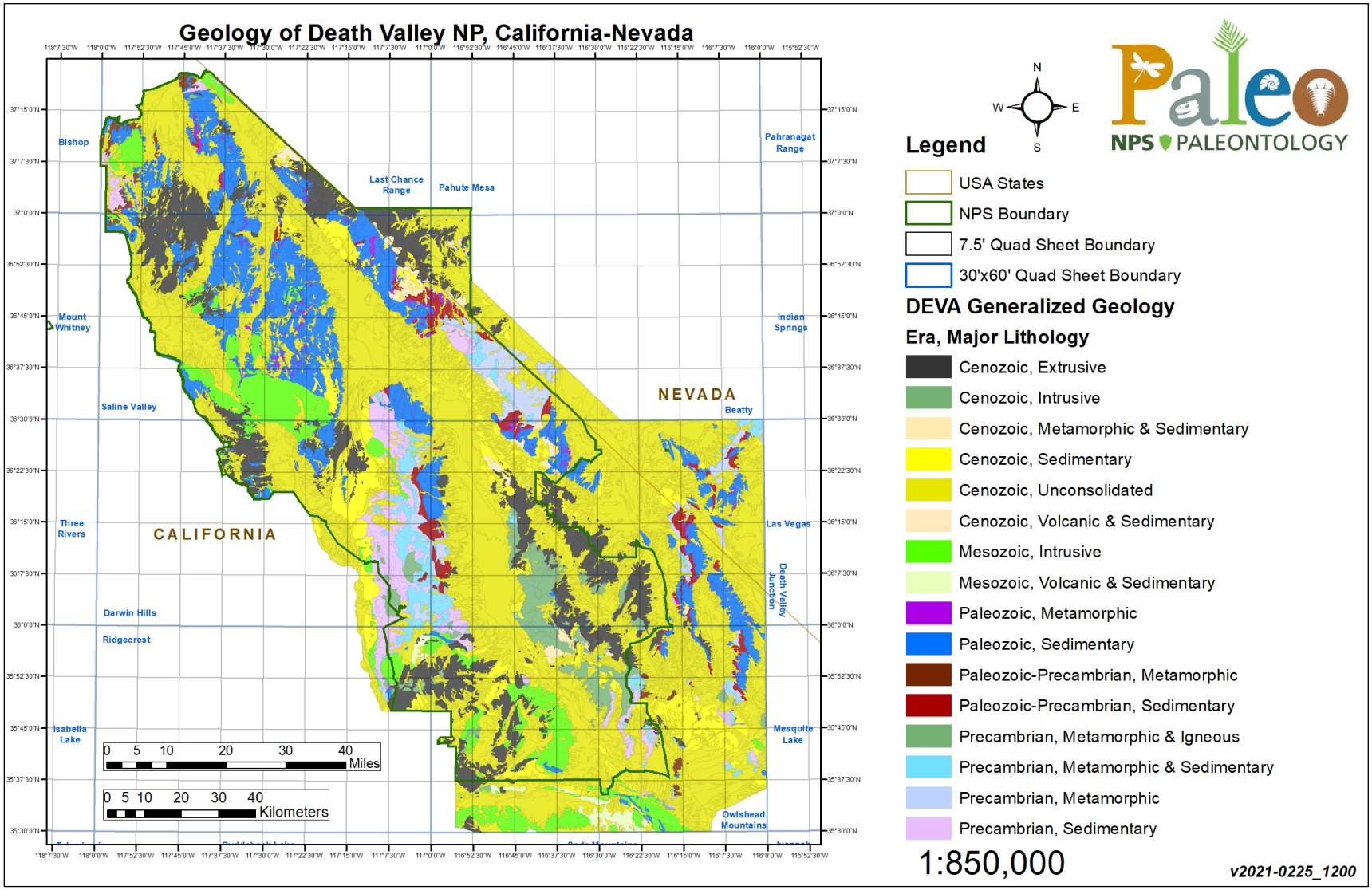


Figure 6. Generalized geologic map of DEVA, California. Units are lumped by time and type of rock for simplicity.

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

Unit Name (map symbol)	Reference	Stratotype Location	Age
Mormon Point Formation (Qmp)	Knott et al. 2005	Type locality: Mormon Point, DEVA	Pleistocene
Confidence Hills Formation (QTp)	Beratan et al. 1999	Type section: canyon exposure (Canyon 1 of Beratan et al. 1999) in the Confidence Hills depositional basin	Pleistocene
Funeral Formation (QTvmB)	Noble 1941; Drewes 1963	Type locality: exposures north of Ryan, a few miles north of the Funeral Peak quadrangle	Pliocene–Pleistocene
Rhodes Tuff (TvsNo)	Wright et al. 1984a	Type section: composite of exposures extending 12 km (7.5 mi) along the lower southwest sides of Salsberry Peak and Sheephead Mountain, from Rhodes Wash eastward to Salsberry Pass in the Black Mountains, Confidence Hills, and Shoshone 15-minute Quadrangles, Inyo Co., CA	Miocene
Copper Canyon Formation	Drewes 1963	Type area: its full exposure in the basin (Copper Canyon area), which is practical in view of the excellent exposure and the rapidly changing facies and thickness of the rocks	Miocene
Furnace Creek Formation (Tfc)	Marvin and Dobson 1979; Knott et al. 2005	Type section: on northeast flank of Black Mountains, Death Valley National Monument, N36°19’53’’, W116°44’17’’W., Ryan Quadrangle, Inyo Co., CA	Miocene
Sheephead Andesite (TvmNo)	Wright et al. 1984a	Type section: composite of exposures extending 12 km (7.5 mi) along the lower southwest sides of Salsberry Peak and Sheephead Mountain, from Rhodes Wash eastward to Salsberry Pass in the Black Mountains, Confidence Hills, and Shoshone 15-minute Quadrangles, Inyo Co., CA	Miocene
Artist Drive Formation (TvmNo, Tsn)	Greene and Fleck 1997	Type area: the west face of the Black Mountains near Artist Drive	Miocene
Panuga Formation	Snow and Lux 1999	Type locality: in the Ubehebe Hills in section UH2 (N36°57.27′, W117°25.44′), northernmost Cottonwood Mountains Reference section 1: in the Marble Canyon area in section MC3 (N36°38.86′, W117°17.49′) Reference section 2: in the Marble Canyon area in section MC4 (N36°39.00′, W117°17.29′)	Miocene

Table 1 (continued). List of DEVA stratotype units sorted by age with associated reference publications and locations.

Unit Name (map symbol)	Reference	Stratotype Location	Age
Navadu Formation (TsN)	Snow and Lux 1999	Type section: (composite) located on a west-facing slope 1.0 km (0.6 mi) N310° from BM 849 in the Entrance Narrows (name applied by Johnson 1971), Marble Canyon 15′ quadrangle, eastern Cottonwood Mountains (Snow and Lux 1999) Reference section: in the Ubehebe Hills in section UH3 (117°26’7.00”W, 36°57’45.00”N) (Snow and Lux 1999)	Miocene
Lemoigne Canyon Member, Navadu Formation (TsN)	Snow and Lux 1999	Type section: (composite) located on a west-facing slope 1.0 km (0.6 mi) N310° from BM 849 in the Entrance Narrows (name applied by Johnson 1971), Marble Canyon 15′ quadrangle, eastern Cottonwood Mountains	Miocene
Entrance Narrows Member, Navadu Formation (TsN)	Snow and Lux 1999	Type section: (composite) located on a west-facing slope 1.0 km (0.6 mi) N310° from BM 849 in the Entrance Narrows (name applied by Johnson 1971), Marble Canyon 15′ quadrangle, eastern Cottonwood Mountains	Miocene
Bullfrog Tuff (TvsH)	Byers et al. 1976	Type locality: mountain north of Bullfrog Mine, Bullfrog quadrangle, Nye Co., NV	Miocene
Titus Canyon Formation	Stock and Bode 1935	Type locality: Titus Canyon, near Leadfield	Eocene
Ubehebe Formation	Snow and Lux 1999	Type locality: in the Ubehebe Hills in section UH1 and UH2, northernmost Cottonwood Mountains in the low hills lying 8.8 km (5.5 mi) N258° from Mesquite Spring, Tin Mountain 15′ quadrangle Reference section 1: in the Marble Canyon area in section MC1 (N36°37.49′, W117°19.60′) Reference section 2: in the Marble Canyon area in section MC2 (N36°37.55’, W117°19.50′)	Oligocene–Miocene
Tihvipah Limestone (PNt)	McAllister 1952	Type locality: on the hill due east of Rest Spring, which is far more accessible than the exposure near Tihvipah Spring	Pennsylvanian
Rest Spring Shale (Mu)	McAllister 1952, 1956; Hunt and Mabey 1966	Type locality: on the hill due east of Rest Spring, which is far more accessible than the exposure near Tihvipah Spring	Mississippian–Pennsylvanian
Perdido Formation (Mu)	McAllister 1952, 1956	Type locality: south of Perdido Canyon, from the foot of the southern wall about 9,000 feet southeast of Quartz Spring, over the hill to the underlying Tin Mountain limestone, Inyo Co., eastern CA. Type locality is supplemented by a second locality, about 3,000 ft south of Rest Spring. Type locality is located northeast of Ubehebe quad.	Mississippian

Table 1 (continued). List of DEVA stratotype units sorted by age with associated reference publications and locations.

Unit Name (map symbol)	Reference	Stratotype Location	Age
Mexican Spring Formation (Mu)	Stevens et al. 1996	Reference section (= type section of Leaning Rock Formation): near Rest Spring in Cottonwood Mountains, about 4 km (2.5 mi) east of mouth of Perdido Canyon, between 1,878–1,902 m (6,160–6,240 ft) elevation, White Top Mountain 7.5' quadrangle, Inyo Co., eastern CA	Mississippian
Leaning Rock Formation (Mu)	Stevens et al. 1996	Type section: near Rest Spring in Cottonwood Mountains, about 4 km (2.5 mi) east of mouth of Perdido Canyon, between 6,160 and 6,240 ft elevation, White Top Mountain 7.5' quadrangle, Inyo Co., eastern CA.	Mississippian
Stone Canyon Limestone	Stevens et al. 1995, 1996	Reference section: in Cottonwood Canyon, Cottonwood Mountains, Cottonwood Canyon quadrangle, Inyo Co., eastern CA	Mississippian
Tin Mountain Limestone (Mu)	McAllister 1952, 1956	Type locality: the southern slope of the hills about 4 km (2.5 mi) southeast of Quartz Spring and about 914 m (3,000 ft) north of the road to Rest Spring	Mississippian
Santa Rosa Hills Limestone (Mu)	Dunne et al. 1981	Type section: on northwest side of hill 6170 in Santa Rosa Hills, Darwin 15' quadrangle, Inyo Co., CA	Mississippian
Lee Flat Limestone	Hall and MacKevett 1958, 1962	Type locality: in Lee Flat, where the formation trends southward from an altitude of 1,609 m (5,280 ft) near the top of the prominent hill 1.4 km (0.9 mi) S. 36° E. of the main shaft of the Lee mine to the contact with alluvium at the foot of the hill at an altitude of 1,524 m (5,000 ft)	Mississippian
Lost Burro Formation (Dlb)	McAllister 1952, 1956; Hunt and Mabey 1966	Type locality: on the western side of Lost Burro gap at the southern entrance	Devonian
Quartz Spring Sandstone Member, Lost Burro Formation (Dlb)	Langenheim and Tischler 1960	Type locality: exposures below type section of Tin Mountain limestone which is on southern slope of hills about 4 km (2.5 mi) southeast of Quartz Spring, Inyo County, and about 914 m (3,000 ft) north of road to Rest Spring	Devonian
Lippincott Member, Lost Burro Formation (Dlb)	McAllister 1955; Hall and MacKevett 1962	Type locality: in the Andy Hills east of Hidden Valley about 11.3 km (7 mi) northeast of the Lippincott mine	Devonian
Hidden Valley Dolomite (DShv)	McAllister 1952, 1956; Hunt and Mabey 1966	Type locality: on the eastern flank of an unnamed mountain about 4 km (2.5 mi) north of Ubehebe Peak, and about 1.2 km (0.75 mi) west of the road in Racetrack Valley	Silurian–Devonian

Table 1 (continued). List of DEVA stratotype units sorted by age with associated reference publications and locations.

Unit Name (map symbol)	Reference	Stratotype Location	Age
Racetrack Dolomite	McAllister 1952, 1956	Type locality: in the Last Chance foothills on the western side of Racetrack Valley, about 4.8 km (3 mi) west of Quartz Spring. More precisely, the type locality extends from the southern tip of the spur west of the Hidden Valley road junction, for roughly 2,134 m (7,000 ft) to the saddle north of the U.S. Geological Survey benchmark at 1,625 m (5,330 ft) above sea level.	Cambrian
Red Pass Limestone Member, Carrara Formation (Cnbc, Cc)	Reynolds 1971; Palmer and Halley 1979	Type locality: Red Pass, about 1 km (0.6 mi) east of the Titanothere Canyon section, in the Grapevine Mountains, CA	Cambrian
Pyramid Shale Member, Carrara Formation (Cnbc, Cc)	Palmer and Halley 1979	Type locality: the west base of Pyramid Peak in the Funeral Mountains, CA	Cambrian
Echo Shale Member, Carrara Formation (Cnbc, Cc)	Palmer and Halley 1979	Type locality: exposures at the “Narrows” of Echo Canyon	Cambrian
Thimble Limestone Member, Carrara Formation (Cnbc, Cc)	Palmer and Halley 1979	Type locality: on the west side of Titanothere Canyon, below Thimble Peak from which its name is derived, in the Grapevine Mountains, CA	Cambrian
Mule Spring Formation (Cms)	Nelson 1962	Type section: along east end of Walcott’s (1908) Waucoba Spring section, east of Waucoba Springs, on Saline Valley road, east of Inyo Range, Inyo Co., central CA.	Cambrian
Saline Valley Formation (Csv)	Nelson 1962	Type section: exposures along the Waucoba Spring section of Walcott (1908), overlooking Saline Valley to the south. The Waucoba section is located east of Waucoba Springs, on Saline Valley Road, east of Inyo Range, Waucoba Spring 15’ quadrangle, Inyo Co., CA	Cambrian
Poleta Formation (Cpo)	Walcott 1908; Nelson 1962	Type section: Waucoba Spring section of Walcott (1908), on Saline Valley road, east of Inyo Range, Inyo Co., central CA. Named from exposures in Poleta Canyon on east-central edge of Bishop quadrangle (west of Blanco Mountain quadrangle), CA	Cambrian
Ibex Formation (Zn)	Wright et al. 1984b	Type section: exposures 2 km (1.2 mi) southwest of Ibex Spring and south of a jeep road that connects the spring with Buckwheat Wash to the west, immediately north of the south border of the southwestern quarter of the Shoshone 15’ quadrangle, San Bernardino Co., CA	Neoproterozoic

Table 1 (continued). List of DEVA stratotype units sorted by age with associated reference publications and locations.

Unit Name (map symbol)	Reference	Stratotype Location	Age
Mahogany Flats Member, Noonday Dolomite (Zn)	Petterson et al. 2011	Type locality: in eastern Wildrose Canyon	Neoproterozoic
Radcliff Member, Noonday Dolomite (Zn)	Petterson et al. 2011	Type locality: in eastern Wildrose Canyon	Neoproterozoic
Sentinel Peak Member, Noonday Dolomite (Zn)	Petterson et al. 2011	Type locality: in eastern Wildrose Canyon	Neoproterozoic

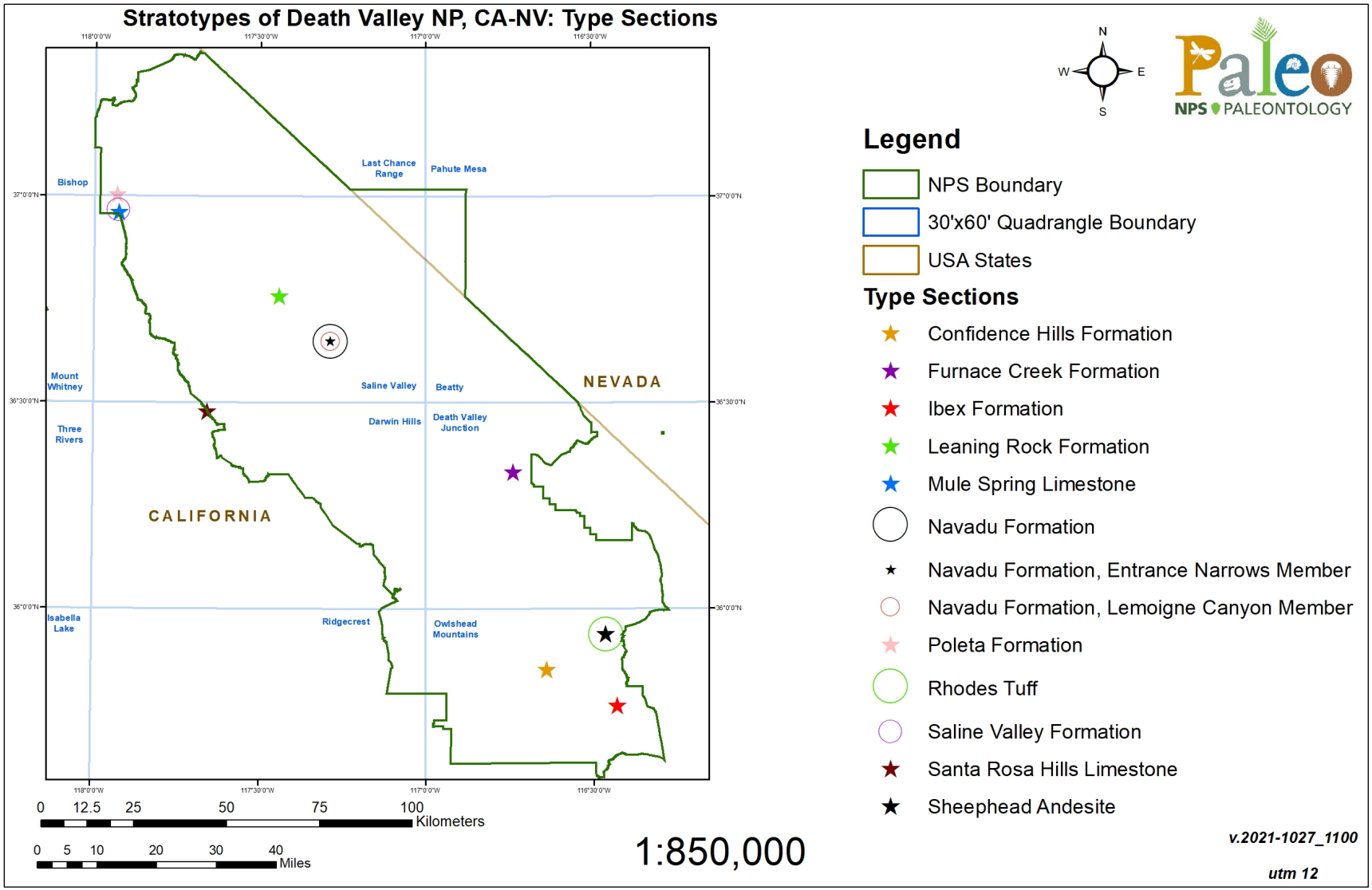


Figure 7. Map of DEVA showing type sections.

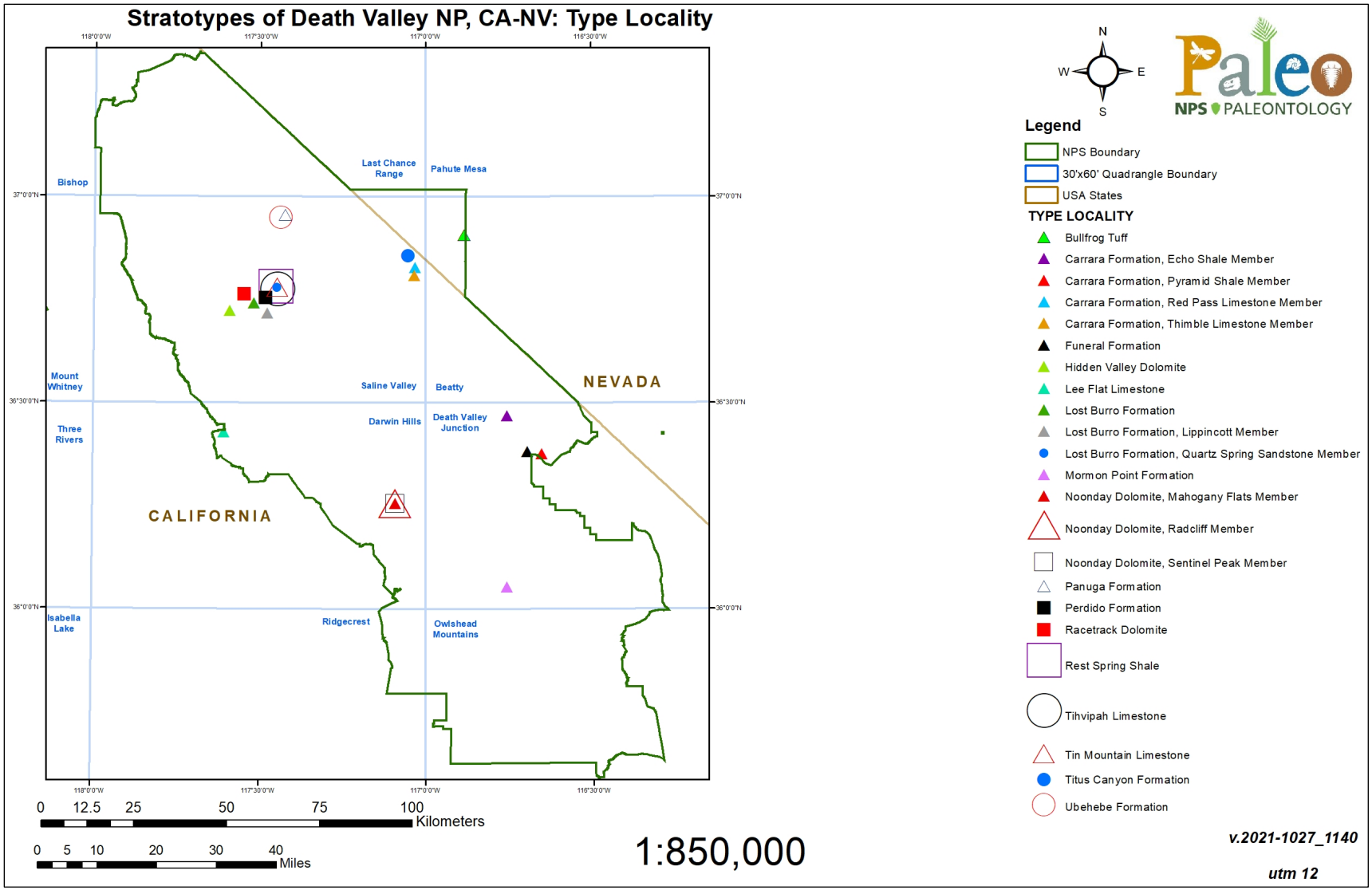


Figure 8. Map of DEVA showing type localities.

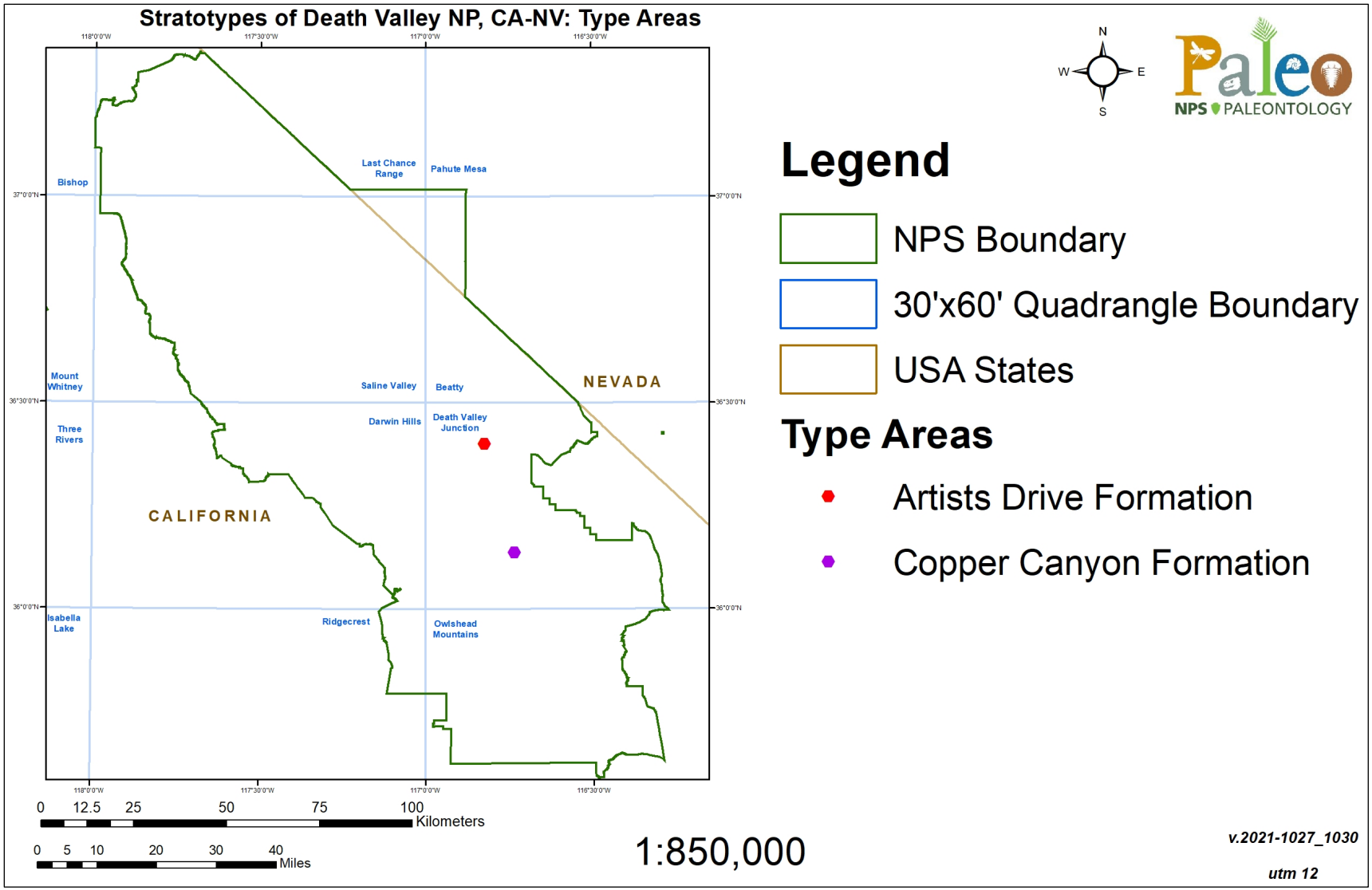


Figure 9. Map of DEVA showing type areas.

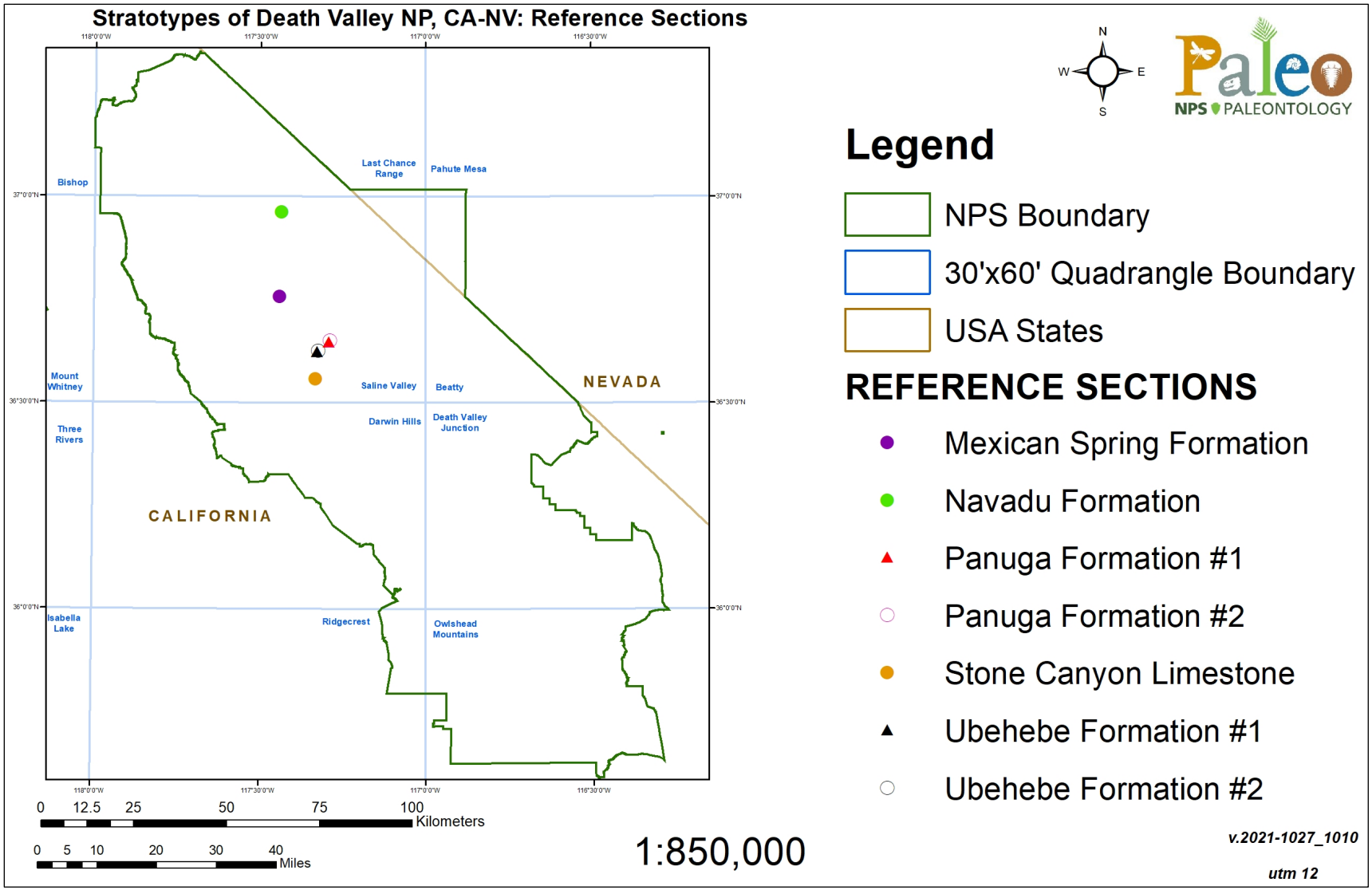


Figure 10. Map of DEVA showing reference sections.

The Neoproterozoic Sentinel Peak Member of the Noonday Dolomite was originally referred to as the Sentinel Dolomite by Murphy (1932) and named after Sentinel Peak in the southern Panamint Range. The type locality of the member is situated in eastern Wildrose Canyon, DEVA (Table 1; Figure 8; Petterson et al. 2011). Type locality exposures are several tens of meters thick and consist of finely crystalline dolostone with spar-filled irregular segregations (Petterson et al. 2011). In eastern Wildrose Canyon, the Sentinel Peak Member can be mapped continuously westward where it thins to ~15 m (49 ft) in thickness and the overlying Radcliff Member progressively onlaps and infills a paleovalley (Petterson et al. 2011). The member stratigraphically overlies the South Park Member of the Kingston Peak Formation and underlies the Radcliff Member of the Noonday Dolomite.

The Neoproterozoic Radcliff Member of the Noonday Dolomite was originally referred to as the Radcliff Formation by Murphy (1932) and re-designated as a member by Carlisle et al. (1980). The type locality of the Radcliff Member is located in eastern Wildrose Canyon, DEVA where exposures are approximately 175 m (574 ft) thick (Table 1; Figure 8; Petterson et al. 2011). At the type locality, Petterson et al. (2011) subdivided the member into two units, the lower unit containing thin-bedded limestone rhythmite (regular repeated layers) and intraformational breccia (conglomerate of angular fragments), and, in places, a lower part of variegated shale. The upper unit is composed of a basal feldspathic sandstone that can be dolomitic, and above which is a siltstone unit that contains locally coarse intraformational sediment gravity flows (Petterson et al. 2011). The Radcliff Member stratigraphically occurs between the overlying Mahogany Flats Member and underlying Sentinel Peak Member of the Noonday Dolomite.

The Neoproterozoic Mahogany Flats Member of the Noonday Dolomite was named by Petterson et al. (2011) for exposures consisting of thin- to thick-bedded, laminated to stromatolitic, fine gray dolostone. Petterson et al. (2011) designated the type locality in eastern Wildrose Canyon, where exposures are ~200 m (656 ft) thick (Table 1; Figure 8). The basal contact with the underlying Radcliff Member is abrupt. The lower beds of the Mahogany Flats Member consist of fine, stromatolitic dolostone with mounds measuring up to 10 m (39 ft) thick (Petterson et al. 2011). Approximately 45 m (148 ft) above the base is a 5 m (16 ft) thick lens of hummocky cross-stratified siltstone and sandstone that can be traced laterally for several hundred meters (Petterson et al. 2011). The uppermost beds of the member consist of cross-stratified, fine- to medium-grained sandstone.

The Neoproterozoic Ibex Formation was first regarded as the Ibex facies of the Noonday Dolomite by Troxel (1982) and re-classified as a formation by Wright et al. (1984b). The formation is named after its type locality exposures located approximately 2 km (1.2 mi) southwest of Ibex Spring and south of a jeep road that connects the spring area with Buckwheat Wash to the west (Table 1; Figure 8; Wright et al. 1984b). Estimated thickness of the formation at the type locality is approximately 200 m (656 feet). At the type locality the Ibex Formation consists of conglomerate, arkose (feldspar-rich sandstone), limestone, shaly limestone, and dolomite that overlie the Kingston Peak Formation and underlie the Johnnie Formation (Wright et al. 1984b).

The Cambrian Poleta Formation was named by Nelson (1962) after exposures in Poleta Canyon on the east-central edge of the Bishop 15' quadrangle. The type section is exposed in the Waucoba

Spring section of Walcott (1908) in eastern DEVA where the formation measures approximately 366 m (1,200 ft) thick (Table 1; Figure 7; Nelson 1962). Exposures of the Poleta Formation in the Waucoba Spring section can be divided into two members. The basal member consists of massive to thick-bedded bluish-gray limestone and dolomitized limestone that contain archaeocyathid sponges (Nelson 1962). The upper member is composed of greenish-gray shale, bluish-gray limestone, *Skolithos*-bearing quartzite (recrystallized quartz sandstone), capped by a thin bluish-gray limestone that contains archaeocyathids (Nelson 1962). The Poleta Formation overlies the Harkless Formation and underlies the Campito Formation.

The Cambrian Saline Valley Formation was designated by Nelson (1962) after its type section exposure along the Waucoba Spring section, overlooking Saline Valley to the south (Table 1; Figure 7). Thickness of the formation at the type section is approximately 259 m (850 ft) and can be divided into two members. The basal member consists of medium- to coarse-grained sandstone capped by a bluish-gray, sandy limestone, with an upper member composed of sandstone, limestone, and grayish-green and black shale (Nelson 1962). Stratigraphically, the Saline Valley Formation overlies the Harkless Formation and underlies the Mule Spring Formation.

The Cambrian Mule Spring Formation was named by Nelson (1962) after exposures at Mule Spring on the west flank of the Inyo Mountains in the Waucoba Mountain quadrangle. Nelson (1962) designated the type section exposure along the east end of the Waucoba Spring section of Walcott (1908) (Table 1; Figure 7). The Mule Spring Formation consists of predominantly massive to well-bedded bluish-gray limestones that contain *Girvanella* stromatolites and are locally interbedded with gray shale (Nelson 1962). The Mule Spring Formation overlies the Saline Valley Formation and underlies the Monola Formation.

The Cambrian Red Pass Limestone Member of the Carrara Formation was designated by Palmer and Halley (1979) after its type locality exposures at Red Pass, about 1 km (0.6 mi) east of Titanothere Canyon in the Grapevine Mountains (Table 1; Figures 8 and 11). The member is a prominent cliff-forming unit that consists of burrowed, oncolitic (spherical microbial structures), and skeletal-fragment lime mudstones, oolite, and a variety of laminated lime mudstones and fenestral (relatively large pores) limestones that form a relatively thin cap (Palmer and Halley 1979). Maximum measured thickness of the member in the type locality is 107 m (351 ft). The Red Pass Limestone Member stratigraphically occurs between the underlying Pyramid Shale Member and overlying Pahrump Hills Shale Member of the Carrara Formation.

The Cambrian Pyramid Shale Member of the Carrara Formation was named by Palmer and Halley (1979) after its type locality exposures on the west base of Pyramid Peak in the Funeral Mountains (Table 1; Figure 8). The member has a maximum measured thickness of 172 m (564 ft) and consists of green shale interbedded brown and maroon siltstone and shale with minor amounts of quartzite and limestone (Palmer and Halley 1979). Slump folds, flute casts, and bioturbated (disrupted by organisms) beds occur in the siltstone intervals. Basal shales of the member are fossiliferous and contain disarticulated and rarely complete trilobites (Palmer and Halley 1979). The Pyramid Shale Member has a sharp contact with the underlying Gold Ace Limestone Member and is overlain by the Red Pass Limestone Member of the Carrara Formation.

Figure 11. Type locality exposures of the Red Pass Limestone Member at Red Pass, between Titanothere Canyon and Titus Canyon (DANIEL PETTIT). Vehicle for scale.

The Cambrian Echo Shale Member of the Carrara Formation was designated by Palmer and Halley (1979) after its type locality exposures at the "Narrows" of Echo Canyon (Table 1; Figure 8). In the type locality the member has a maximum measured thickness of approximately 42 m (138 ft) and consists of green, platy, mica-rich shale with brown and orange limestone that are locally interbedded (Palmer and Halley 1979). The member is generally non-fossiliferous but contains a single fossil collection of the trilobite *Olenellus clarki* (Palmer and Halley 1979). Stratigraphically, the member overlies the Thimble Limestone Member and is overlain by the Gold Ace Member of the Carrara Formation.

The Cambrian Thimble Limestone Member of the Carrara Formation was designated by Palmer and Halley (1979) after its type locality exposures on the west side of Titanothere Canyon below Thimble Peak in the Grapevine Mountains (Table 1; Figures 8 and 12). The member is a widespread member of the Carrara Formation but is relatively thin and has a maximum measured thickness of 50 m (164 ft) (Palmer and Halley 1979). The Thimble Limestone Member consists of black, brown, and orange, thin-bedded, clay-rich, dolomitic limestone that contain oncolite, hyolithid, trilobite, and echinoderm fragments (Palmer and Halley 1979). The member stratigraphically occurs between the underlying Eagle Mountain Shale Member and overlying Echo Shale Member of the Carrara Formation.

Figure 12. Thimble Peak looking west (CHRIS JENTER). Type locality exposures of the Thimble Limestone Member are located just below the peak to the left in Titanothere Canyon.

The Cambrian Racetrack Dolomite was named by McAllister (1952) after its type locality exposures in the Last Chance foothills on the western side of Racetrack Valley, approximately 4.8 km (3 mi) west of Quartz Spring (Table 1; Figure 8). Type locality exposures extend about 2,134 m (7,000 ft) from the southern tip of the spur west of the Hidden Valley road junction to the saddle north of the U.S. Geological Survey benchmark at 1,625 m (5,330 ft) above sea level in the Ballarat Quadrangle (McAllister 1952). At the type locality the Racetrack Dolomite measures 579 m (1,900 ft) thick and consists of light- to dark-gray, thinly-bedded dolomite with minutely wavy bedding planes that underlie the Nopah Formation (McAllister 1952).

The Silurian–Devonian Hidden Valley Dolomite was designated by McAllister (1952) for exposures on the eastern side of Hidden Valley, approximately 4.8 km (3 mi) east-southeast from benchmark 5980 near Lost Burro Gap. The type locality of the formation is located on the eastern flank of a

nameless mountain ~4 km (2.5 mi) north of Ubehebe Peak, and about 1.2 km (0.75 mi) west of the road in Racetrack Valley (Table 1; Figure 8). Type locality exposures of the Hidden Valley Dolomite measure 416 m (1,365 ft) thick and predominantly consist of massive, medium-gray dolomite that contain considerable chert nodules and Silurian-age fossils in the basal beds (McAllister 1952). Near the upper contact of the formation is a 15 m (50 ft)-thick fossiliferous zone containing Devonian-age fossils (McAllister 1952). The formation stratigraphically occurs between the underlying Lost Burro Formation and overlying Ely Springs Dolomite.

The Devonian Lost Burro Formation was named by McAllister (1952) after exposures at Lost Burro Gap that connects Racetrack Valley to Hidden Valley. The type locality is designated on the western side of Lost Burro Gap at the southern entrance and extends from the Hidden Valley Dolomite at the base of the slope to the Tin Mountain Limestone near the top (Table 1; Figures 8 and 13; McAllister 1952). The formation is a conspicuous cliff-forming unit that consists of light-gray dolostone prominently striped with black limestone and dolostone that preserve stromatoporoid sponges (McAllister 1952). At the type locality the formation is approximately 465 m (1,525 ft) thick.

Figure 13. Banded dolostone and limestone exposures of the Lost Burro Formation at the type locality in Lost Burro Gap (DANIEL PETTIT). Photograph taken looking to the west.

The Lippincott Member of the Lost Burro Formation was designated by McAllister (1955) for exposures northeast of the Lippincott mine. The type locality of the member is located in the Andy Hills east of Hidden Valley ~11 km (7 mi) northeast of the Lippincott mine (Table 1; Figure 8;

McAllister 1955; Hall and MacKevett 1962). Type locality exposures measure approximately 76 m (250 ft) thick and consist of medium-gray sandy dolostone, light-gray sandstone, light gray dolostone containing gray chert, and light-gray mudstone that overlie the Hidden Valley Dolomite (McAllister 1955).

The Quartz Spring Sandstone Member of the Lost Burro Formation was named by Langenheim and Tischler (1960) for exposures in the Quartz Spring area. Type locality exposures of the member are located below the type section of the Tin Mountain Limestone on the southern hillslopes about 4 km (2.5 mi) southeast of Quartz Spring and approximately 914 m (3,000 ft) north of the road to Rest Spring (Table 1; Figure 8; Langenheim and Tischler 1960). The Quartz Spring Sandstone Member consists of white quartzite and interbedded dolomitic sandstone that contain *Skolithos* ichnofacies and abundant crossbedding (Langenheim and Tischler 1960). Thickness of the member is ~12 m (38 ft). The member stratigraphically occurs between the overlying Tin Mountain Limestone and underlying Lippincott Member of the Lost Burro Formation.

The Mississippian Lee Flat Limestone was designated by Hall and MacKevett (1958, 1962) for exposures on the southwest side of Lee Flat. The type locality of the formation in Lee Flat trends southward from an altitude of 1,609 m (5,280 ft) near the top of the prominent hill 1.4 km (0.9 mi) S. 36° E. of the main shaft of the Lee mine to where the unit is in contact with alluvium at the foot of the hill at an altitude of 1,524 m (5,000 ft) (Table 1; Figure 8; Hall and MacKevett 1958, 1962). At the type locality the formation is approximately 158 m (520 ft) thick and is divisible into two units. The lower unit is predominantly thin-bedded, medium- to dark-gray limestone that contains chert lenses and nodules with localized crinoid-rich beds (Hall and MacKevett 1962). The upper unit differs by its absence of chert and presence of 1.3–7.6 cm (0.5–3 in) thick iron-stained bed partings and white calcite veins that cut thin limestone beds (Hall and MacKevett 1962). Stratigraphically, the Lee Flat Limestone occurs between the underlying Perdido Formation and overlying Keeler Canyon Formation.

The Mississippian Santa Rosa Hills Limestone was designated by Dunne et al. (1981) for abundantly fossiliferous exposures located on the northeast flank of the Santa Rosa Hills. The type section of the formation is situated on the northwest side of hill 6170 in Santa Rosa Hills, from an elevation of ~1,786 m (5,860 ft) on the eastern saddle slope to an approximate elevation of 1,839 m (6,035 ft) (Table 1; Figure 7; Dunne et al. 1981). Measured thickness of the type section is 83.2 m (272.8 ft) and consists of light- to medium-gray, massive limestone with moderately abundant echinoderm debris and minor amounts of interbedded, gray to brown chert (Dunne et al. 1981). The Santa Rosa Hills Limestone occurs between the underlying Perdido Formation and overlying Rest Spring Shale.

The Mississippian Tin Mountain Limestone was named by McAllister (1952) after the northernmost peak in the Panamint Range where the formation forms prominent cliffs on the eastern and southern sides of the mountain. The type locality of the formation is located in the southern hillslopes about 4.0 km (2.5 mi) southeast of Quartz Spring and ~914 m (3,000 ft) north of the road to Rest Spring (Table 1; Figure 8; McAllister 1952). Type locality exposures measure 145 m (475 ft) thick and consist of thin-bedded, medium- to dark-gray limestone, pale-red shale beds and partings, and chert

nodules (McAllister 1952). The Tin Mountain Limestone stratigraphically occurs between the underlying Lost Burro Formation and overlying Perdido Formation.

The Mississippian Stone Canyon Limestone was designated by Stevens et al. (1996) for exposures located 0.5 km (0.3 mi) north of Stone Canyon on the east flank of the Argus Range. A reference section for the formation is located in Cottonwood Canyon (Table 1; Figure 10; Stevens et al. 1996). The reference section measures 417 m (1,368 ft) thick and consists of dark-gray, thin- to medium-bedded micrite (recrystallized lime mud), black chert, and brown-weathering, silicified micrite (Stevens et al. 1995, 1996). The Stone Canyon Limestone conformably overlies the Tin Mountain Limestone and is conformably overlain by the Santa Rosa Hills Limestone.

The Mississippian Leaning Rock Formation was designated by Stevens et al. (1996) after Leaning Rock Peak. The type section of the formation is located approximately 1 km (0.6 mi) south of Rest Spring in the Quartz Spring area (Table 1; Figure 7; Stevens et al. 1996). In its type section the formation measures 83 m (272 ft) thick and consists of interbedded, commonly deformed, dark-gray chert, cherty micrite, spiculite (made up of spicules from organism skeletons), micrite, reddish-brown mudstone, and shale (Stevens et al. 1996). Bioturbation features and slump folds are common throughout the formation. The Leaning Rock Formation overlies the Tin Mountain Limestone and is overlain by the Mexican Spring Formation.

The Mississippian Mexican Spring Formation was named by Stevens et al. (1996) for its type section exposure near Mexican Spring in the southern Inyo Mountains. Although the type section of the formation is located outside DEVA, a reference section is designated near Rest Spring in the Quartz Spring area and lies above the type section of the Leaning Rock Formation (Table 1; Figure 10; Stevens et al. 1996). At the reference section, the Mexican Spring Formation measures approximately 100 m (328 ft) thick and consists of reddish-brown, calcareous, highly bioturbated siltstone, interbedded fossiliferous limestone, and pinkish-gray conglomerate (Stevens et al. 1996). At the reference section the Mexican Spring Formation occurs between the underlying Leaning Rock Formation and overlying Rest Spring Shale.

The Mississippian Perdido Formation was designated by McAllister (1952) after its type locality exposures south of Perdido Canyon from the foot of the southern wall, ~2,743 m (9,000 ft) southeast of Quartz Spring, over the hill to the underlying Tin Mountain Limestone (Table 1; Figure 8). At the type locality the Perdido Formation measures 186 m (610 ft) thick and is composed of interbedded medium-gray limestone, reddish-brown siltstone and silty limestone, grayish-black chert, and minor amounts of conglomerate (McAllister 1952). The formation overlies the Rest Spring Shale and is overlain by the Tin Mountain Limestone.

The Mississippian Rest Spring Shale was named by McAllister (1952) after extensive exposures located around Rest Spring. McAllister (1952) designated the type locality from the head of the gulch 610 m (2,000 ft) south of Rest Spring northward to within 61 m (200 ft) of the top of the hill that is 610 m (2,000 ft) northwest of Burro Spring (Table 1; Figure 8). Type locality exposures are approximately 94 m (310 ft) thick and predominantly consist of olive-gray, clay-rich shale that grades into siltstone, fine-grained sandstone, and conglomeratic sandstone (McAllister 1952). The

more sandy and silty layers show the effects of channeling and display crossbedding and ripple marks (McAllister 1952). The Rest Spring Shale occurs between the underlying Perdido Formation and overlying Tihvipah Limestone.

The Pennsylvanian Tihvipah Limestone was designated by McAllister (1952) for exposures northwest of Tihvipah Spring, which is 3.2 km (2 mi) north of Burro Spring. The type locality of the formation is on the hill due east of Rest Spring and measures approximately 61 m (200 ft) thick (Table 1; Figure 8). Lithologically, the Tihvipah Limestone consists of platy light-gray limestone interbedded with shaly limestone and fine-grained, medium-gray limestone (McAllister 1952). A diagnostic feature of the formation is the widespread presence of dark-gray chert concretions up to 5 cm (2 in) in diameter (McAllister 1952). At the type locality the Tihvipah Limestone overlies the Rest Spring Shale.

The Oligocene–Miocene Ubehebe Formation was named by Snow and Lux (1999) after Ubehebe Crater. Type locality exposures of the formation are situated in the Ubehebe Hills in the northernmost Cottonwood Mountains (Table 1; Figure 8; Snow and Lux 1999). At the type locality the formation measures approximately 332 m (1,090 ft) thick and is composed of three lithofacies typified by conglomerate, sandstone, and lacustrine (lake) rocks that exhibit an overall fining-upward trend (Snow and Lux 1999). Conglomerate facies rocks are reddish-gray to light brown, poorly sorted subangular clasts in a matrix of sandy siltstone or silty mudstone (Snow and Lux 1999). The sandstone facies is dominated by pale red, brown, or olive lithic wacke (poorly sorted sandstone) containing poorly sorted, subangular, medium- to coarse-grained clasts in a muddy matrix (Snow and Lux 1999). Rocks of the lacustrine facies are greenish-yellow or pale brown mudstones with interstratified siltstone, silty mudstone, lime-rich mudstone, tuff (volcanic ash)-rich claystone, and marl (carbonate-rich mudstone) (Snow and Lux 1999). Snow and Lux (1999) also assigned two reference sections for the Ubehebe Formation in the Marble Canyon area that measure approximately 130 m (427 ft) (Table 1; Figure 10).

The Eocene Titus Canyon Formation was designated by Stock and Bode (1935) for its type locality exposures in Titus Canyon near Leadfield in the Grapevine Mountains (Table 1; Figures 8, 14, and 15). At the type locality the formation consists of conglomerates, sandstone, lime-rich mudstones, algal limestones, and tuff-rich sandstone with an approximate thickness of 671 m (2,200 ft) (Stock and Bode 1935). Mammalian fossils have been found in the lower portion of the formation. The Titus Canyon Formation is unconformably overlain by several hundred feet of conglomerate that is interbedded with rhyolitic flows and associated tuffs (Stock and Bode 1935).

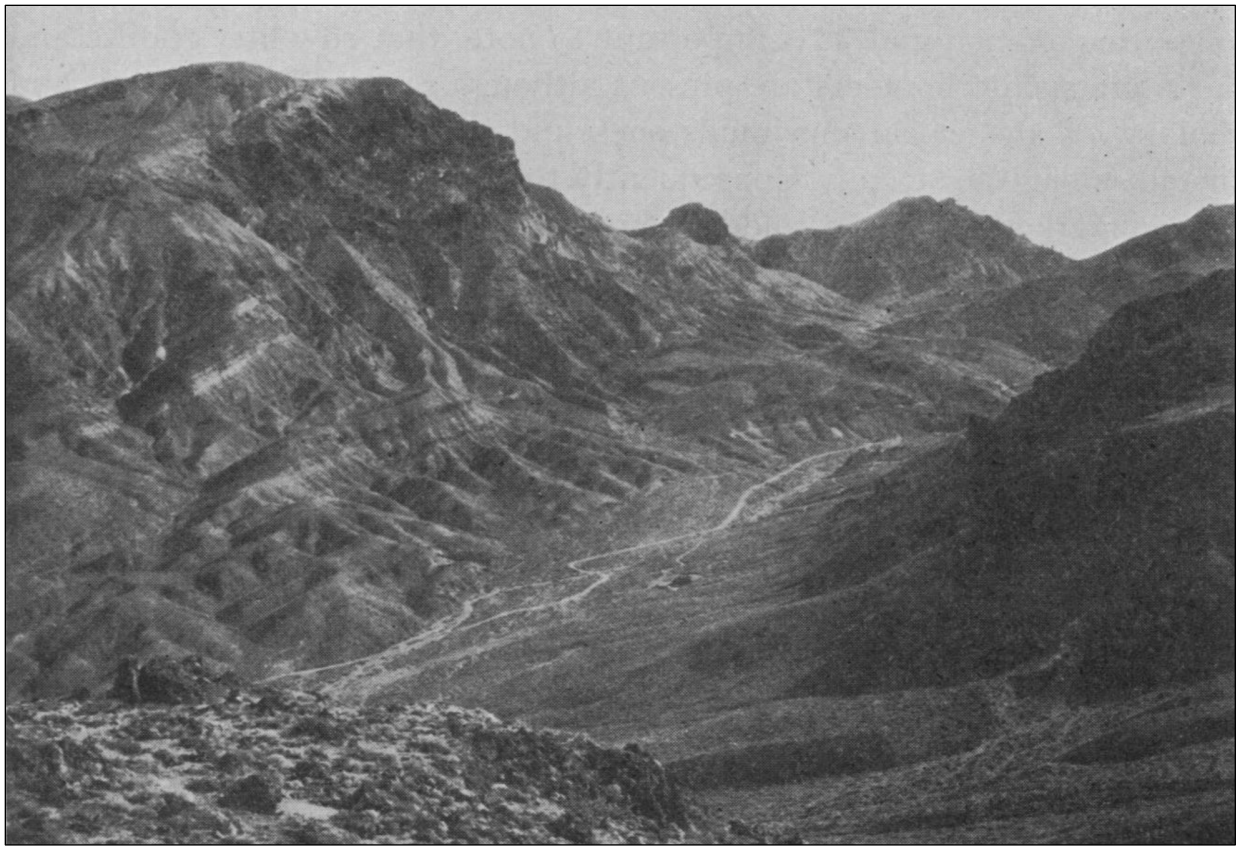


Figure 14. Type locality exposures of the Titus Canyon Formation in the vicinity of Leadfield, Grapevine Mountains, California. Basal limestone breccia lies on Paleozoic rocks seen in right wall of canyon. Lower red beds are concealed beneath alluvium of canyon bottom; the middle and upper parts of the section are exposed on the mountain face at left. Overlying volcanics form the left skyline. The difference in elevation between the top of the mountain on left and the canyon bottom is more than 914 m (3,000 ft). Plate 3B from Stock and Bode (1935).

Figure 15. Type locality exposures of the Titus Canyon Formation near the ghost town of Leadfield, Grapevine Mountains, California (BOB PALIN).

The Miocene Bullfrog Tuff was originally named the Bullfrog Member of the Crater Flat Tuff by Byers et al. (1976) and was revised to formation rank by Sawyer et al. (1994). Byers et al. (1976) derived the name of the unit from its type locality at Bullfrog Mountain just north of the original Bullfrog mine (Table 1; Figures 8 and 16). At the type locality the Bullfrog Tuff ranges from 130–180 m (430–590 ft) thick and consists of light yellowish-gray, microcrystalline ash-flow tuff that is slightly mottled and weathers to yellow and pale reddish-brown (Byers et al. 1976).

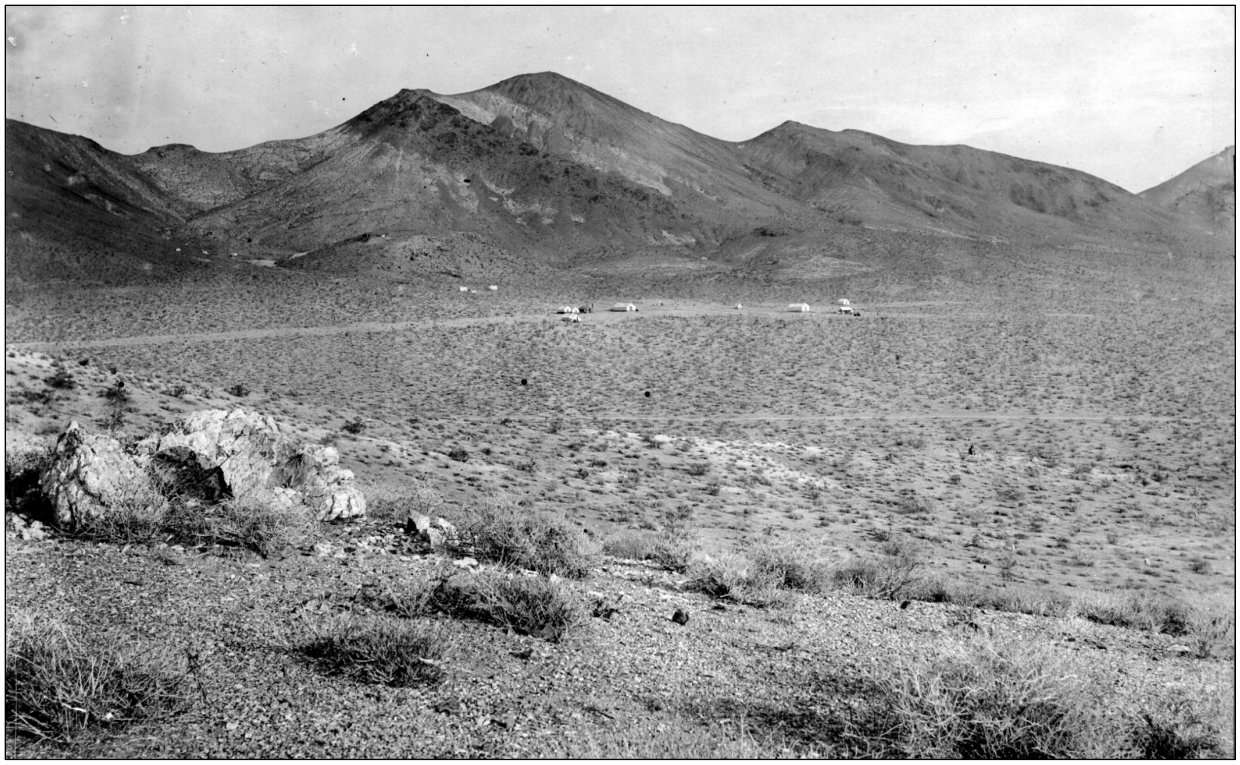


Figure 16. Bullfrog Mountain as viewed from the south, Nye County, Nevada (USGS). Bullfrog Mountain is the type locality of the Bullfrog Tuff. The low hills in the foreground are composed of limestone and shale, against which the volcanic flows forming the mass of the mountain are faulted.

The Miocene Navadu Formation was designated by Snow and Lux (1999) after a Shoshone village once located near Cottonwood Springs in Cottonwood Canyon. A composite type section of the formation consists of the type sections of the lower Entrance Narrows Member and upper Lemoigne Canyon Member. The type section is a composite of two measured sections: 1) in a west-facing slope 1.0 km (0.6 mi) N310° from BM 849 in the Entrance Narrows, Marble Canyon 15' Quadrangle; and 2) in the gentle hills atop the mesa lying 6.0 km (3.7 mi) N182° from BM 849 (Table 1; Figures 7 and 17; Snow and Lux 1999). Combined thickness of the composite type section is approximately 358 m (1,175 ft). The basal Entrance Narrows Member is ~36 m (118 ft) thick and is composed of pale yellow-brown, poorly sorted, typically clast-supported conglomerate with angular, pebble- to boulder-sized clasts. The upper Lemoigne Canyon Member measures ~322 m (1,056 ft) thick and consists of light brown conglomerate similar to the Entrance Narrows Member but has a sandy matrix, abundant interstratified pebbly wacke, and more abundant Paleozoic carbonate material (Snow and Lux 1999). A reference section for the Navadu Formation is located in the Ubehebe Hills area and measures ~946 m (3,105 ft) thick (Table 1; Figure 10; Snow and Lux 1999).

Figure 17. Backpackers explore the dark scenic passageway of Marble Canyon near the type section of the Navadu Formation (NPS/DAN KISH).

The Miocene Panuga Formation was designated by Snow and Lux (1999) after a Shoshone village once located near Mesquite Spring adjacent to the type locality in the Ubehebe Hills in the northern Cottonwood Mountains. The type locality is situated on the southwest side of peak 3454 (Unconformity Hill of Snow 1990) lying 5.4 km (3.4 mi) N258° from Mesquite Spring in the Tin Mountain 15' quadrangle (Table 1; Figure 8; Snow and Lux 1999). Type locality exposures measure approximately 99 m (325 ft) thick and are comprised of interstratified clast-supposed conglomerate, medium-bedded pebbly sandstone and pebble-conglomerate to lithic wacke, siltstone, and mudstone typically arranged in fining-upward cycles (Snow and Lux 1999). The formation displays high-angle cross-stratification often outlined by heavy mineral concentrations (Snow and Lux 1999). Two reference sections for the formation are located in the Marble Canyon area and have an approximately thickness of 70 m (230 ft) (Table 1; Figure 10; Snow and Lux 1999). The Panuga Formation unconformably overlies the Ubehebe Formation.

The Miocene Artist Drive Formation was first designated by Noble (1941) who credits the name to T. P. Thayer. The type area of the formation is the west face of the Black Mountains near Artist Drive where exposures reach a maximum measured thickness of 1,770 m (5,280 ft) (Table 1; Figure 9; Greene and Fleck 1997). Lithologically, the Artist Drive Formation is a heterogeneous sequence of well-stratified sandstone, mudstone, and multi-colored ash beds, conformably overlain by alternating basalt, andesite, dacite, rhyolite, and tuffs including ash-flow tuff (Figure 18; Noble 1941; Greene and Fleck 1997). The Artist Drive Formation unconformably underlies the Furnace Creek Formation.

Figure 18. Well-stratified, multi-colored strata of the Artist Drive Formation in the type area (NPS).

The Miocene Sheephead Andesite was named by Wright et al. (1984a) after Sheephead Mountain in the Black Mountains, central Death Valley volcanic field. The type section is a composite of exposures extending 12 km (7.5 mi) along the lower southwest sides of Salsberry Peak and Sheephead Mountain, from Rhodes Wash eastward to Salsberry Pass in the Black Mountains, Confidence Hills and Shoshone 15' Quadrangles (Table 1; Figure 7; Wright et al. 1984a). At the type section the formation measures 210 m (689 ft) thick and can be divided into two units. The lower unit is a pale-red to grayish-red, vesicular andesite containing phenocrysts (crystals significantly larger than the surrounding groundmass) and a basal flow breccia. The upper unit is composed of pale-red to grayish-red andesite comprising a single flow measuring 60 m (197 ft) thick (Wright et al. 1984a). The Sheephead Andesite conformably overlies the Rhodes Tuff and is overlain by the Shoshone Volcanics.

The Miocene Furnace Creek Formation was named by Axelrod (1940) for lavas, pyroclastics (rock fragments produced by volcanic eruptions), and terrestrial sediments lying in the area drained by Furnace Creek Wash in the central Death Valley region. The type section of the formation is located on the northeast flank of the Black Mountains in the Ryan quadrangle and measures approximately 762 m (2,500 ft) thick (Table 1; Figure 7; Noble 1941; Marvin and Dobson 1979). Lithologically, the formation is comprised of tuffaceous lacustrine mudstone and sandstone interbedded with conglomerates and volcanic rocks (Noble 1941; McAllister 1970). The Furnace Creek Formation occurs between the underlying Artist Drive Formation and overlying Funeral Formation.

The Miocene Copper Canyon Formation was informally referred to as the Copper Canyon beds by Curry (1941) before Drewes (1963) formally designated the formation after thick exposures in the

lower Copper Canyon area. Drewes (1963) states that the type area of the formation is its full exposure in the basin of Copper Canyon, which is practical in view of the excellent exposure and the rapidly changing facies and thickness of the rocks (Table 1; Figure 9). Thickness of the formation ranges from 2,134–3,048 m (7,000–10,000 ft) in the type area and consists of red conglomerate, yellowish-gray siltstone and evaporites with intercalated basalt (Figures 19 and 20; Drewes 1963). The Copper Canyon Formation unconformably underlies the Funeral Formation.

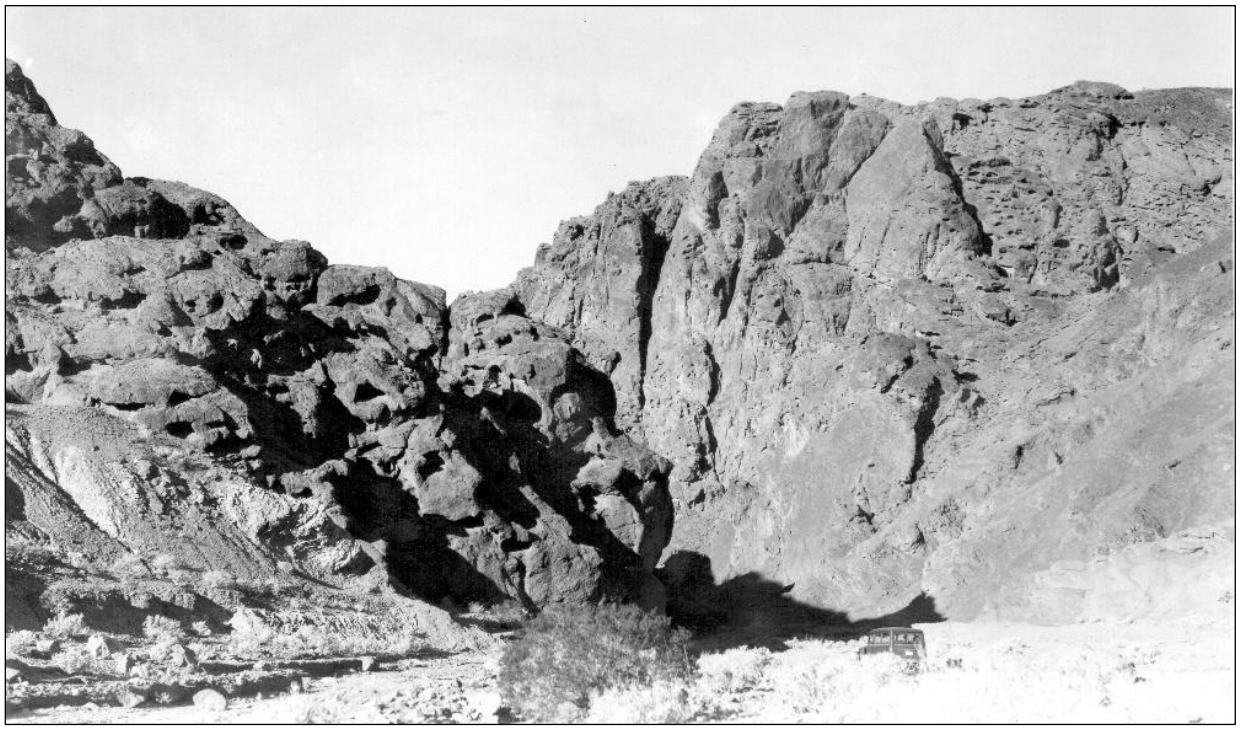


Figure 19. Conglomerate exposures of the Copper Canyon Formation in the lower Copper Canyon type area (USGS). Note the car for scale in lower right.

Figure 20. Type area exposures of the Copper Canyon Formation on the southern wall of Copper Canyon near its mouth. The light-colored rock is a lens of siltstone about 61 m (200 ft) thick enclosed by and interbedded with dark conglomerate. The white bands in the small fluted cliffs are evaporites. Figure 5 from Drewes (1963).

The Miocene Rhodes Tuff was designated by Wright et al. (1984a) after Rhodes Wash in the central Death Valley volcanic field. The type section of the tuff is a composite of exposures extending for 12 km (7.5 mi) along the lower southwest sides of Salsberry Peak and Sheephead Mountain, from Rhodes Wash eastward to Salsberry Pass in the Black Mountains, Confidence Hills and Shoshone 15' Quadrangles (Table 1; Figure 7; Wright et al. 1984a). At the type section the formation is approximately 450 m (1,476 ft) thick and consists of three units: 1) a basal unit composed of air-fall lapilli tuff, ash-flow tuff, and black obsidian that grades upward into grayish-red vitrophyre (volcanic rock with large crystals in volcanic glass); 2) a middle unit of grayish-brown partially welded tuff; and 3) an upper unit of grayish-pink tuff (Wright et al. 1984a). The Rhodes Tuff conformably overlies the Sheephead Andesite.

The Pliocene–Pleistocene Funeral Formation was originally referred to as the Funeral fanglomerate by Noble (1941) and was re-designated by Drewes (1963). The type locality of the formation is located north of the town of Ryan, a few miles north of the Funeral Peak quadrangle (Table 1; Figure 8; Noble 1941; Drewes 1963). Type locality exposures have a maximum estimated thickness of 914 m (3,000 ft) (Noble 1941). Lithologically, the formation is informally divided into three interfingering members that include: 1) a conglomerate member composed of conglomerate, sandstone, and siltstone; 2) a megabreccia member; and 3) an andesite and basalt member consisting of flows and dikes (Drewes 1963). The Funeral Formation unconformably overlies the Furnace Creek Formation.

The Pleistocene Confidence Hills Formation was named by Beratan et al. (1999) after its type section exposure within the Confidence Hills depositional basin. The type section is approximately 300 m (984 ft) thick and is composed of ten distinct sedimentary lithofacies (Table 1; Figure 7; Beratan et al. 1999). Siliciclastic-dominated facies display an overall coarsening- and thickening-upward trend and include the siltstone, fine- to coarse-grained sandstone, and interbedded coarse-grained sandstone conglomerate lithofacies (Figure 21; Beratan et al. 1999). Evaporitic-dominated facies include halitic to gypsiferous mudstone to fine-grained sandstone, banded anhydrite (gypsum without water), and thin-bedded to massive anhydrite (Beratan et al. 1999). The Confidence Hills Formation is overlain by shoreline features related to Lake Manly (Beratan et al. 1999).

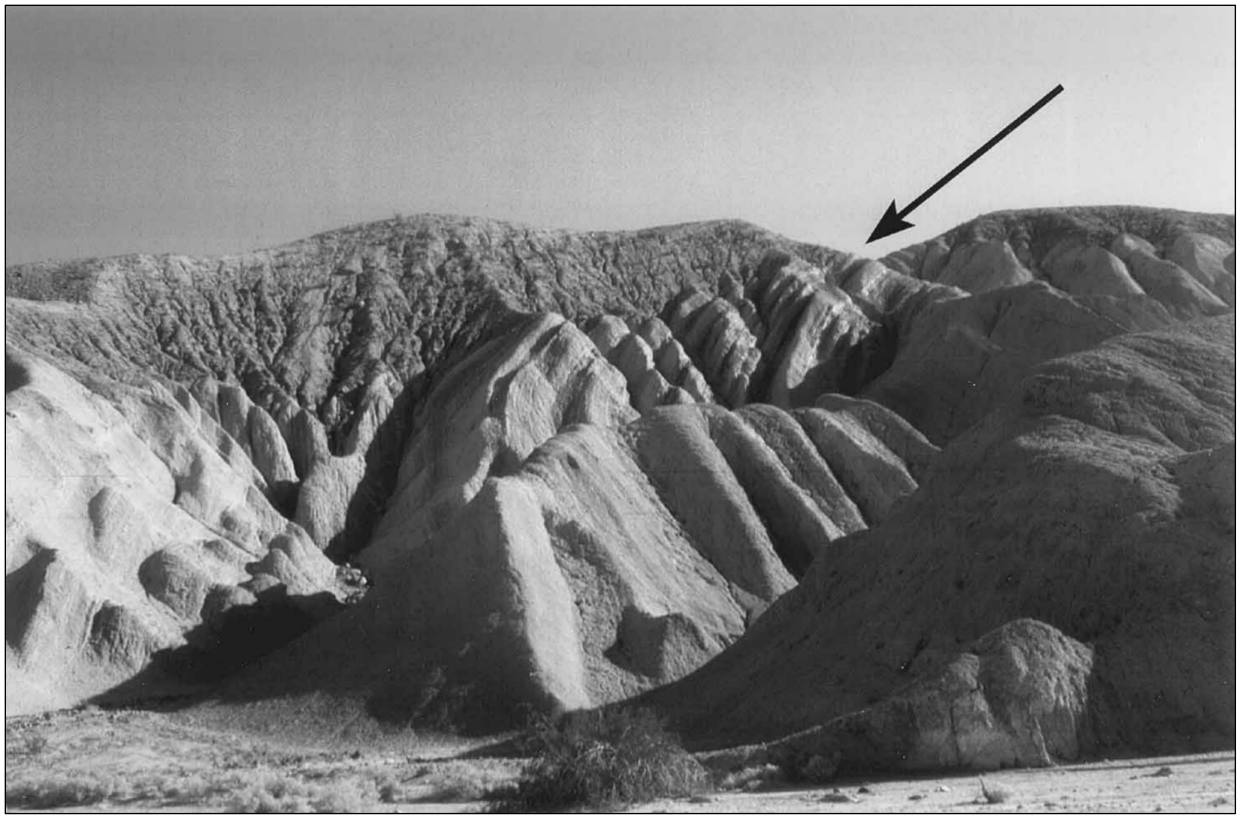


Figure 21. Photograph of the Confidence Hills type locality showing interbedded coarse-grained sandstone and conglomerate unconformably overlying the fine-grained Confidence Hills Formation. The arrow points to the unconformity. Note the fold in the fine-grained strata. Figure 8 from Beratan et al. (1999).

The Pleistocene Mormon Point Formation was designated by Knott et al. (1999, 2005) after its type locality exposures at Mormon Point in the southern Black Mountains (Table 1; Figure 8). Type locality exposures consist of interbedded green, massive to laminated mudstones, conglomerates, and tephra (volcanic fragment) beds. At the type locality the Mormon Point Formation is unconformably overlain by Lake Manly gravels and its base is in fault contact with Proterozoic rocks (Figure 22; Knott et al. 2005).

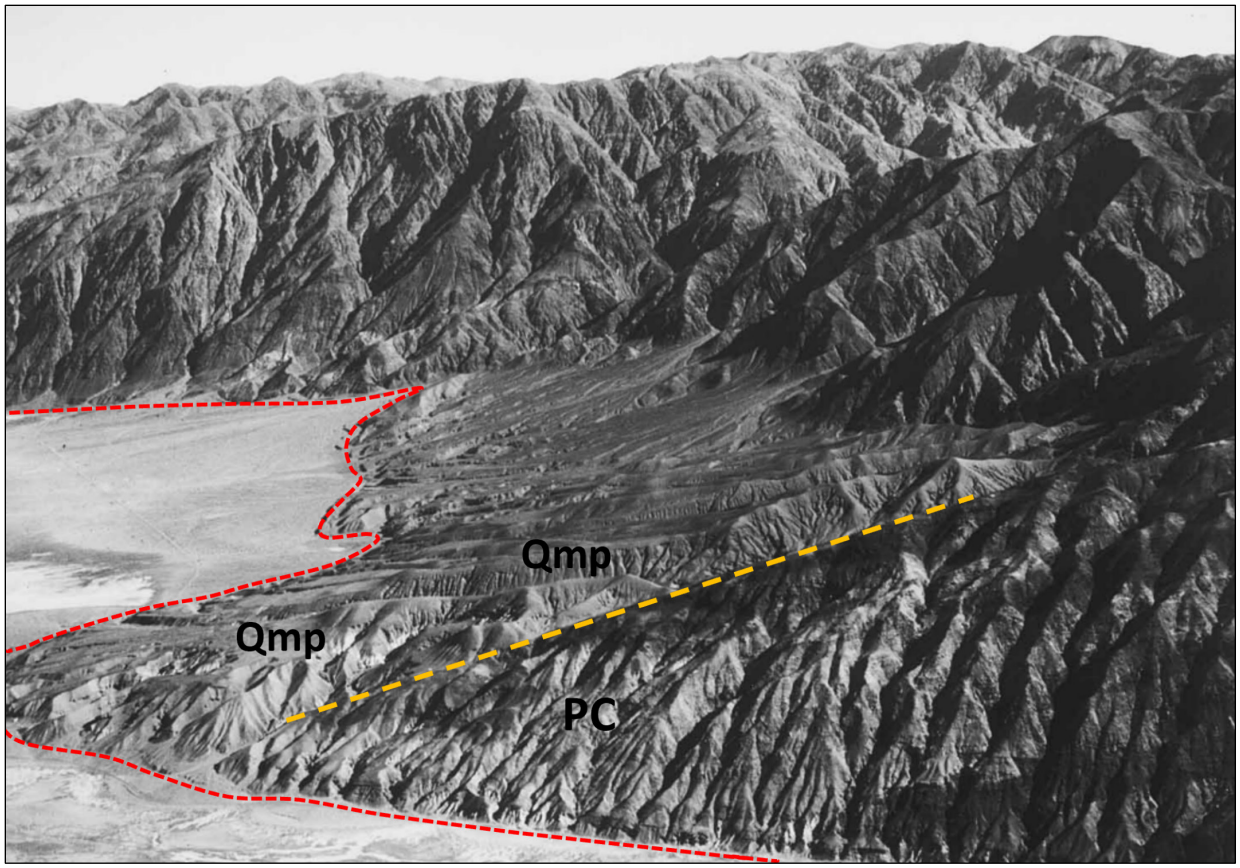


Figure 22. Oblique aerial view to the east of Mormon Point, type locality of the Mormon Point Formation. The yellow dashed line is along the trace of the Mormon Point low-angle or turtleback fault. This fault separates the Mormon Point Formation (Qmp) and metamorphosed Proterozoic rocks (PC). Low hills along the mountain front are composed predominantly of the Mormon Point Formation. Fault scarps in Pleistocene to Holocene alluvial fans in lower left and center left define mountain front (red dashed line). Figure 14 from Knott et al. (1999) with annotations added.

In addition to the designated stratotypes located within DEVA boundaries, a list of stratotypes located within 48 km (30 mi) of park boundaries is included here for reference. These nearby stratotypes include: the Neoproterozoic Reed Dolomite (type section), Deep Spring Formation (type area), Stirling Quartzite (type locality), Noonday Dolomite (type locality), Horse Thief Spring Formation (type locality), Johnnie Formation (type locality), and Limekiln Spring Member of the Kingston Peak Formation (type section); Neoproterozoic–Cambrian Wood Canyon Formation (type locality); Cambrian Nopah Formation (type locality), Tamarack Canyon Dolomite (type section), Emigrant Pass Member of the Zabriskie Quartzite (type locality), Carrara Formation (type section), Gold Ace Member of the Carrara Formation (type section), Eagle Mountain Member of the Carrara Formation (type locality), Pahrump Hills Member of the Carrara Formation (type locality), Monola Formation (type section), Andrews Mountain Member of the Campito Formation (reference section), and Harkless Formation (type section); Ordovician Johnson Spring Formation (type section) and Al Rose Formation (type section); Silurian–Devonian Vaughn Gulch Limestone (type section); Devonian Sunday Canyon Formation (type section) and Squares Tunnel Formation (type section);

Mississippian Stone Canyon Limestone (type section), Mexican Spring Formation (type section), Kearsarge Formation (type section), Bee Member of the Kearsarge Formation (type section), and Snowcaps Member of the Kearsarge Formation (type section); Pennsylvanian–Permian Keeler Canyon Formation (type section); Permian Upland Valley Limestone (type section), Conglomerate Mesa Formation (type section and reference section), Owens Valley Group (type locality), Lone Pine Formation (type section and reference section), Reward Conglomerate Member of the Lone Pine Formation (type section), Osbourne Canyon Formation (type section), Darwin Canyon Formation (type section), Miller Spring Member of the Darwin Canyon Formation (type section), and Panamint Spring Member of the Darwin Canyon Formation (type section); Triassic Union Wash Formation (type section); Jurassic Cottonwood Granite (type locality) and Avawatz Mountain Quartz Monzodiorite (type locality); Cretaceous Alabama Hills Granite (type locality) and Kern Knob Granite (type locality); and the Miocene Tram Tuff (type locality), Bat Mountain Formation (type locality), Eagle Mountain Formation (type locality), and Military Canyon Formation (type section).

Great Basin National Park (GRBA)

Great Basin National Park (GRBA) is located in eastern Nevada's Southern Snake Range in White Pine County (Figure 23). Originally proclaimed as Lehman Caves National Monument on January 24, 1922, the park unit was upgraded to national park status on October 27, 1986. The park preserves 31,234 hectares (77,180 acres) of the Great Basin and is home to ancient bristlecone pines, remnant rock glaciers, igneous intrusions, majestic mountains, alpine ecosystems, cave systems, and desert landscapes. Wheeler Peak is the highest point in GRBA at 3,982 m (13,063 ft) and contains historic cultural remains that include late 19th century mining relics and stone hut foundations that once served as heliograph stations (Graham 2014).

The geology of GRBA consists of rock formations ranging in age from Neoproterozoic to Quaternary and record a wide variety of ancient environments that include marine, shallow marine, estuarine, fluvial, and volcanic deposits (Figure 24; Bell et al. 2016). Some of the oldest rocks in GRBA are represented by the Neoproterozoic McCoy Creek Group (~660–580 million years ago), located in the northwestern part of the park (Yonkee et al. 2014). The park's namesake, the Great Basin, is within the northern part of the Basin and Range physiographic province, a unique topographic landscape characterized by extensive, north–south trending, fault-bounded mountain ranges (horsts) separated by equally extensive, relatively flat basins (grabens) (Graham 2014).

GRBA contains six identified stratotypes that are subdivided into one type section and five type localities (Table 2; Figure 25). The Cambrian Pole Canyon Limestone is located within the boundaries of GRBA but currently lacks a stratotype designation (see "Recommendations" below; Drewes and Palmer 1957).

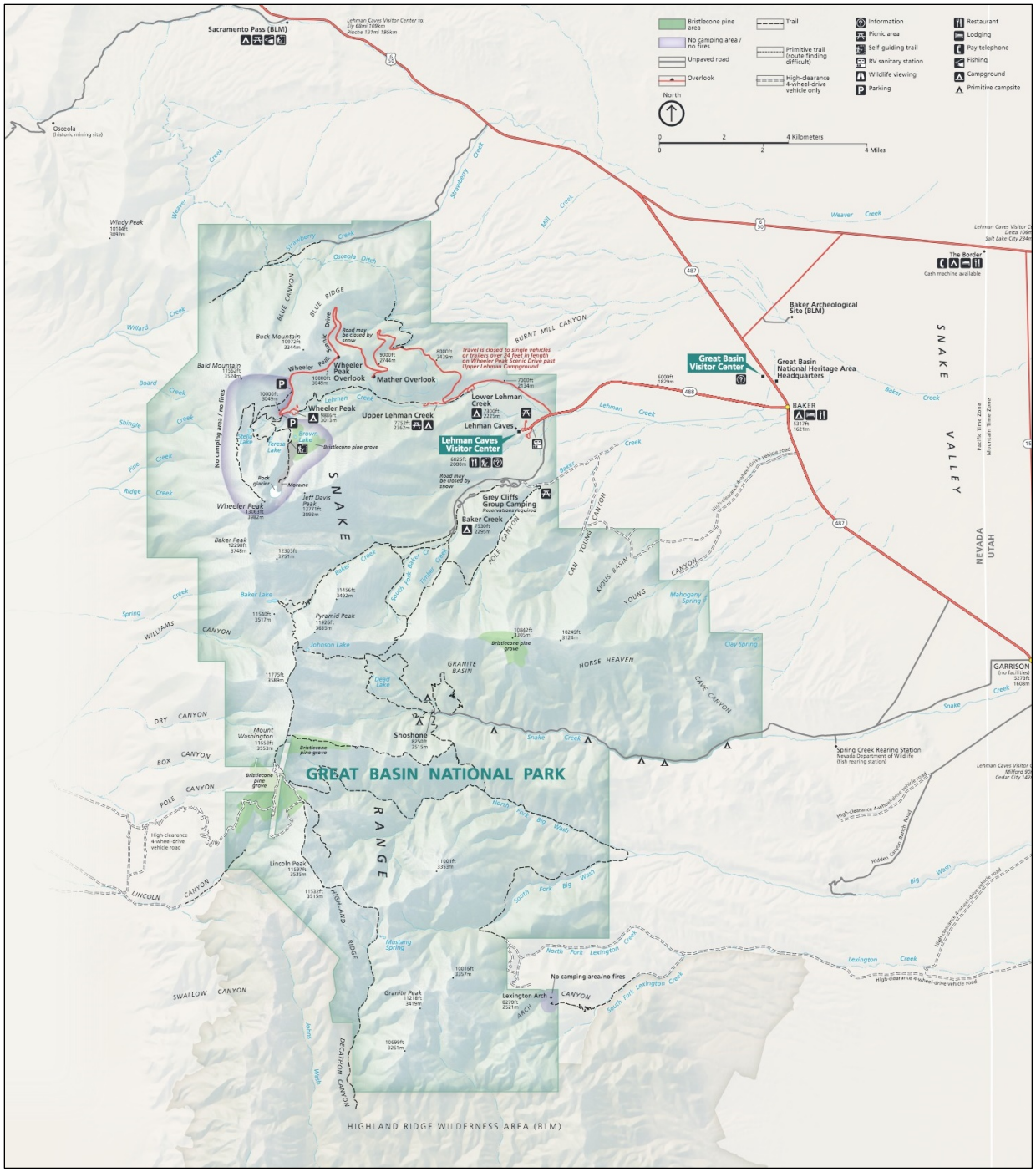


Figure 23. Park map of GRBA, Nevada (NPS).

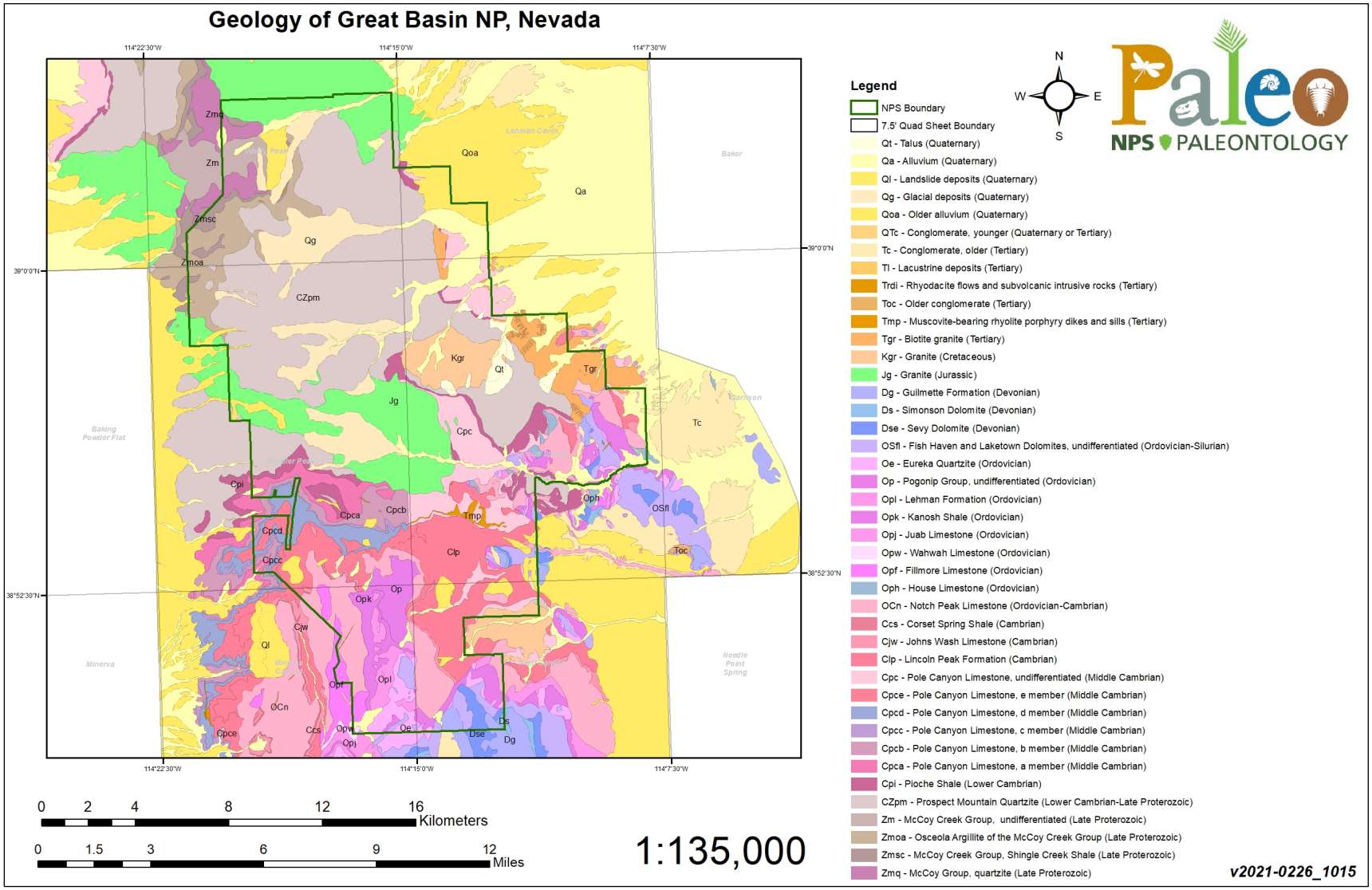


Figure 24. Geologic map of GRBA, Nevada.

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

Unit Name (map symbol)	Reference	Stratotype Location	Age
Lincoln Peak Formation (Clp)	Drewes and Palmer 1957	Type section: south slope of south fork of Lincoln Canyon, directly below head of Johns Wash [in T. 12 N., R. 68 E., Wheeler Peak 15-min quadrangle, White Pine Co.], NV (Drewes and Palmer 1957)	middle–late Cambrian
Stella Lake Quartzite, McCoy Creek Group (not differentiated on Figure 21)	Misch and Hazzard 1962	Type locality: south of Stella Lake, northern part of southern Snake Range, Wheeler Peak 7.5-min quadrangle, White Pine Co., NV.	Neoproterozoic
Osceola Argillite, McCoy Creek Group (Zmoa)	Misch and Hazzard 1962	Type locality: slightly northwest of Strawberry Peak (now Bald Mountain) in the southern Snake Range, Windy Peak 7.5-min quadrangle, White Pine Co., NV (Misch and Hazzard 1962)	Neoproterozoic
Shingle Creek Quartzite, McCoy Creek Group (Zmsc)	Misch and Hazzard 1962	Type locality: north of Strawberry Peak (now Bald Mountain). Well exposed in upper Willard Creek–Strawberry Pass area and in Shingle Creek where base is not exposed, northern part of southern Snake Range	Neoproterozoic
Strawberry Creek Formation, McCoy Creek Group (not differentiated on Figure 21)	Misch and Hazzard 1962	Type locality: in vicinity of Strawberry Peak (now Bald Mountain), northern part of southern Snake Range. Where best exposed [= type locality] on north side of upper Strawberry and upper Willard Creeks where its rocks are altered by contact metamorphism. Named from Strawberry Creek, southern Snake Range, White Pine Co., northeastern NV	Neoproterozoic
Willard Creek Quartzite, McCoy Creek Group (not differentiated on Figure 21)	Misch and Hazzard 1962	Type locality: north of Strawberry Pass and north of Strawberry Creek in the southern Snake Range, White Pine Co., NV (Great Basin region). Well exposed on north side of upper Strawberry and upper Willard Creeks in the southern Snake Range. Named from Willard Creek, southern Snake Range, White Pine Co., northeastern NV (Great Basin region)	Neoproterozoic

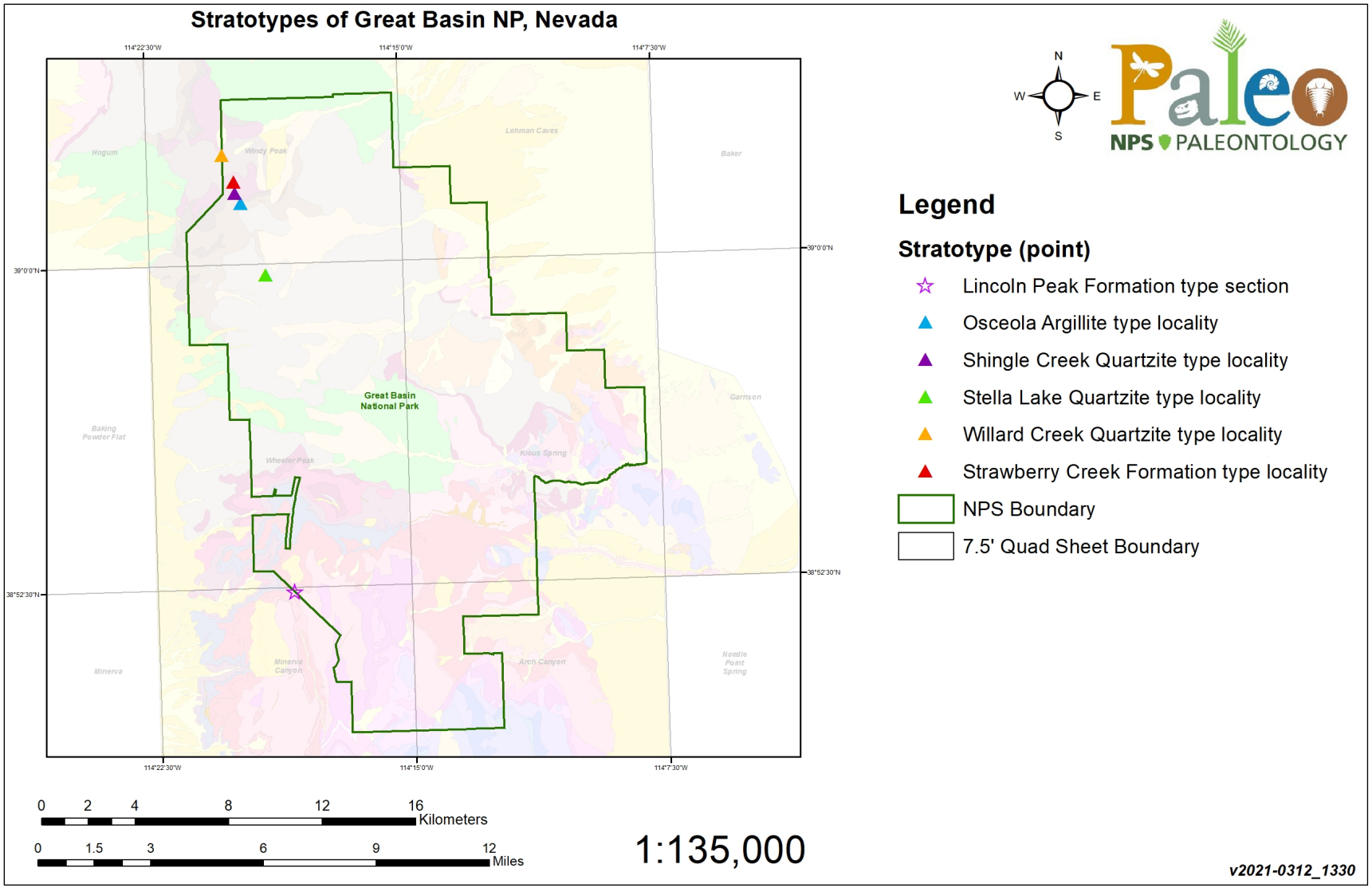


Figure 25. Modified geologic map of GRBA showing stratotype locations. The transparency of the geologic units layer has been increased.

The Neoproterozoic Willard Creek Quartzite of the McCoy Creek Group was named by Misch and Hazzard (1962) after excellent exposures along Willard Creek in White Pine County, northeastern Nevada. Misch and Hazzard (1962) designated the type locality of the quartzite north of Strawberry Pass and north of Strawberry Creek in the southern Snake Range (Table 2; Figure 25). Type locality exposures measure approximately 152 m (500 ft) thick and consist of light gray to white, massive, cliff-forming quartzite that is partially conglomeratic. Quartz veins are locally abundant, and small scale cross-bedding occurs in some places (Misch and Hazzard 1962). The Willard Creek Quartzite conformably underlies the Strawberry Creek Formation and overlies an unnamed quartzite unit at the base of the McCoy Creek Group.

The Neoproterozoic Strawberry Creek Formation of the McCoy Creek Group was designated by Misch and Hazzard (1962) after its type locality exposures on the north side of upper Strawberry and upper Willard Creeks in the southern Snake Range, northeastern Nevada (Table 2; Figure 25). The thickness of the formation at the type locality measures approximately 229 m (750 ft) at the head of Strawberry Creek (Misch and Hazzard 1962). The formation consists of quartzites, argillites (clay-rich rocks), and meta-siltstones that form smooth slopes. Argillites and meta-siltstones are described as olive-drab, greenish-gray and gray, quartzose, silty, partly phyllitic, and very-fine grained (Misch and Hazzard 1962). Quartzites occur in thin beds that alternate with the argillites and meta-siltstones and are described as gray, fine-grained, and weather rusty brown (Misch and Hazzard 1962). The Strawberry Creek Formation overlies the Willard Creek Quartzite and underlies the Shingle Creek Conglomeratic Quartzite.

The Neoproterozoic Shingle Creek Conglomeratic Quartzite of the McCoy Creek Group was named by Misch and Hazzard (1962) after Shingle Creek in the southern Snake Range, northeastern Nevada. Misch and Hazzard (1962) designated the type locality of the unit north of Strawberry Peak (now called Bald Mountain) (Table 2; Figure 25). Type locality exposures measure approximately 152 m (500 ft) thick and consist of gray and brownish-gray, coarse- to fine-grained quartzite with conglomeratic lenses (Misch and Hazzard 1962). The unit is generally massive, forms conspicuous cliffs, and has poorly defined bedding with rare cross-bedding (Misch and Hazzard 1962). Stratigraphically, the Shingle Creek Conglomeratic Quartzite overlies the Strawberry Creek Formation and underlies the Osceola Argillite.

The Neoproterozoic Osceola Argillite of the McCoy Creek Group was first proposed by Misch and Hazzard (1962) for a thick exposed section approximately 3 km (2 mi) east of Osceola on the east side of the southern Snake Range. Misch and Hazzard (1962) designated the type locality of the unit slightly northwest of Strawberry Peak (now called Bald Mountain) in White Pine County, Nevada (Table 2; Figures 25 and 26). Type locality exposures are approximately 244 m (800 ft) thick and consist of a colorful sequence of slate-gray argillaceous rocks that commonly have bluish and purplish hues with distinctive green laminae (Misch and Hazzard 1962). Graded bedding and cross-bedding are locally common. The Osceola Argillite overlies the Shingle Creek Conglomeratic Quartzite and underlies the Stella Lake Quartzite.

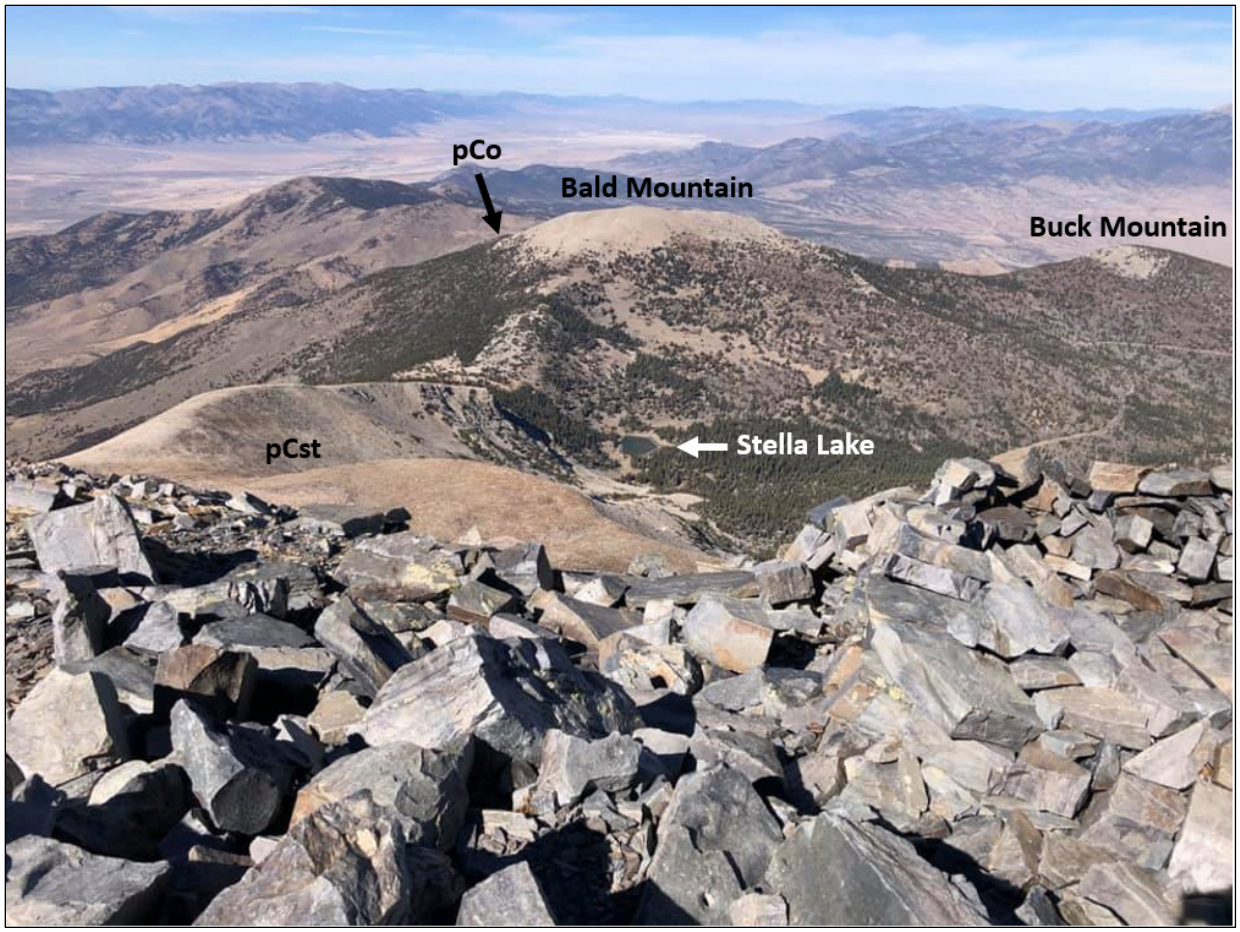


Figure 26. View looking north at Bald Mountain, showing the type localities of the Stella Lake Quartzite (pCst) and Osceola Argillite (pCo) (JOHN OSAKI). Stella Lake sits below Bald Mountain, and Buck Mountain is located to the right.

The Neoproterozoic Stella Lake Quartzite of the McCoy Creek Group was designated by Misch and Hazzard (1962) after its type locality exposures south of Stella Lake in the southern Snake Range (Table 2; Figures 25 and 26). Exposures south of Stella Lake measure approximately 213–244 m (700–800 ft) thick and are composed of a white to light-gray, coarse-grained, massive quartzite (Misch and Hazzard 1962). Minor cross-bedding and pebbly streaks and lenses occur. The quartzite weathers white in contrast to the brownish weathering of the overlying Prospect Mountain Quartzite, which is conspicuous on the east face of Baker Peak (Misch and Hazzard 1962). The Stella Lake Quartzite stratigraphically occurs between the overlying Prospect Mountain Quartzite and underlying Osceola Argillite.

The Cambrian Lincoln Peak Formation was named by Drewes and Palmer (1957) after Lincoln Peak in the southern Snake Range, Nevada. The type section is located on the south slope of the south fork of Lincoln Canyon directly below the head of Johns Wash (Table 2; Figure 25; Drewes and Palmer 1957). Exposures at the type section measure 314 m (1,031 ft) thick and consist of dark gray silty shale and limestone (Drewes and Palmer 1957). Shale beds of the formation are thin (1–5 cm or 0.5–2 in thick) but finer beds and laminae (some cross-bedded) are common (Drewes and Palmer 1957).

The Lincoln Peak Formation has a basal fault contact with the underlying Pole Canyon Formation and is overlain by the Johns Wash Limestone.

In addition to the designated stratotypes located within GRBA, a list of stratotypes located within 48 km (30 mi) of the park boundaries is included here for reference. These nearby stratotypes include the Cambrian Johns Wash Limestone Member and Corset Spring Shale Member of the Orr Formation (type sections), Devonian–Mississippian Pilot Shale (reference section), and Oligocene Needles Range Formation (type locality), Cottonwood Wash Tuff (type locality), and Beers Spring Member of the Escalante Desert Formation (type section).

Joshua Tree National Park (JOTR)

Joshua Tree National Park (JOTR) is located approximately 160 km (100 mi) east of San Diego and the Los Angeles metropolitan area in Riverside and San Bernardino Counties, southern California (Figure 27). The park unit was proclaimed a national monument on August 10, 1936 and re-designated a national park on October 31, 1994. JOTR preserves approximately 319,959 hectares (790,636 acres) of sand dunes, dry lakes, flat valleys, rugged mountains, granitic monoliths, and oases. Several mountain ranges are found within or along the boundaries of the park: the Pinto Mountains on the northern boundary; the Coxcomb Mountains in easternmost JOTR; the Eagle Mountains in southeastern JOTR; the Cottonwood Mountains on the southern boundary; the Little San Bernardino Mountains on the southwestern boundary; and the Hexie Mountains in the central part of the park (Tocci et al. 2018). The park is home to a fascinating, diverse biological community representative of both the Mojave and Colorado desert ecosystems, and was designated a Biosphere Reserve in 1984.

The geologic history of JOTR records the effects of plate tectonics, volcanism, mountain-building, and stark erosion. The bedrock geology of the park is represented primarily by crystalline igneous and metamorphic rocks of several time intervals, with significant sedimentary units limited to approximately the past 10 million years (Figure 28; Tocci et al. 2018). The oldest rocks in the park date back to the Proterozoic Eon at 1.7–1.4 billion years old and consist of metamorphic rocks that have been intruded and altered by subsequent igneous activity. Within JOTR there are at least five different bodies of igneous rock; the oldest of which rival the metamorphic rocks in age, and the youngest only tens of millions of years old. Overall, the geologic time periods best-preserved at JOTR include the Paleoproterozoic Era, Mesoproterozoic Era, Mesozoic Era, and Miocene Epoch to present (Tocci et al. 2018).

As of the writing of this paper, there are no designated stratotypes identified within the boundaries of JOTR. Three units, the Paleoproterozoic Pinto Gneiss, Jurassic–Cretaceous White Tank Monzonite, and informal Pleistocene Pinto Formation, occur within and are named after locations inside JOTR boundaries but lack designated stratotypes (see “Recommendations” below). There are 15 identified stratotypes located within 48 km (30 mi) of JOTR boundaries, for the Proterozoic Dog Wash Gneiss (type locality); Cambrian Cadiz Formation (type section), Jurassic Dale Lake Volcanics (type locality), Virginia Dale Quartz Monzonite (type locality), and Bullion Mountains Intrusive Suite (type locality); Jurassic–Cretaceous Coxcomb Intrusive Suite (type locality); Cretaceous Clarks Pass Granodiorite (type locality), Iron Mountains Intrusive Suite (type locality), Iron Granodiorite Gneiss (type locality), Granite Pass Granite (type locality), and Danby Lake Granite Gneiss (type locality); Eocene Maniobra Formation (type section); Oligocene–Miocene Valley Springs Formation (type section); Miocene Table Mountain Latite (type locality); and the Miocene–Pliocene Mehrten Formation (type section).

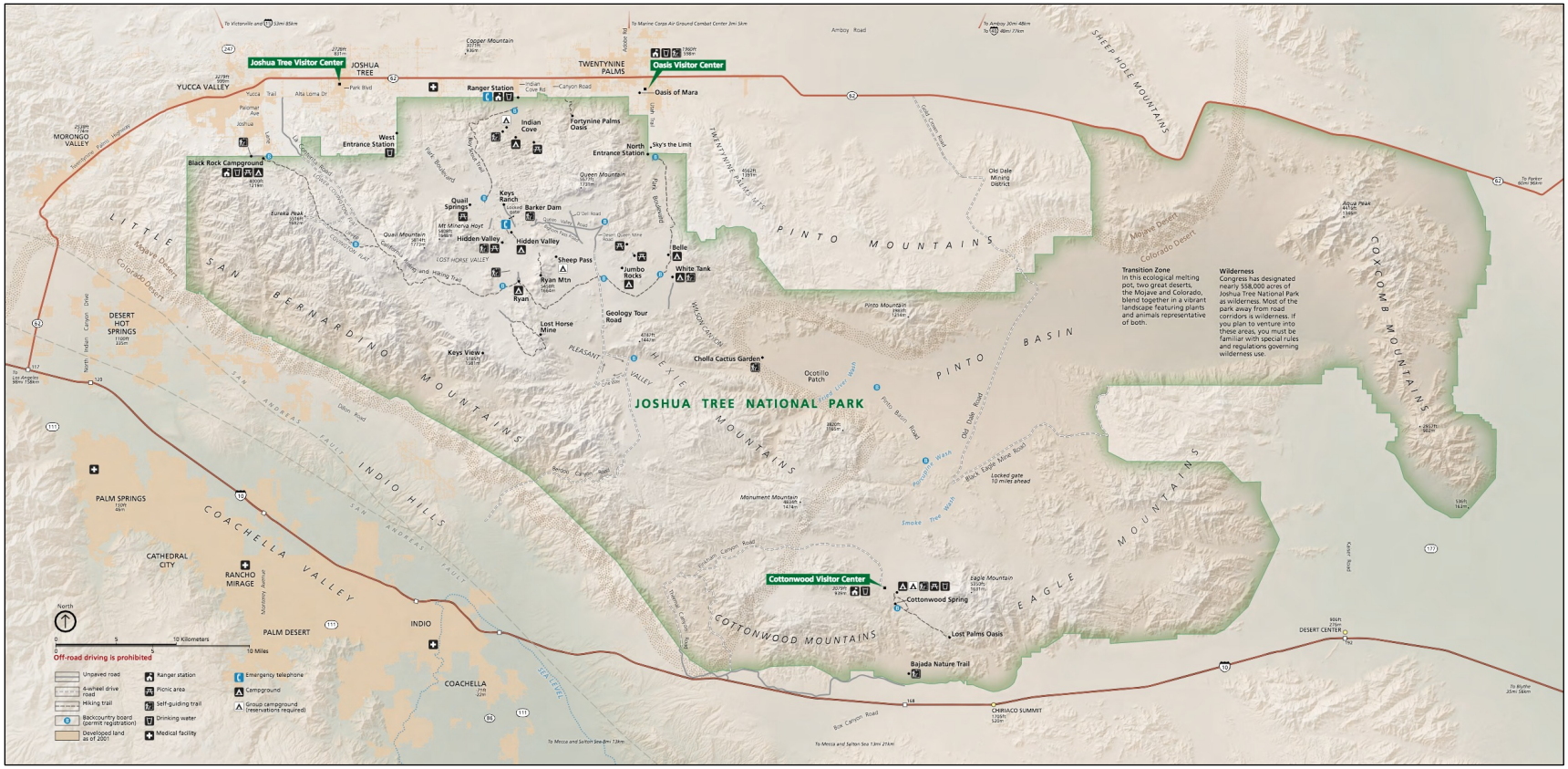


Figure 27. Park map of JOTR, California (NPS).

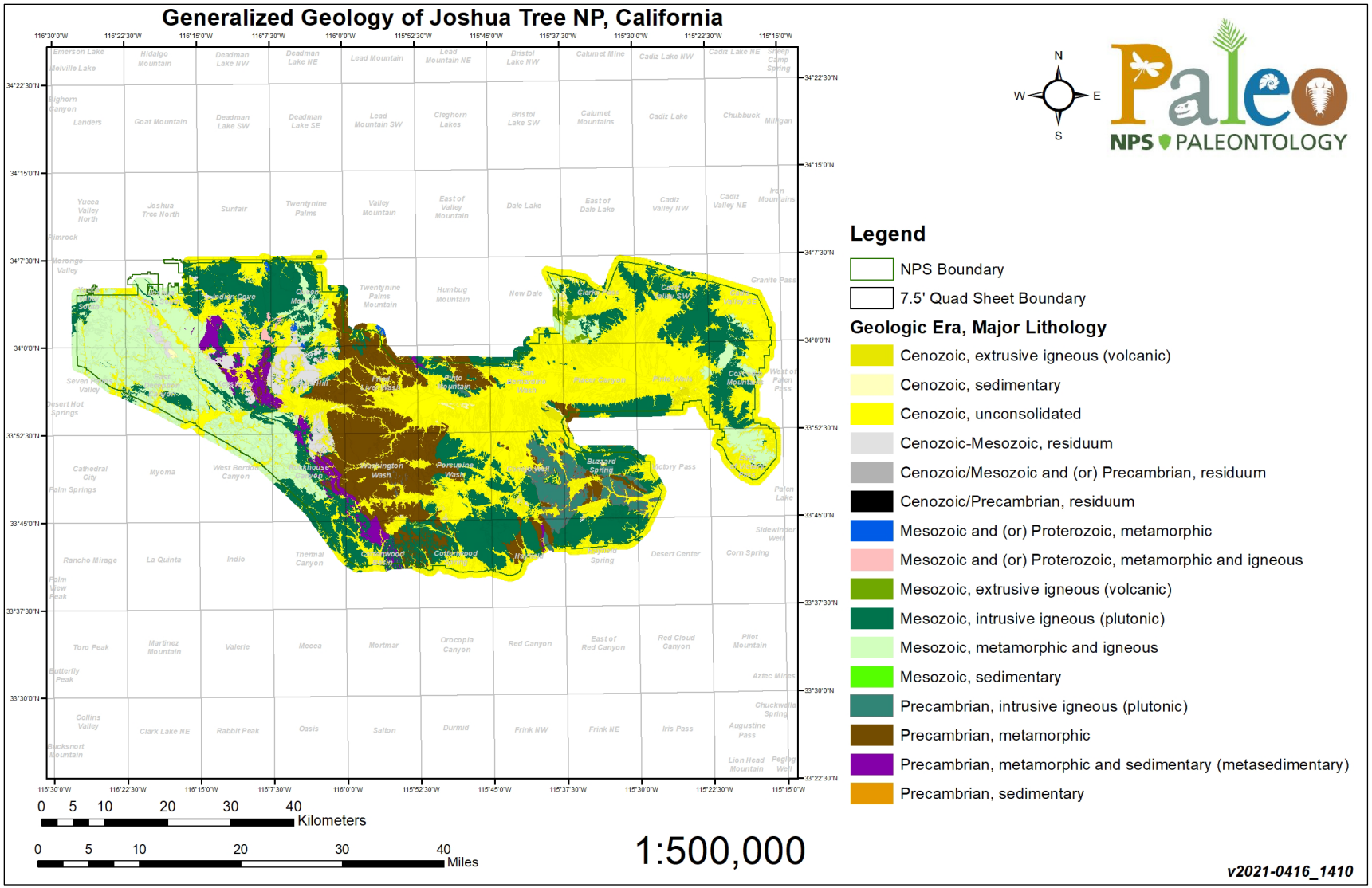


Figure 28. Generalized geologic map of JOTR, California.

Lake Mead National Recreation Area (LAKE)

Lake Mead National Recreation Area (LAKE) is the first and largest national recreation area in America. It is located in Clark County, Nevada and Mohave County, Arizona (Figure 29). LAKE is situated along the boundary between the Colorado Plateau and Basin and Range provinces, marked by the Grand Wash Cliffs which cross the easternmost part of the Lake Mead segment (Bonde et al. 2018). Lake Mead, formed by Hoover Dam, and Lake Mohave, by Davis Dam, represent two important reservoirs on the Colorado River and provide ~751 km^2 (290 mi^2) of water on which to boat, fish, swim, ski, and sail. The recreation area began as Boulder Dam Recreation Area on October 13, 1936 and received its current name in 1947. It was managed jointly by the NPS and the Bureau of Reclamation until it was placed under the sole jurisdiction of the NPS on October 8, 1964. LAKE encompasses 605,331 hectares (1,495,806 acres) of mountains, canyons, valleys, and two lakes. The recreation area protects nine wilderness areas and 1,347 recorded archaeological sites (Anderson 2017).

The geologic history of LAKE is expansive and records rocks ranging in age from the Proterozoic to the Pleistocene (Figures 30 and 31). The oldest bedrock in LAKE includes Paleoproterozoic schist and gneiss (between 2.5 to 1.6 Ga) and late Paleoproterozoic–Mesoproterozoic intrusive igneous bodies (1.7 to about 1.4 Ga) (Beard et al. 2007; Bonde et al. 2018). Few gaps in the geologic record can be found since the Cambrian (541 Ma), affording LAKE a long and impressive record that includes Paleozoic–lower Mesozoic sedimentary units, Neogene–Quaternary sedimentary units, and Neogene igneous rocks (Bonde et al. 2018). The Hamblin–Cleopatra Volcano and many of the black volcanic flow-capped mesas, such as Fortification Hill and Callville Mesa, were formed during Neogene-age volcanic episodes.

Excluding lands in Arizona that are also part of Grand Canyon-Parashant National Monument (PARA; see below), LAKE contains two identified stratotypes that are represented by type localities of the Miocene Mount Davis Volcanics and the Hualapai Limestone Member of the Muddy Creek Formation (Table 3; Figure 32). Three formally named units, the Mesoproterozoic Davis Dam Granite and Gold Butte Granite, and Miocene–Pliocene Fortification Basalt Member of the Muddy Creek Formation, occur within and are named after locations inside LAKE boundaries but lack designated stratotypes (see “Recommendations” below).

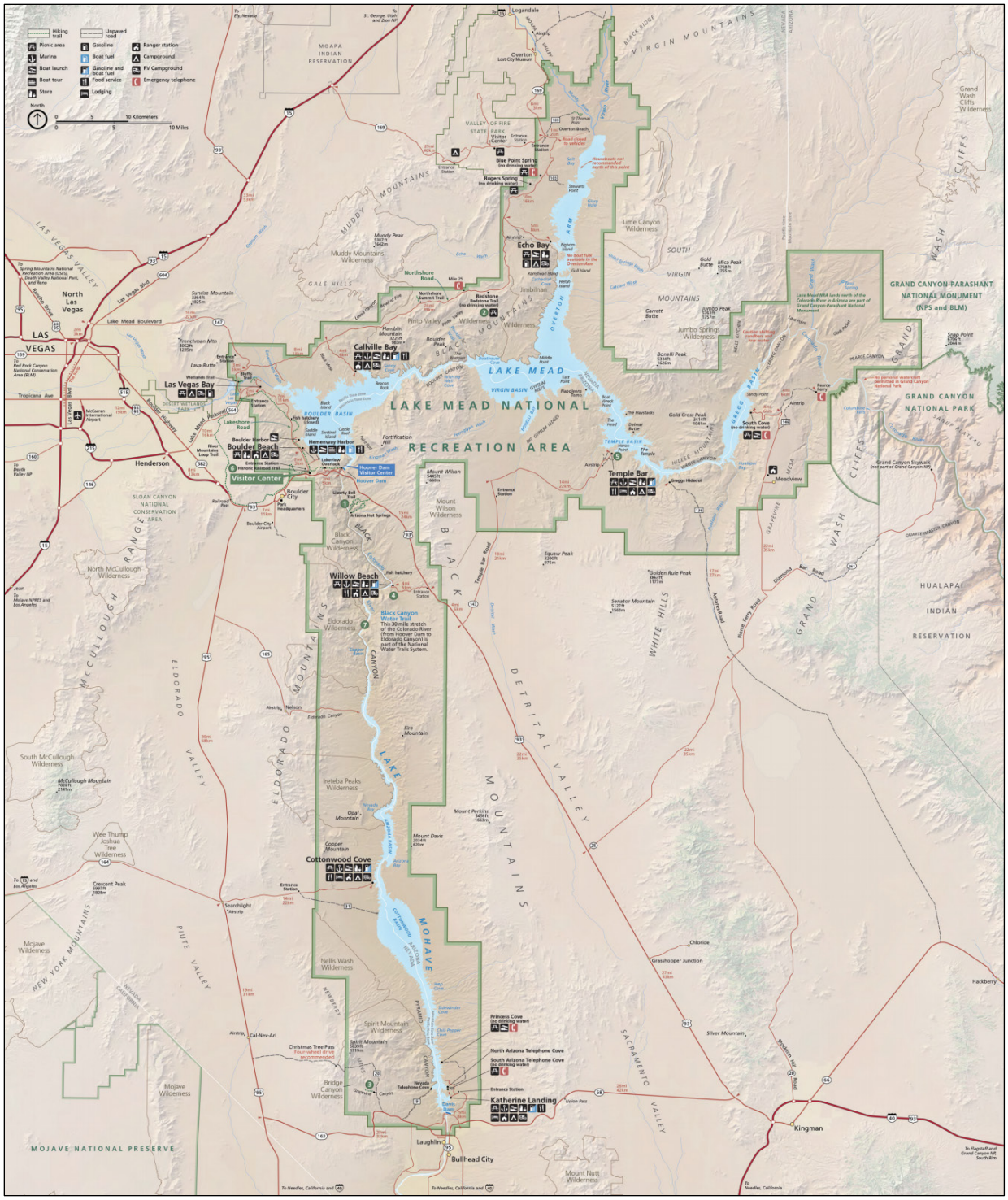


Figure 29. Park map of LAKE, Arizona–Nevada (NPS).

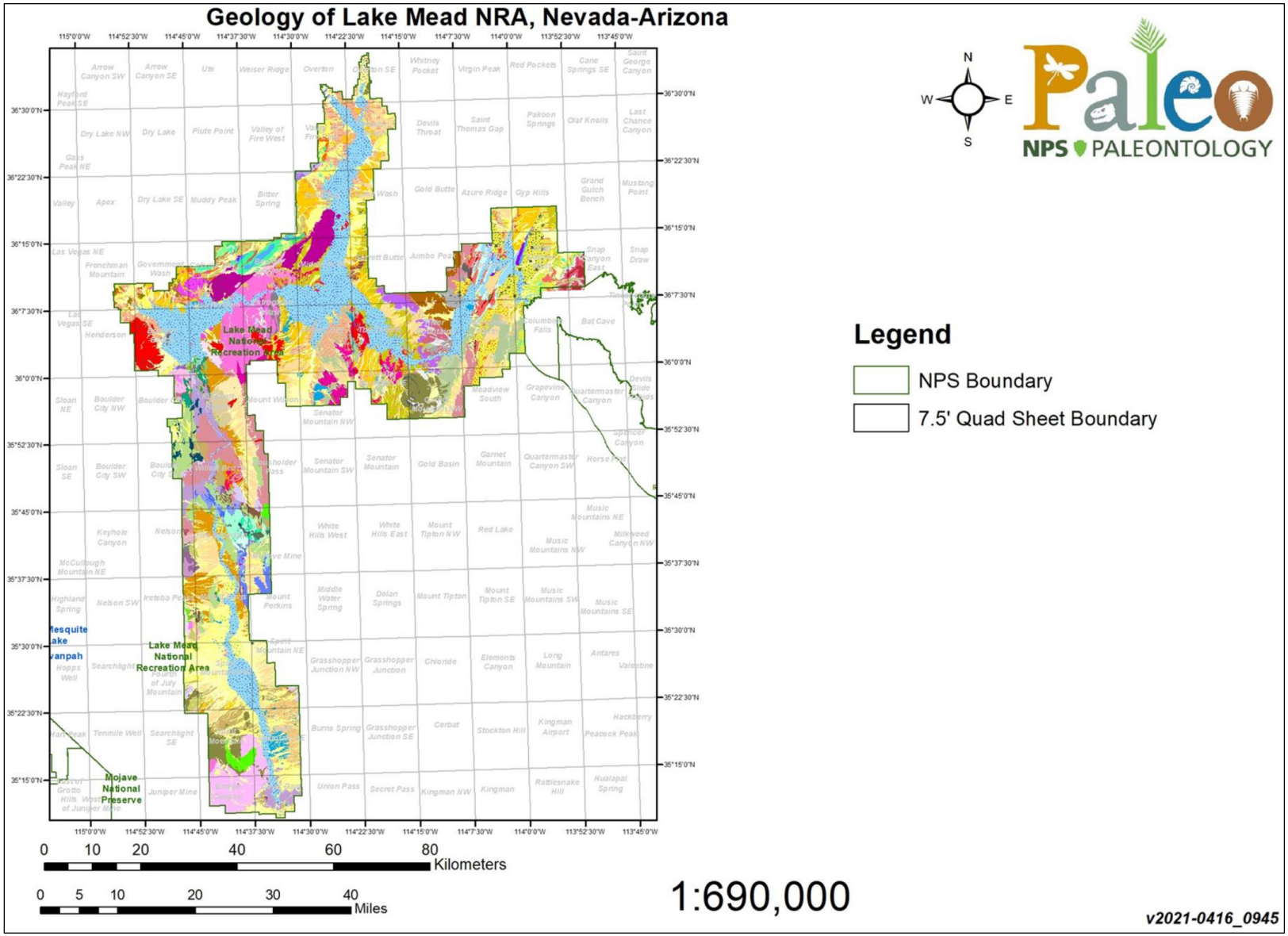


Figure 30. Geologic map of LAKE, Arizona–Nevada (see Figure 31 for legend).

Figure 31. Geologic map legend of LAKE, Arizona–Nevada.

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

Unit Name (map symbol)	Reference	Stratotype Location	Age
Hualapai Limestone Member, Muddy Creek Formation (Th)	Blair and Armstrong 1979	Type locality: the best exposure along Hualapai Wash from spot where the wash joins Lake Mead south along wash for about 9 km (5.5 mi), Mohave Co, AZ (Blair and Armstrong 1979)	late Miocene
Mount Davis Volcanics (Tdv)	Longwell 1963	Type locality: on and near Mount Davis, in western Mohave County, Arizona (Longwell 1963)	middle Miocene

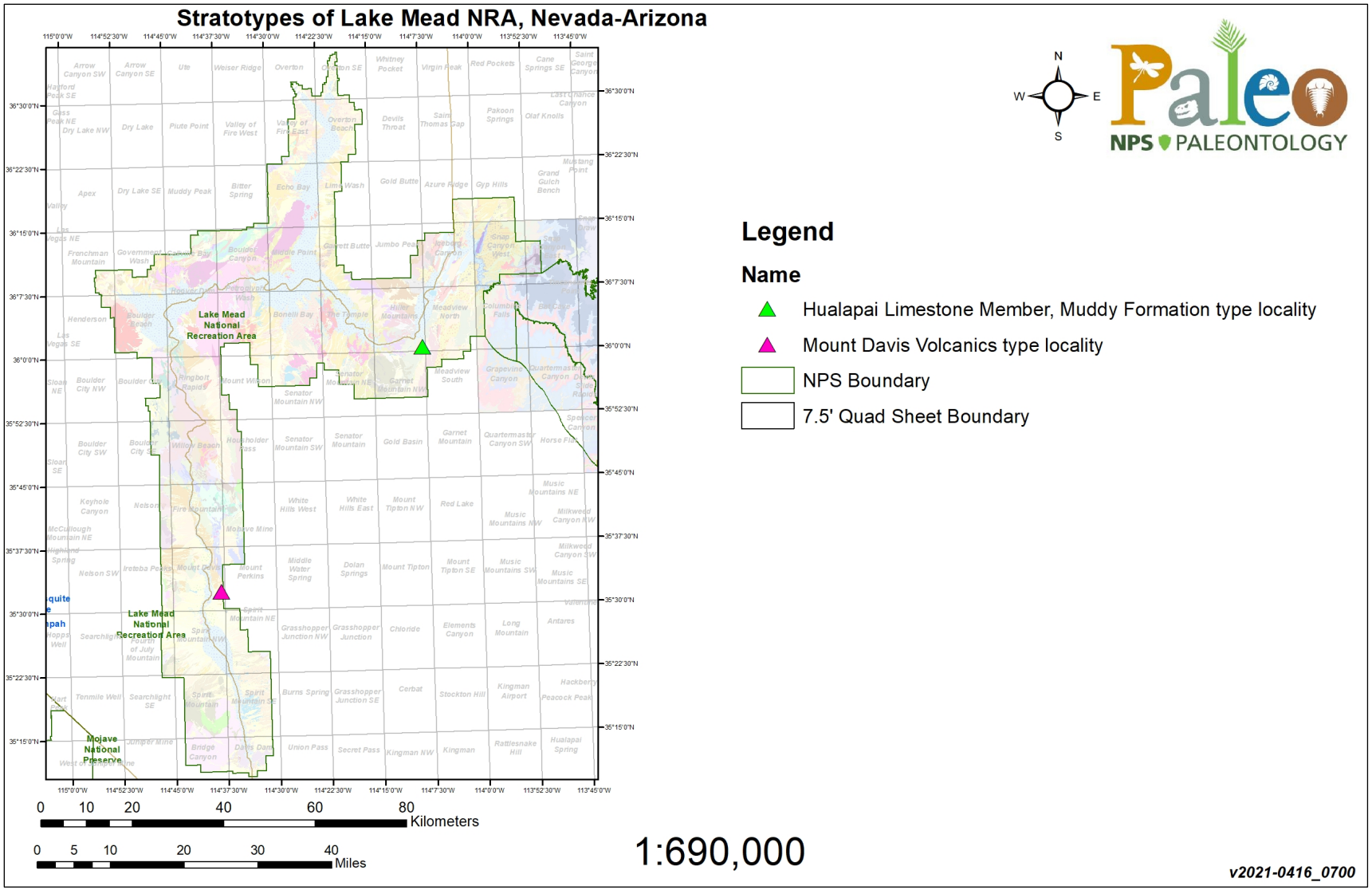


Figure 32. Modified geologic map of LAKE showing stratotype locations. The transparency of the geologic units layer has been increased.

The Miocene Mount Davis Volcanics were named by Longwell (1963) after its type locality exposures on and near Mount Davis in western Mohave County, Arizona (Table 3; Figure 32). Maximum measured thickness of the formation exceeds 1,219 m (4,000 ft) and an assemblage of brownish basalt flows, dark gray andesite flows, and several conspicuous horizons of rhyolitic glass and white, pumiceous tuff (Longwell 1963). The Mount Davis Volcanics are unconformably overlain by the Muddy Creek Formation and are unconformably underlain by several units, including the Golden Door Volcanics, Patsy Mine Volcanics, or older Proterozoic rocks (Longwell 1963).

The Miocene Hualapai Limestone Member of the Muddy Creek Formation was originally named by Longwell (1936) after its type locality exposures along Hualapai Wash in Mojave County, Arizona (Table 3; Figures 32–34). Blair and Armstrong (1979) state the best exposure and type locality of the member begins where Hualapai Wash joins Lake Mead and extends south for approximately 9 km (5.5 mi). Type locality exposures measure over 240 m (787 ft) thick and consist of reddish, cliff-forming limestone with thin interbeds of claystone, mudstone, and siltstone (Figure 33; Blair and Armstrong 1979). The upper section of the member contains scattered chert nodules, and an airfall tuff measuring 15 cm (6 in) thick occurs in the basal portion of the unit (Blair and Armstrong 1979).

Figure 33. Reddish, cliff-forming limestone exposures of the Hualapai Limestone Member of the Muddy Creek Formation along its type locality in Hualapai Wash (DERRICK GOERN).

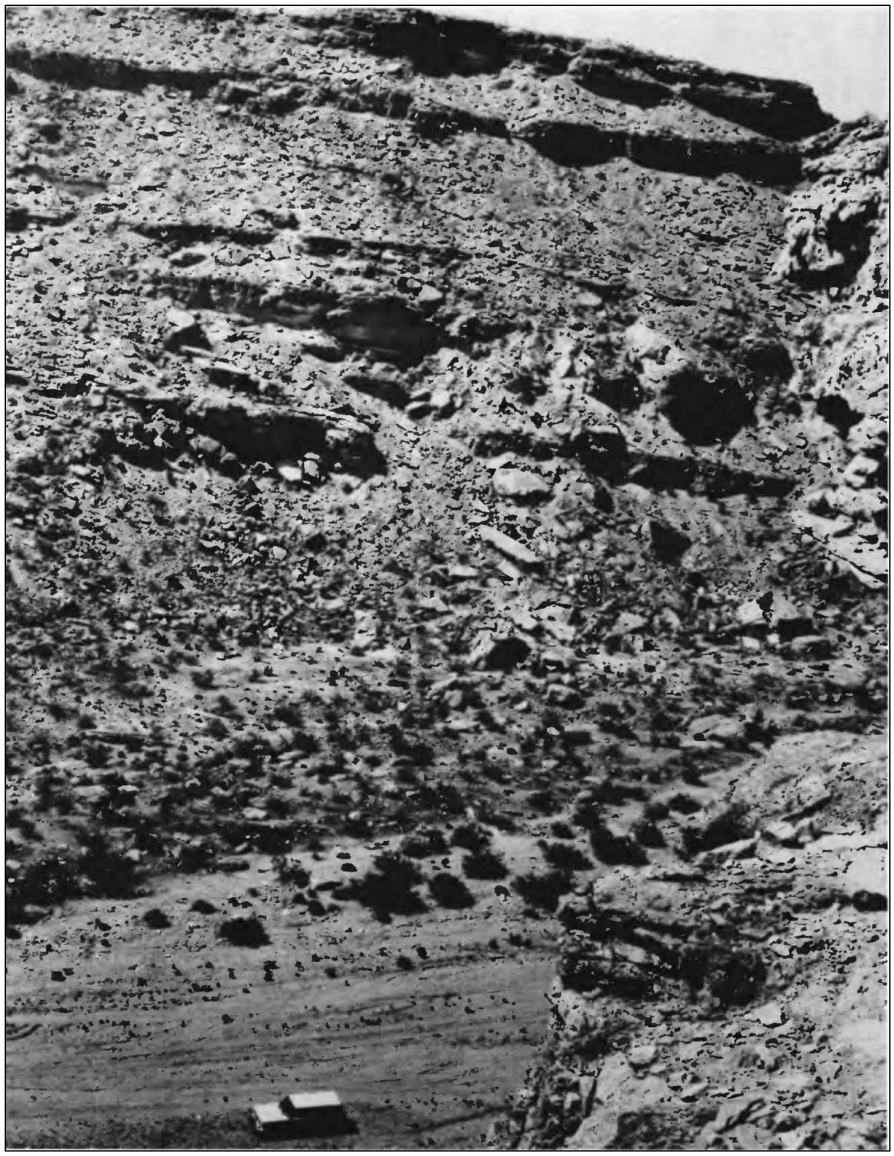


Figure 34. Type locality exposures of the Hualapai Limestone Member of the Muddy Creek Formation at Hualapai Wash. Note the vehicle for scale at bottom left. Unnumbered lead figure from Blair and Armstrong (1979).

In addition to the designated stratotypes located within LAKE, a list of stratotypes located within 48 km (30 mi) of the recreation area boundaries is included here for reference. These nearby stratotypes include the Mississippian Surprise Canyon Formation (type section) and Indian Springs Formation (reference section); Permian Pakoon Limestone (type section); Cretaceous Baseline Sandstone (type section) and Willow Tank Formation (type section); and the Miocene Peach Springs Tuff (type locality), Patsy Mine Volcanics (type section), Horse Spring Formation (reference section), Thumb Member of the Horse Spring Formation (type section and reference section), Rainbow Gardens Member of the Horse Spring Formation (type section), Lovell Wash Member of the Horse Spring Formation (type section), and Bitter Ridge Limestone Member of the Horse Spring Formation (type section).

Manzanar National Historic Site (MANZ)

Manzanar National Historic Site (MANZ) is situated against the backdrop of the Sierra Nevada Mountains in Inyo County, California. Located on the western side of Owens Valley, the historic site is positioned on an easterly sloping alluvial fan approximately 8 km (5 mi) east of the Sierra Nevada Front escarpment (Figure 35; Thornberry-Ehrlich 2009). MANZ was authorized as an NPS unit on March 3, 1992 and protects 329 hectares (814 acres) of natural, cultural, and historical resources, including those related to the relocation and internment of ~120,000 Japanese Americans during World War II (Anderson 2017). The historic site records a long history of human settlement, but also preserves a rich geologic history with active tectonic processes that continue to modify the landscape.

Most of the geologic history of the MANZ area is not visible within MANZ itself, which is blanketed by Quaternary valley fill (Tweet et al. 2016). MANZ includes no bedrock outcrops, and the majority of its surficial geology can be lumped together as Holocene alluvium, with a small area of older Pleistocene alluvial deposits on the west edge of the site (Figure 36; Tweet et al. 2016). The last few million years in the Owens Valley has been a time of faulting, volcanism, glacial deposition, and large lakes. The major transform-normal faults of the valley are active to the present day, continuously uplifting the surrounding mountains relative to the valley floor due to regional Basin and Range-style crustal extension. Factors countering uplift include the continuous weathering and erosion of the highlands by glaciers, wind and water, and the deposition of immense amounts of sediment into Owens Valley (Thornberry-Ehrlich 2009).

As of the writing of this paper, there are no designated stratotypes identified within the boundaries of MANZ. There are 23 identified stratotypes located within 48 km (30 mi) of MANZ boundaries, for the Cambrian Tamarack Canyon Formation (type section), Harkless Formation (type section), Andrew Mountains Member of the Campito Formation (reference section), and Monola Formation (type section); Ordovician Johnson Spring Formation (type section); Silurian–Devonian Vaughn Gulch Limestone (type section); Devonian Squares Tunnel Formation (type section) and Sunday Canyon Formation (type section); Mississippian Kearsarge Formation (type section), Bee Member of the Kearsarge Formation (type section), Snowcaps Member of the Kearsarge Formation (type section), and Mexican Spring Formation (type section); Pennsylvanian–Permian Keeler Canyon Formation (type section); Permian Upland Valley Limestone (type section), Lone Pine Formation (type section and reference section), and Reward Conglomerate Member of the Lone Pine Formation (type section); Permian–Triassic Owens Valley Group (type locality) and Conglomerate Mesa Formation (type section and reference section); Triassic Union Wash Formation (type section); and Cretaceous Alabama Hills Granite (type locality) and Kern Knob Granite (type locality).

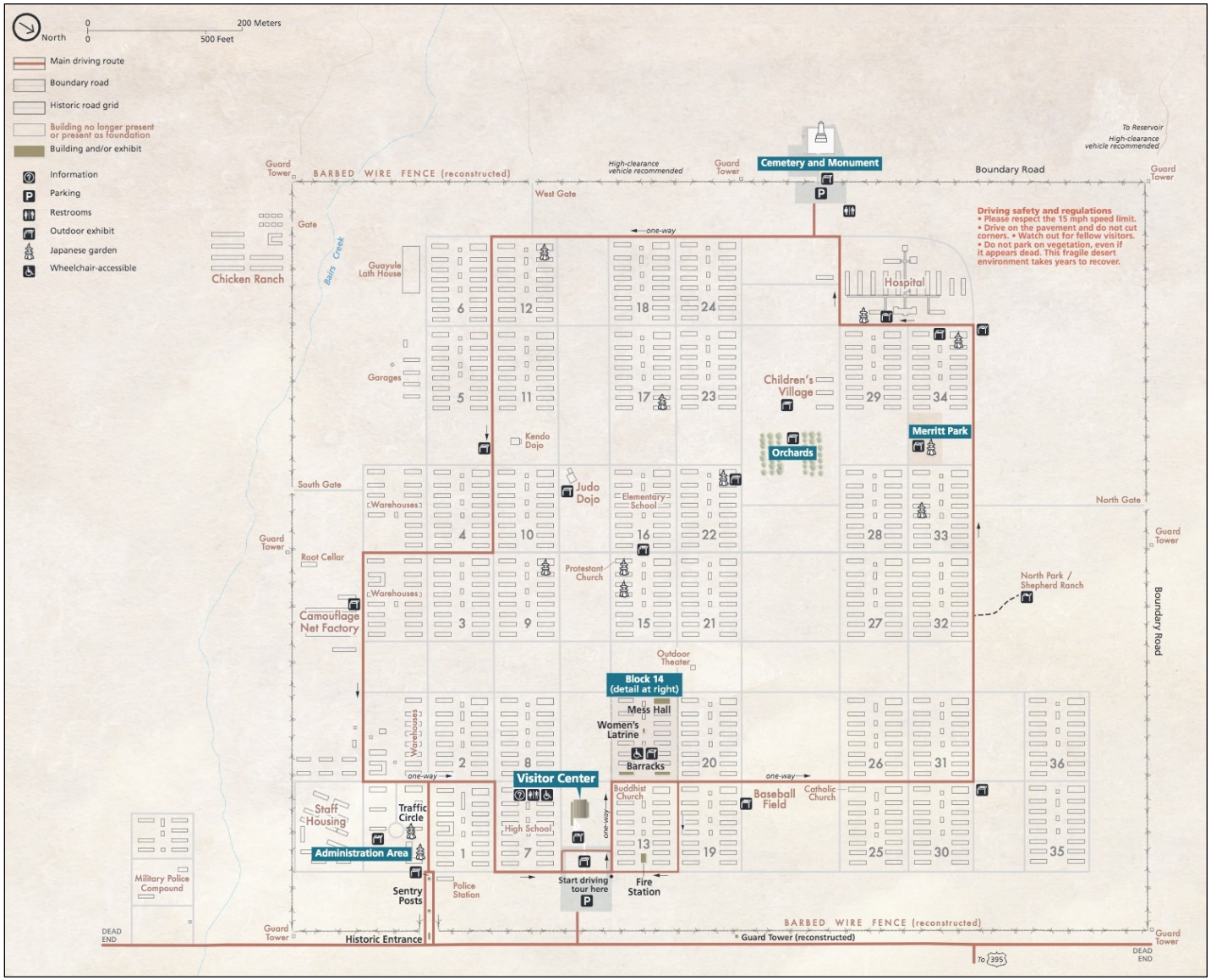


Figure 35. Park map of MANZ, California (NPS).

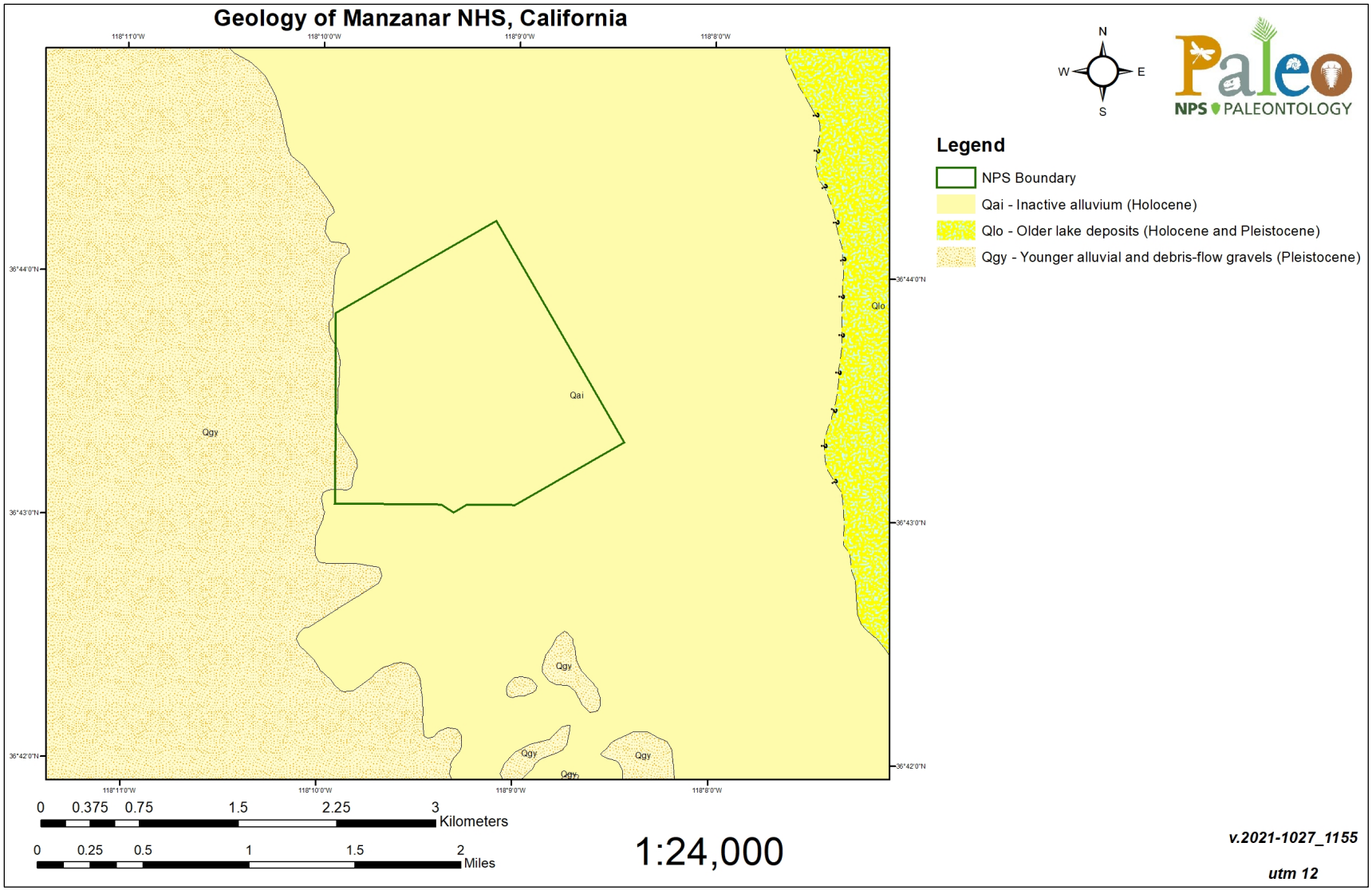


Figure 36. Geologic map of MANZ, California.

Mojave National Preserve (MOJA)

Mojave National Preserve (MOJA) is located approximately 75 km (47 mi) southwest of the Las Vegas metropolitan area in San Bernardino County, southern California (Figure 37). Established on October 31, 1994, MOJA preserves 624,325 hectares (1,542,742 acres) of diverse natural and cultural resources of the Mojave Desert, including wildlife, mountain ranges, and remnants of historic mining, ranching, and railroad activities (Anderson 2017). MOJA is home to canyons, mesas, mountains, sand dunes, ephemeral lakes, cinder cone volcanoes, and a large Joshua tree forest. The topography of MOJA is dominated by numerous mountain ranges, and the preserve is approximately bisected by the SW–NE trending chain of Providence Mountains, Mid Hills, and New York Mountains. It also surrounds smaller Castle Mountains National Monument (CAMO) on three sides. CAMO was authorized February 12, 2016 and protects 8.470 hectares (20,920 acres) of the Castle Mountains and surrounding valleys.

The geologic record in MOJA is extensive, with units ranging in age from Paleoproterozoic (2.5 to 1.7 billion years ago) to the Quaternary (Figure 38). A thick sequence of Neoproterozoic and Paleozoic strata is present in MOJA. The Mesozoic of MOJA is marked by igneous rocks, signaling the development of an active western plate margin (Dunne 1977). During the Neogene and Quaternary igneous activity renewed, particularly in the form of the Cima volcanic field (Farmer et al. 1995).

MOJA contains two identified stratotypes that are represented by the type localities of the Cambrian Latham Shale and the Bonanza King Formation (Table 4; Figure 39). Several formal geologic units are named after features within MOJA but currently lack stratotype designations (see “Recommendations” below).

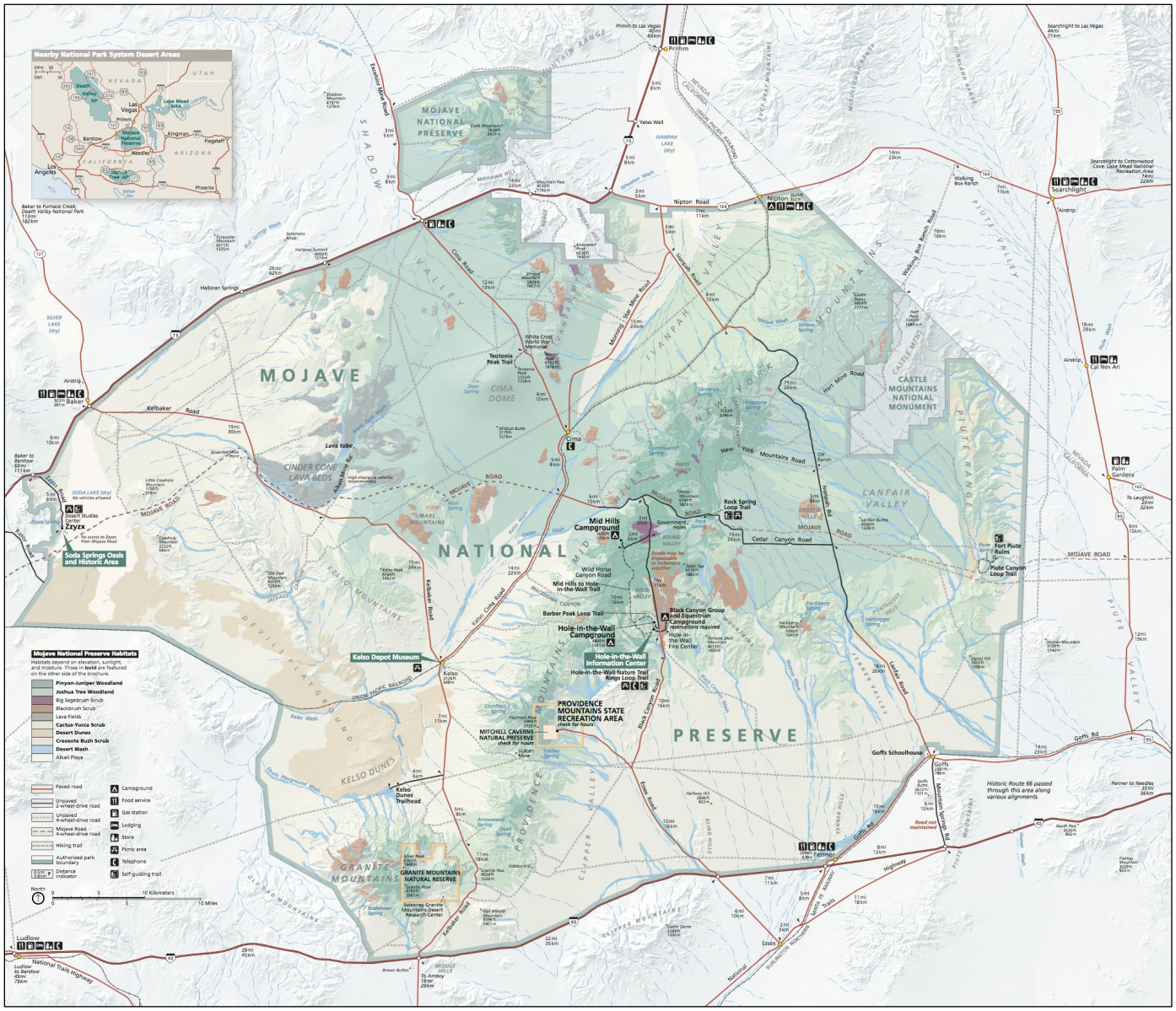


Figure 37. Park map of MOJA and CAMO, California (NPS).

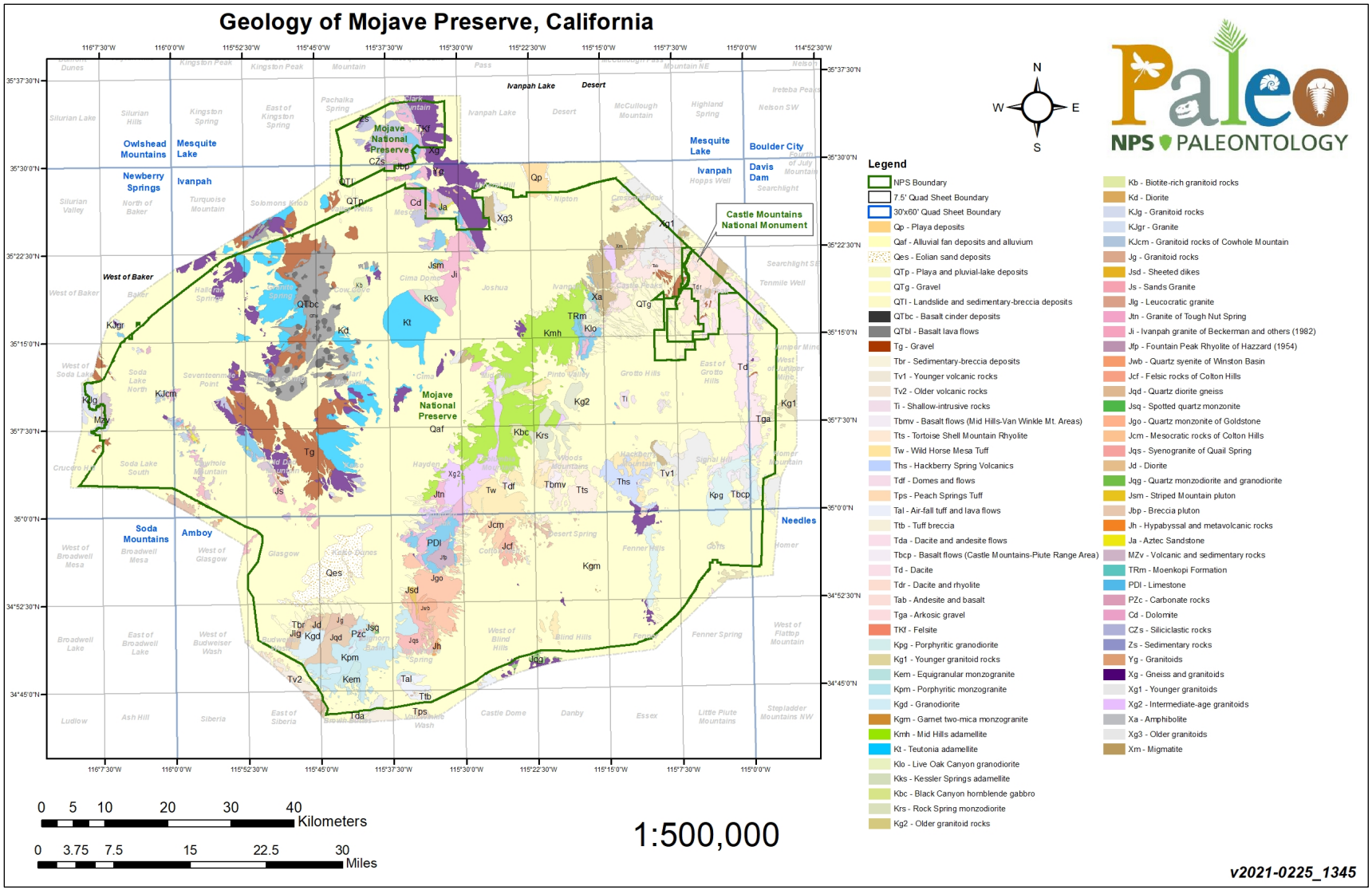


Figure 38. Geologic map of MOJA and CAMO, California.

Table 4. List of MOJA stratotype units sorted by age with associated reference publications and locations.

Unit Name (map symbol)	Reference	Stratotype Location	Age
Bonanza King Formation	Hazzard and Mason 1936, Hunt and Mabey 1966	Type locality: exposures near Bonanza King mine, on east side of Providence Mountains, San Bernardino Co., southeastern CA. [Mine in sec. 3, T. 10 N., R. 14 E., Flynn 15-min quadrangle, San Bernardino Co., southeastern CA] (Hazzard and Mason 1936) (Hunt and Mabey 1966 citing Hazzard)	Cambrian
Latham Shale	Hazzard 1954	Type locality: about 1.6 km (1 mi) southwest of Latham's cabin in the northern Providence Mountains, San Bernardino County, CA (section Cs–Cs' in Hazzard 1954)	Cambrian

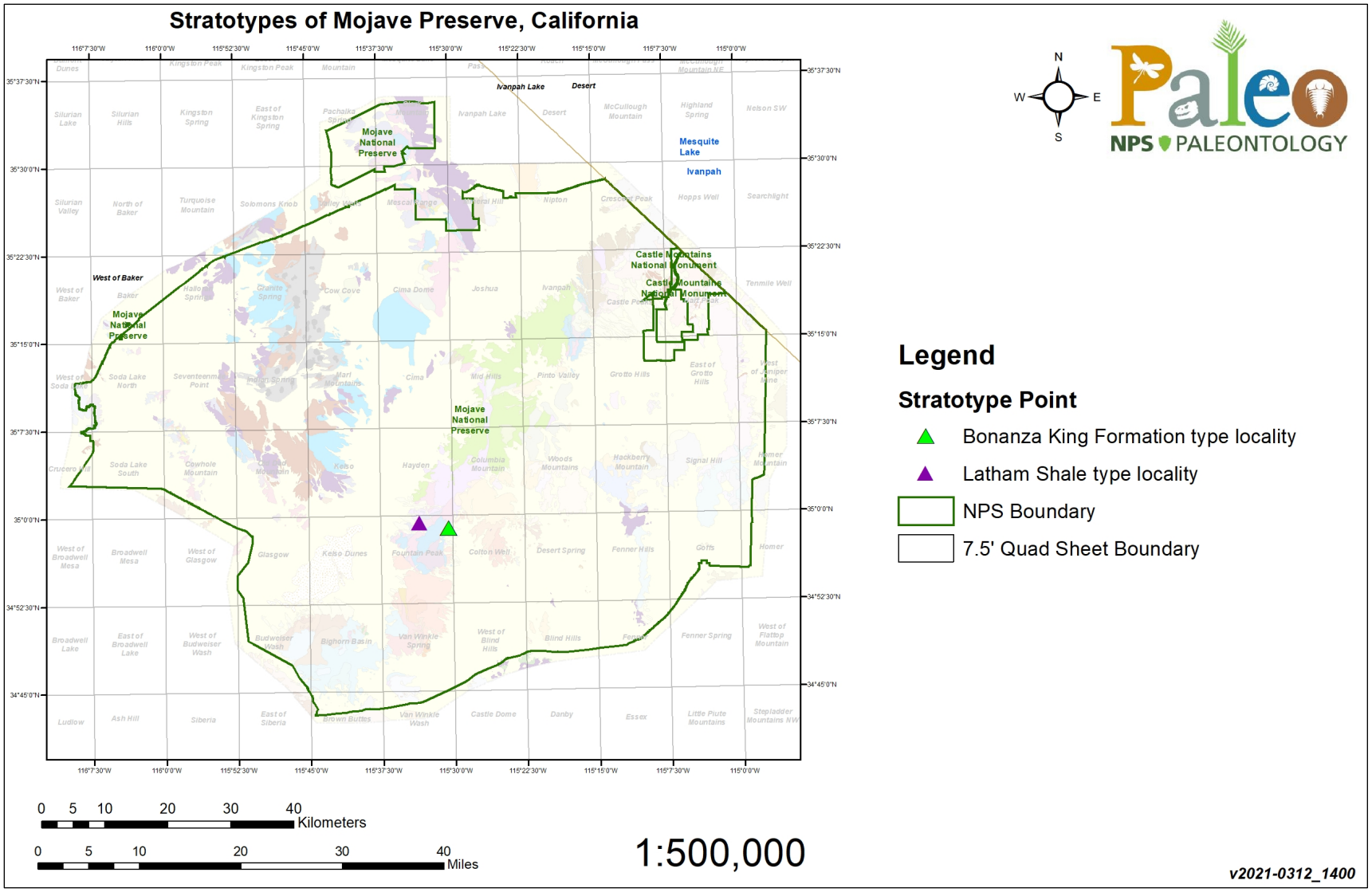


Figure 39. Modified geologic map of MOJA showing stratotype locations. The transparency of the geologic units layer has been increased.

The Cambrian Latham Shale was named by Hazzard (1954) for its type locality exposures approximately 1.6 km (1 mi) southwest of a landmark Hazzard knew as “Latham’s cabin” in the northern Providence Mountains in San Bernardino County, California (Table 4; Figure 39). MOJA staff is unfamiliar with the name “Latham’s cabin” but there is an unnamed, old, collapsed cabin near a spring in this location (A. Andeskie, MOJA physical scientist, pers. comm., October 2021). Type locality exposures measure approximately 17–23 m (55–75 ft) thick and are composed of greenish-gray, platy shale and thin layers of sandy limestone (Hazzard 1954). Stratigraphically, the Latham Shale underlies the Chambless Limestone and overlies the Prospect Mountain Quartzite.

The Cambrian Bonanza King Formation was designated by Hazzard and Mason (1936) after its type locality exposures near Bonanza King mine on the east side of the Providence Range in San Bernardino County, California (Table 4; Figures 39 and 40). Thickness of the formation in the type locality exceeds 610 m (2,000 ft) and consists of reddish-brown sandy dolomite, light to dark gray dolomite, dolomitized limestone, and chert in the basal 30 m (100 ft) of the section (Hazzard and Mason 1936). The Bonanza King Formation stratigraphically occurs between the overlying Cornfield Springs Formation (now obsolete) and underlying Cadiz Formation.

Figure 40. Type locality exposures of the Bonanza King Formation at Bonanza King Mine, MOJA (MICHAEL WOLF).

In addition to the designated stratotypes located within MOJA, a list of stratotypes located within 48 km (30 mi) of the preserve boundaries is included here for reference. These nearby stratotypes include the Proterozoic Noonday Dolomite (type locality); Cambrian Cadiz Formation (type section), Chambless Limestone (type locality) and Emigrant Pass Member of the Zabriskie Quartzite (type locality); Ordovician–Devonian Mountain Springs Formation (type section); Devonian–Mississippian Sultan Limestone (type locality), Valentine Limestone Member of the Sultan Limestone (type locality), Ironside Dolomite Member of the Sultan Limestone (type area), and Crystal Pass Limestone Member of the Sultan Limestone (type locality); Mississippian Monte Cristo Formation (type locality), Anchor Limestone Member of the Monte Cristo Formation (type locality), Bullion Dolomite Member of the Monte Cristo Formation (type locality), Dawn Limestone Member of the Monte Cristo Formation (type locality), and Yellowpine Limestone Member of the Monte Cristo Formation (type locality); Jurassic Mountain Pass Rhyolite (type area) (now known to be Cretaceous in age; also known as the informal Delfonte Volcanics [Fleck et al. 1994]), Avawatz Mountain Quartz Monzodiorite (type locality), Aztec Sandstone (type locality) and Bullion Mountains Intrusive Suite (type locality); Oligocene–Miocene Valley Springs Formation (type section); Miocene Horse Thief Spring Formation (type locality) and Patsy Mine Volcanics (type section) and the Miocene–Pliocene Mehrten Formation (type section).

Grand Canyon-Parashant National Monument (PARA)

Grand Canyon-Parashant National Monument (PARA) (commonly referred to as Parashant National Monument) is located on the northern edge of the Grand Canyon at the junction of the Colorado Plateau and Basin and Range physiographic provinces in Mohave County, Arizona (Figure 41). Established on January 11, 2000, PARA protects 410,351 hectares (1,014,000 acres) of biologically diverse and impressive remote landscape. PARA has a rich human history dating back over 11,000 years in the form of rock art images, agricultural features, rock shelters, and burial sites. The deep canyons, mountains, and buttes in PARA provide iconic vistas in a setting known for its solitude, silence, night skies, and wilderness. PARA is administered jointly by the NPS and the Bureau of Land Management, and the NPS portions of PARA are also technically part of LAKE.

PARA is a geological treasure predominantly consisting of relatively flat, unobscured Paleozoic and Mesozoic sedimentary strata that tell the rich history of the Colorado Plateau (Figures 42 and 43). The deep canyons of the monument are a testament to the powerful forces of the Colorado River that have continuously eroded and exposed a variety of colorful geologic formations. PARA contains numerous faults such as the Dellenbaugh, Hurricane, Grand Wash, and Toroweap faults that range in age from several million years old to as recent as 30,000 years ago. The landscape of PARA has been volcanically active since the Miocene (7–6 million years ago), with several lava flows that infilled small portions of the Grand Canyon and temporarily dammed the Colorado River (Billingsley et al. 2000).

There are two designated stratotypes identified within the boundaries of the NPS-administered portion of PARA, for the Permian Queantoweap Sandstone and Miocene Shivwits Basalt (Table 5; Figure 44). In addition, there are 12 stratotypes found within the BLM-administered portion of PARA. Although detailed discussion is outside of the scope of this report, it is worth listing these for reference. They are for the Permian-age Pakoon Limestone (type section), Coconino Sandstone (reference section), Toroweap Formation (reference section), Brady Canyon Member of the Toroweap Formation (reference section), Woods Ranch Member of the Toroweap Formation (type locality), Kaibab Formation (reference section), Fossil Mountain Member of the Kaibab Formation (reference section), and Harrisburg Member of the Kaibab Formation (reference section); the Pliocene Grassy Mountain Basalt (type area) and Poverty Mountain Basalt (type area); the Pleistocene Basalt of Hill 6588 (type area); and the Holocene Little Spring Basalt (type locality). Finally, there are eight other stratotypes located within 48 km (30 mi) of PARA-NPS boundaries, for the Mississippian Surprise Canyon Formation (type section); the Mississippian–Pennsylvanian Watahomigi Formation (type section); the Pennsylvanian Manakacha Formation (type section) and Wescogame Formation (type section); the Permian Esplanade Sandstone (type section), Coconino Sandstone (type section); and Toroweap Formation (type section); and the Miocene Blue Mountain Basalt (type locality).

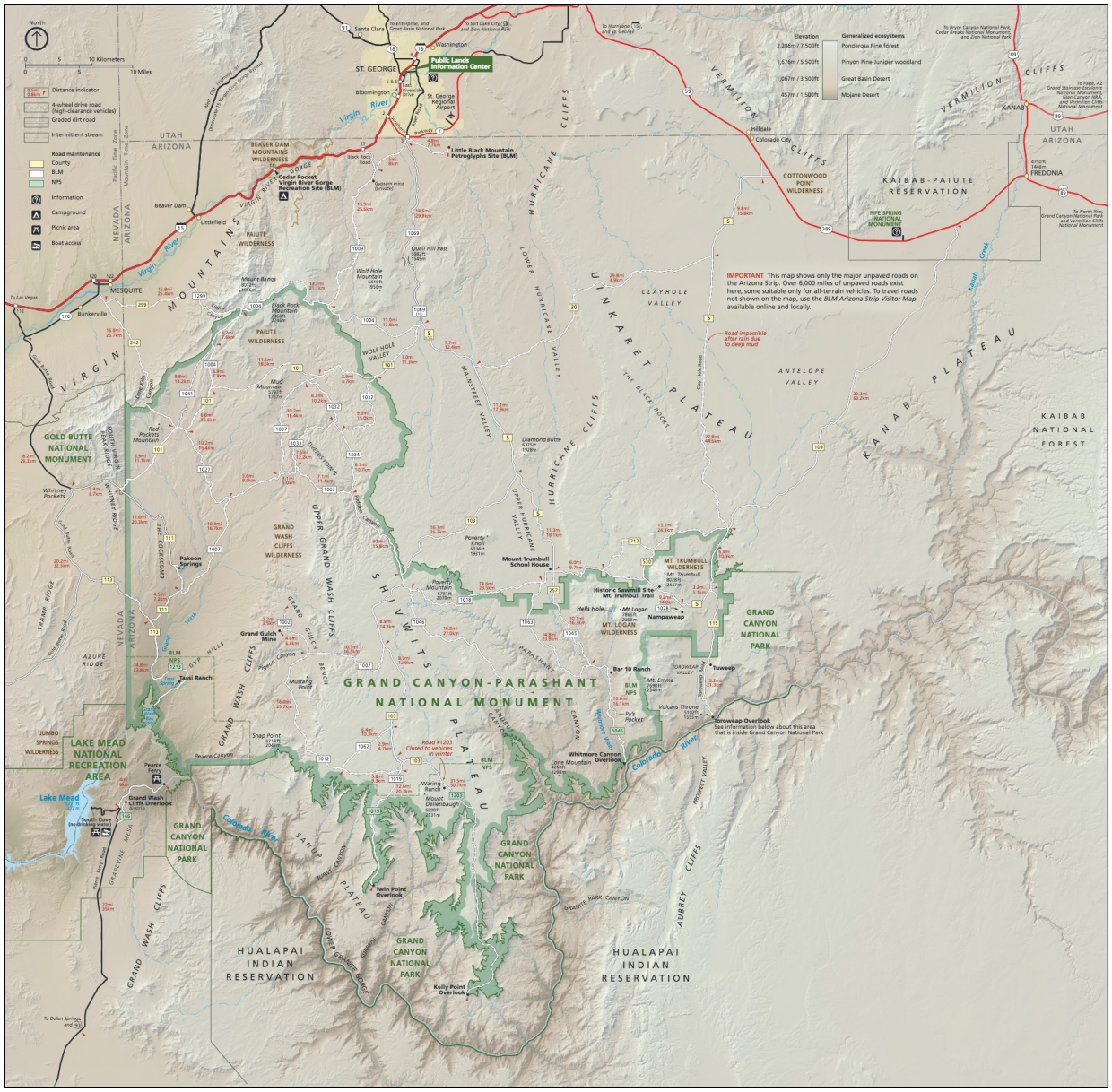


Figure 41. Park map of PARA, Arizona (NPS).

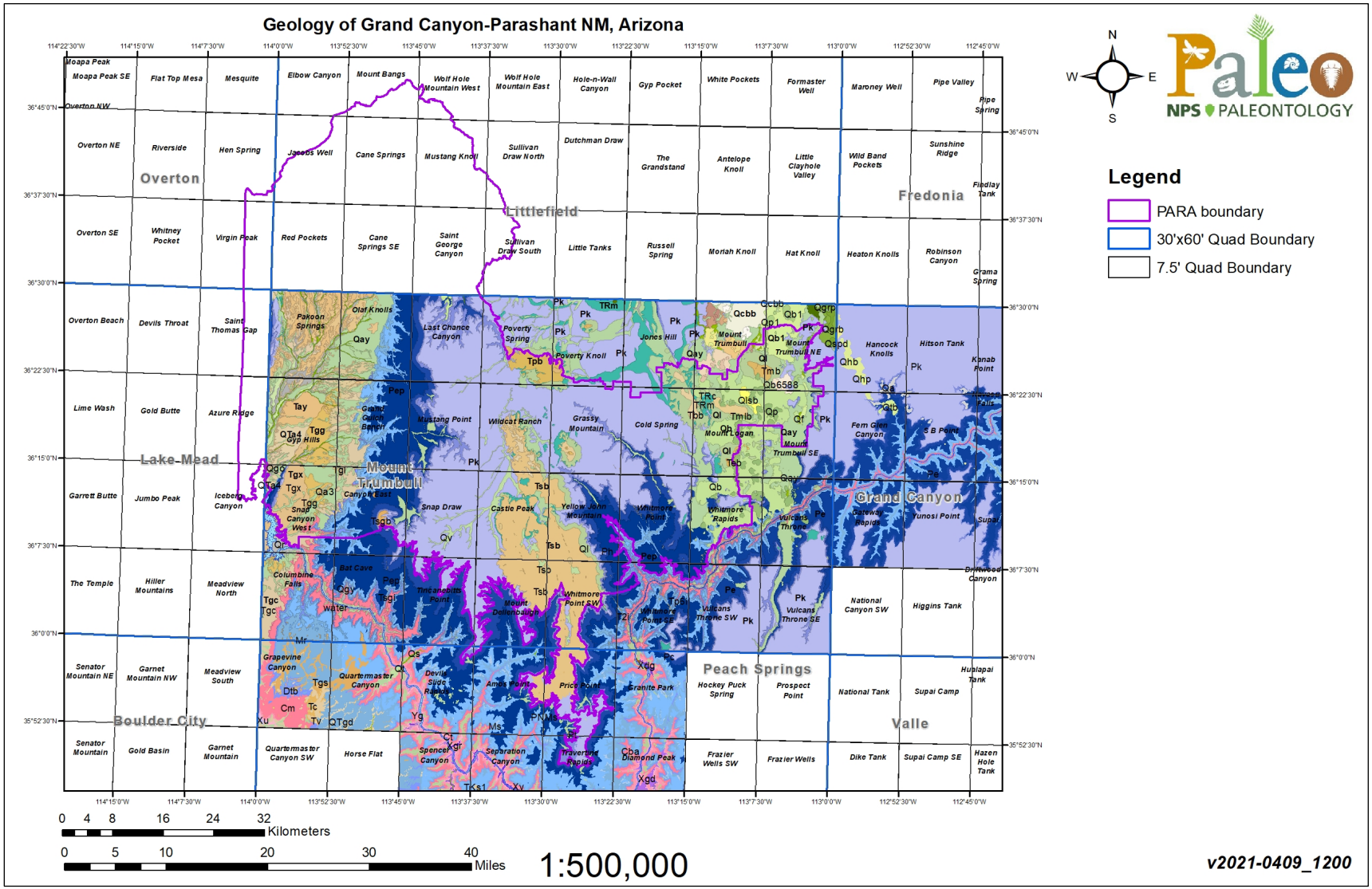


Figure 42. Geologic map of PARA, Arizona (see Figure 43 for legend).

Legend

- PARA boundary
- NPS Boundary
- 7.5' Quad Boundary
- Water - Lakes
- Qay - Younger alluvial deposits (Holocene and latest Pleistocene?)
- Qai - Intermediate-age alluvial deposits (Pleistocene)
- Qao - Older alluvial deposits (Pleistocene)
- Qr - River deposits, undifferentiated (Pleistocene)
- QTtc - Talus and colluvium (Holocene, Pleistocene, and Pliocene)
- QTl - Landslide deposits (Pliocene? to Pleistocene)
- QTa - Oldest alluvial deposits (upper Pliocene to Pleistocene)
- QTk - Calcrete (upper Pliocene? to lower Pleistocene)
- QTs - Spring deposits of uncertain age (Pliocene to Pleistocene)
- Ta - Alluvial fan deposits (Pliocene)
- Trb - Bullhead alluvium and equivalent age deposits (Pliocene)
- Tgc - Paleozoic-clast conglomerate in Grand Wash trough (Pliocene)
- Tgr - Red siltstone, sandstone and conglomerate in Grand Wash trough (Pliocene)
- Tgb - Basalt flows and minor gravels of Grand Wash (lower Pliocene)
- Tgbg - Interbedded mainstream gravels (lower Pliocene)
- Th - Hualapai Limestone (upper Miocene)
- Tgws - Rocks of the Grand Wash Trough, sandstone and siltstone (upper and middle Miocene)
- Tgwg - Rocks of the Grand Wash Trough, gypsum (upper and middle Miocene)
- Tgwc - Rocks of the Grand Wash Trough, conglomerate (upper and middle Miocene)
- Tgwcb - Rocks of the Grand Wash Trough, limestone-clast breccia (upper and middle Miocene)
- Tgwcl - Rocks of the Grand Wash Trough, conglomerate, bearing limestone clast (upper and middle Miocene)
- Tgwcp - Rocks of the Grand Wash Trough, conglomerate, bearing granitic and metamorphic clast (upper and middle Miocene)
- Thr - Horse Spring Formation, Rainbow Gardens Member (lower Miocene and upper Oligocene)
- Ti - Intrusive rocks, undifferentiated (middle Miocene)
- Pkt - Kaibab and Toroweap Formations, undivided (Lower Permian)
- Phe - Hermit Formation and Esplanade Sandstone, undivided (Lower Permian)
- Pep - Supai Group, Esplanade Sandstone and Pakoon Limestone (Lower Permian)
- PMpc - Supai Group, Pakoon Limestone and Callville Formation, undivided (Upper Mississippian to Lower Permian)
- PNMs - Supai Group, undivided (Pennsylvanian and Upper Mississippian)
- Ms - Surprise Canyon Formation (Upper Mississippian)
- Mr - Redwall Limestone (Upper and Lower Mississippian)
- Dtb - Temple Butte Formation (Upper and Middle Devonian)
- Cm - Muav Formation (Middle Cambrian)
- Cba - Bright Angel Shale (Middle Cambrian)
- Ctb - Tapeats Sandstone and Bright Angel Shale, undivided (Middle and Lower Cambrian)
- Yg - Gold Butte Granite (Mesoproterozoic)
- Xlg - Leucogranite and pegmatite gneiss (Paleoproterozoic)
- Xum - Mafic and ultramafic metamorphic rocks, undivided (Paleoproterozoic)
- Xgn - Gneiss, undivided (Paleoproterozoic)
- Xgg - Granitic gneiss (Paleoproterozoic)
- Xqs - Quartz syenite gneiss (Paleoproterozoic)
- Xggn - Garnet gneiss (Paleoproterozoic)

Figure 43. Geologic map legend of PARA, Arizona.

Table 5. List of PARA stratotype units sorted by age with associated reference publications and locations.

Unit Name (map symbol)	Reference	Stratotype Location	Age
Shivwits Basalt	Billingsley et al. 2006	Type section: Mount Dellenbaugh (sec. 2, T. 31 N., R.12 W.), the highest point on Shivwits Plateau (elev. 7,072 ft), AZ (Billingsley et al. 2006)	late Miocene
Queantoweap Sandstone	McNair 1951	Type section: east side of Queantoweap Valley (now referred to as Pa's Pocket) between the upper and lower lava flows, near a well locally known as "Gramps Basin", Mohave Co., AZ	Permian

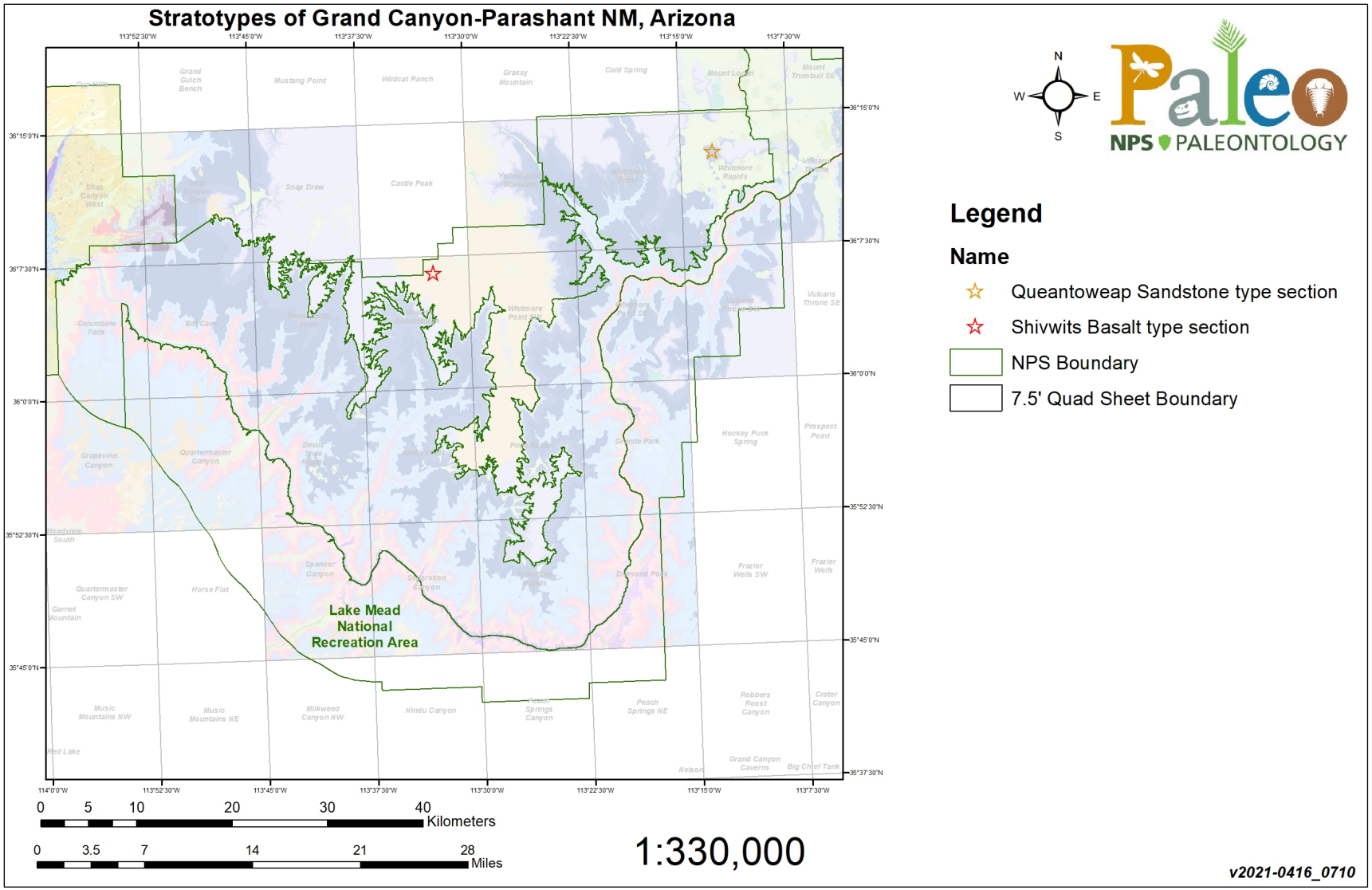


Figure 44. Modified geologic map of PARA showing stratotype locations. The transparency of the geologic units layer has been increased.

The Permian Queantoweap Sandstone was named by McNair (1951) after its type section exposure on the east side of Queantoweap Valley (now referred to as Pa's Pocket) in Mohave County, Arizona (Table 5; Figure 44). The type section measures approximately 120 m (393 ft) thick and consists of pink and gray, massive, cliff-forming, cross-bedded sandstone (McNair 1951). Stratigraphically, the Queantoweap Sandstone overlies the Pakoon and upper Callville limestones and underlies the Hermit Shale.

The Miocene Shivwits Basalt was informally named by Best et al. (1980) after Shivwits Plateau in northern Mojave County, Arizona. The unit was formally designated by Billingsley et al. (2006), who measured and described the type section on Mount Dellenbaugh, the highest point on Shivwits Plateau at 2,156 m (7,072 ft) (Table 5; Figure 44). In the region of the type section, the Shivwits Basalt is a widespread unit of basaltic flows and associated pyroclastic vents and dikes. Flows of the unit are associated with several mountains centered around Mount Dellenbaugh, including Blue Mountain, Yellow John Mountain, Grassy Mountain, and Poverty Mountain (Best et al. 1980). The Shivwits Basalt commonly overlies the Moenkopi Formation or Kaibab Formation (Billingsley et al. 2006).

Tule Springs Fossil Beds National Monument (TUSK)

Tule Springs Fossil Beds National Monument (TUSK) is located approximately 13 km (8 mi) north of the Las Vegas metropolitan area in Clark County, Nevada (Figure 45). Established as an NPS unit on December 19, 2014, the monument preserves 9,166 hectares (22,650 acres) of fossil-rich Pleistocene strata that include Columbian mammoths, sloths, American lions, camels, bobcats, horses, deer, bison, snakes, birds, frogs, lizards, rodents, and more. The fossil assemblage found in TUSK, called the Tule Springs local fauna, represents one of the most important Pleistocene vertebrate faunas in the American Southwest (Springer et al. 2018a). The history of the Pleistocene Epoch preserved at TUSK may hold clues about local and regional climate change, including periods of time where the climate was wetter than today and a vast wetland ecosystem existed throughout the Las Vegas Valley (Anderson 2017).

The geologic record at TUSK is limited to Pleistocene and younger deposits that form a thick (greater than 30 m or 100 ft) sequence of lithified to unlithified sediments deposited between the middle Pleistocene and the present (Figures 46 and 47; Tweet et al. 2016). The abundant and diverse vertebrate fossil assemblage of the Tule Springs local fauna occurs throughout most of the Pleistocene Las Vegas Formation and spans from ~100,000–12,500 years ago (Scott et al. 2017); the base of the formation is significantly older, with one date of 573,000 ± 52,000 years (Springer et al. 2018a). Once thought to be the remnants of an ancient lake, the Las Vegas Formation is now recognized as representing a vast spring ecosystem (Springer et al. 2018b). Rocks of the Las Vegas Formation record hydrologic conditions where the water table was so high that groundwater flowed to the surface to feed springs and oases that allowed a diversity of life to thrive.

TUSK once contained an identified stratotype assigned to the Pleistocene Las Vegas Formation (Table 6; Figure 48). Due to urban expansion and development, the type section assigned by Longwell et al. (1965) has been destroyed but numerous measured sections of the formation have been made by Springer et al. (2018a) within the boundaries of TUSK (Table 6). See "Recommendations" below.

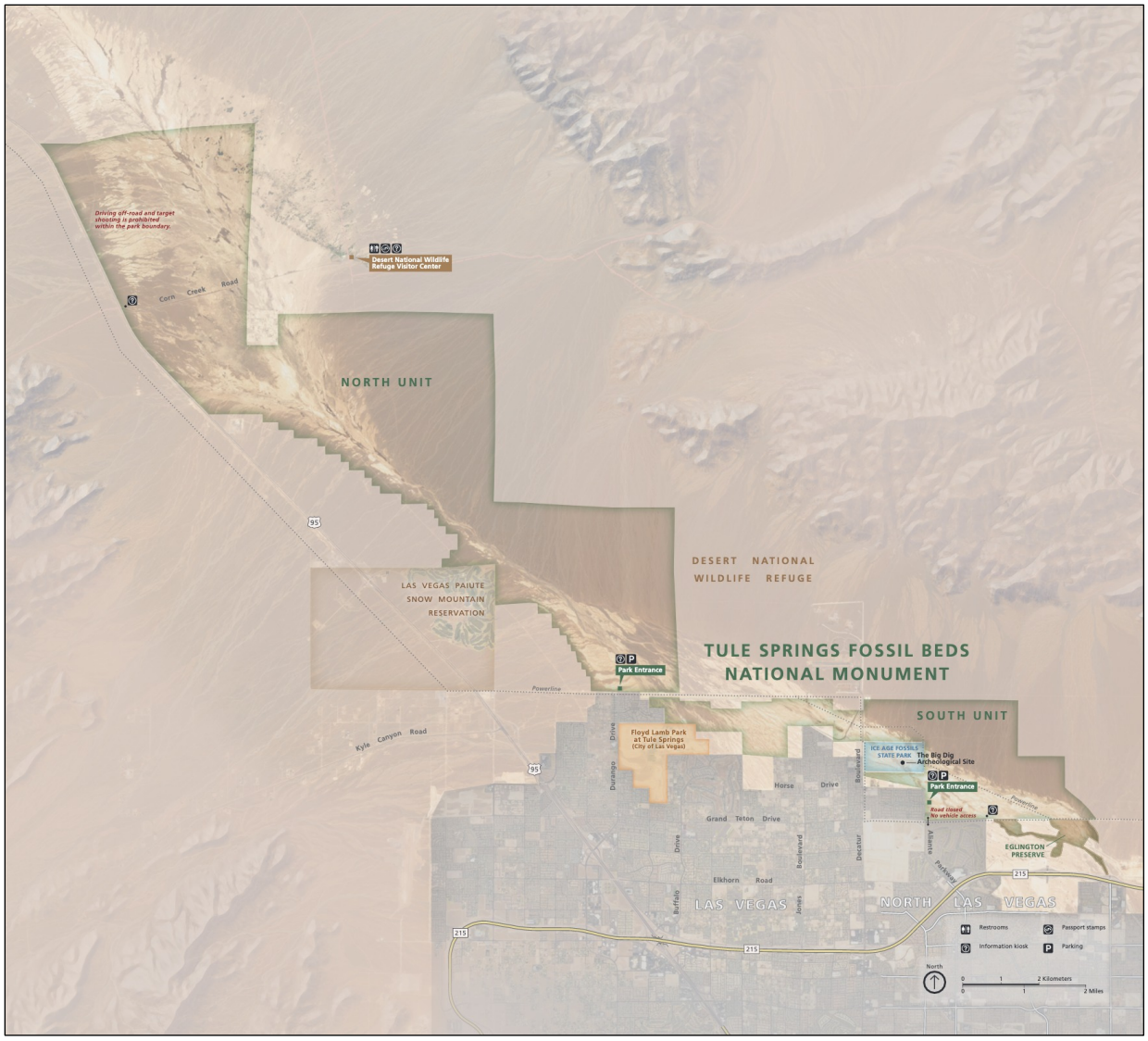


Figure 45. Regional map of TUSK, Nevada (NPS).

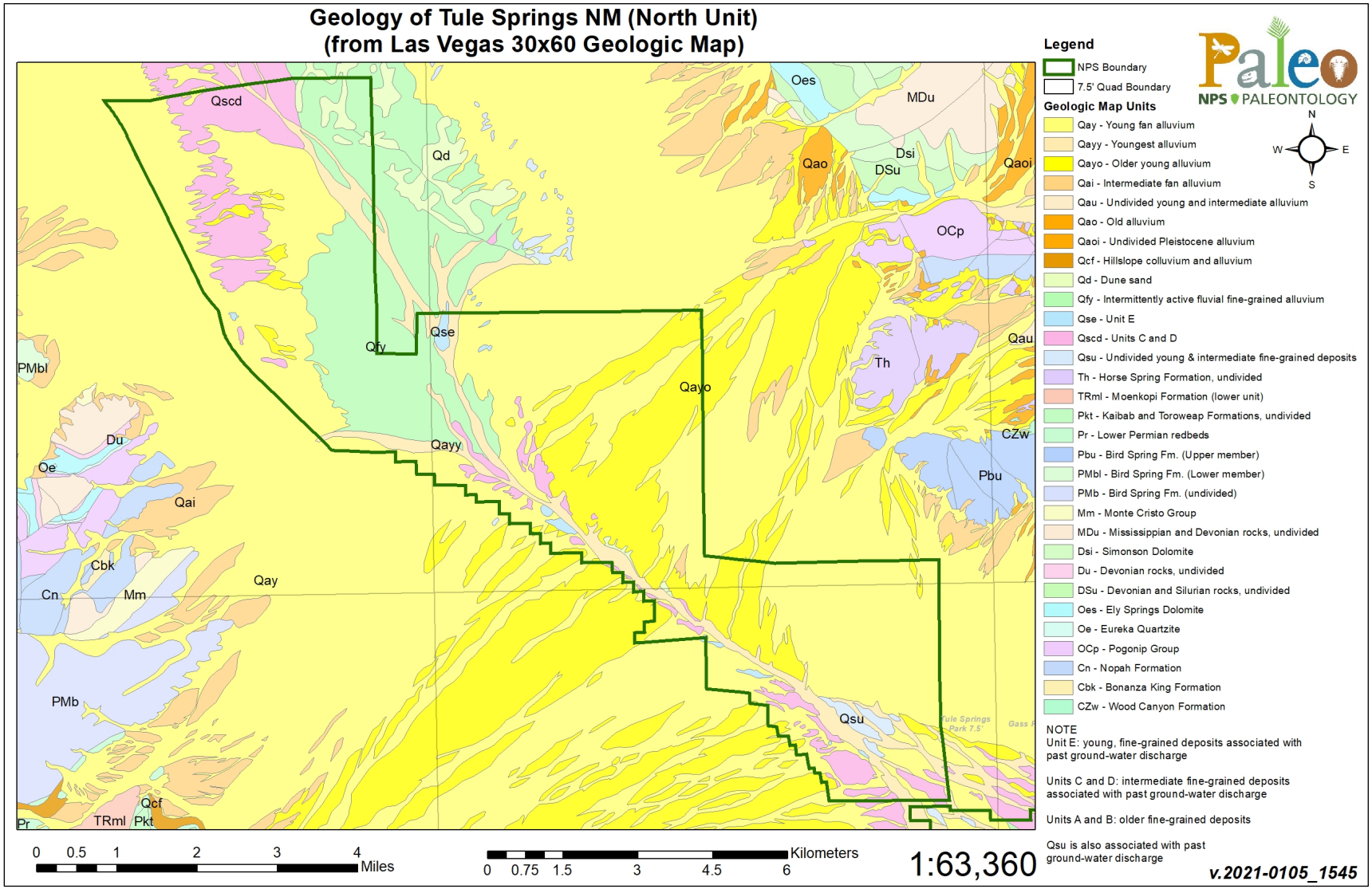


Figure 46. Geologic map of TUSK (north unit), Nevada.

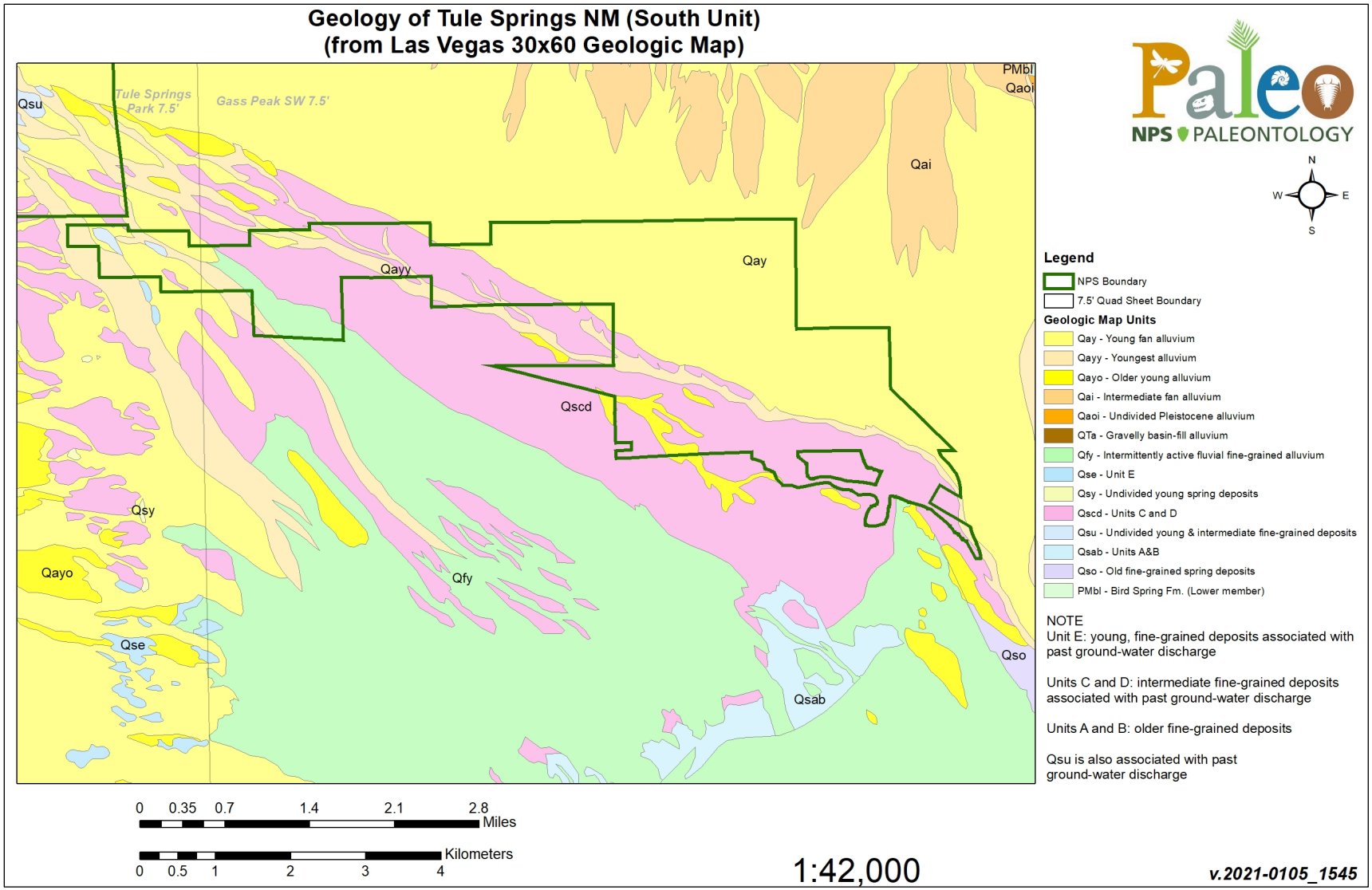


Figure 47. Geologic map of TUSK (south unit), Nevada.

Table 6. List of TUSK stratotype units sorted by age with associated reference publications and locations.

Unit Name (map symbol)	Reference	Stratotype Location	Age
Las Vegas Formation	Longwell et al. 1965; Springer et al. 2018a	Type section: along Las Vegas Wash east of Tule Springs, NE/4 of T. 19 S., R. 60 E., Clark Co., southeastern NV (***NOW DESTROYED OR RESTRICTED WITHIN TUSK***)	Pleistocene

Figure 48. Buff-colored, fine-grained, fossiliferous sedimentary deposits of the Las Vegas Formation sit against the backdrop of the Las Vegas Range in the northern Las Vegas Valley, Nevada. Cover photo from Springer et al. (2018a).

The Pleistocene Las Vegas Formation was named by Longwell et al. (1965) for light-colored, fine-grained, fossiliferous sedimentary deposits along Las Vegas Valley, Nevada. The type section of the formation is designated along Las Vegas Wash east of Tule Springs (NE1/4 of T. 19 S., R. 60 E.) in Clark County, southeastern Nevada (Table 6; Longwell et al. 1965). Such a wide distribution would be characterized as type locality or type area by modern definition (North American Commission on Stratigraphic Nomenclature 2005; K. Springer, pers. comm., 2021). The formation consists of silt, clay, sand, carbonate, and charcoal deposits that form thin, regular bedding (Figure 48; Longwell et al. 1965; Springer et al. 2018a). Since the publication of Longwell et al. (1965), urban development and expansion has destroyed the type section and limited much of the formation exposure distribution to within the boundaries of TUSK (Springer et al. 2018a). The heterogeneous nature and extent of the formation cannot be captured in one location; numerous stratigraphic sections are reported by Springer et al. (2018a) along the Las Vegas Wash and within TUSK (see "Recommendations" below).

In addition to the designated stratotypes located within TUSK, a list of stratotypes located within 48 km (30 mi) of monument boundaries is included here for reference. These nearby stratotypes include the Neoproterozoic Stirling Quartzite (type locality); Neoproterozoic–Cambrian Wood Canyon Formation (type locality); Cambrian Desert Range Limestone Member of the Carrara Formation (type locality); Ordovician Ranger Mountains Member of the Antelope Valley Formation (type locality); Ordovician–Devonian Mountain Springs Formation (type section); Mississippian Indian Springs Formation (type area) and Dawn Limestone Member of the Monte Cristo Formation (type locality); Jurassic Aztec Sandstone (type locality); and the Miocene Horse Spring Formation (reference section), Thumb Member of the Horse Spring Formation (type section and reference section), Rainbow Gardens Member of the Horse Spring Formation (type section), Lovell Wash Member of the Horse Spring Formation (type section), and Bitter Ridge Limestone Member of the Horse Spring Formation (type section).

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). *Stratotypes represent unique geologic exposures and should be considered extremely important to protect for the advancement of the scientific community for future generations*.

2) Once the MOJN Geologic Type Section Inventory report is finalized, the NPS Geologic Resources Division should schedule a briefing for the staff of the MOJN and respective network parks on the significance of this report.

3) Several recognized geologic units are named after features located within the boundaries of DEVA but lack designated stratotypes. These units include the Neoproterozoic Sourdough Limestone Member of the Kingston Peak Formation and Surprise Member of the Kingston Peak Formation; Triassic Butte Valley Formation; Jurassic Warm Spring Formation; Cretaceous Hunter Mountain Quartz Monzonite; Miocene Shoshone Volcanics, Little Chief Granite, and Willow Spring Gabbro; and Pliocene Nova Formation. It is recommended that stratotype designations of these units be made in order to: A) provide a standard reference for scientific research; B) educate park staff and visitors about the geoheritage significance of these units; and C) help safeguard these exposures.

4) The Cambrian Pole Canyon Limestone is located within the boundaries of GRBA but currently lacks a complete type section (Drewes and Palmer 1957). It is recommended that a stratotype designation of the unit be made in order to: A) provide a standard reference for scientific research; B) educate park staff and visitors about the geoheritage significance of these units; and C) help safeguard these exposures.

5) Several recognized geologic units are named after features located within the boundaries of JOTR but lack designated stratotypes. These units include the Pleistocene Pinto Formation (informal), Paleoproterozoic Pinto Gneiss, and Jurassic–Cretaceous White Tank Monzonite. It is recommended that stratotype designations of these units be made in order to: A) provide a standard reference for scientific research; B) educate park staff and visitors about the geoheritage significance of these units; and C) help safeguard these exposures.

6) Several recognized geologic units are named after features located within the boundaries of LAKE but lack designated stratotypes. These units include the Mesoproterozoic Davis Dam Granite and Gold Butte Granite, and Miocene–Pliocene Fortification Basalt Member of the Muddy Creek Formation. It is recommended that stratotype designations of these units be made in order to: A) provide a standard reference for scientific research; B) educate park staff and visitors about the geoheritage significance of these units; and C) help safeguard these exposures.

7) Several recognized geologic units are named after features located within the boundaries of MOJA but lack designated stratotypes. These units include the Jurassic Sands Granite and Fountain Peak Rhyolite; Cretaceous Mid Hills Adamellite and Teutonia Quartz Monzonite; and Miocene Tortoise Shell Mountain Rhyolite, Wild Horse Mesa Tuff, and Hackberry Spring Volcanics. It is recommended that stratotype designations of these units be made in order to: A) provide a standard reference for scientific research; B) educate park staff and visitors about the geoheritage significance of these units; and C) help safeguard these exposures.
8) The Pleistocene Las Vegas Formation has been geospatially restricted due to urban expansion and development since its type section designation by Longwell et al. (1965) in the vicinity of TUSK. Numerous stratigraphic sections of the formation are described by Springer et al. (2018a) within TUSK. It is recommended that stratotype reference sections for the Las Vegas Formation be designated in order to: A) provide a standard reference for scientific research; B) educate park staff and visitors about the geoheritage significance of these units; and C) help safeguard these exposures.
9) 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. Preservation of stratotypes should not limit availability for future scientific research but help safeguard these exposures from infrastructural development.
10) 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 statewide), based on lithology, stratigraphy, fossils or notable features using procedural code outlined by the North American Commission on Stratigraphic Nomenclature.
11) From the assessment in (10), 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.
12) 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.
13) The NPS Geologic Resources Division should ensure the park-specific Geologic Type Section Inventory Reports are widely distributed and available online.
14) 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.
15) 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.

16) 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.

17) 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).

Literature Cited

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

Axelrod, D. I. 1940. A record of *Lyonothamnus* in Death Valley, California. The Journal of Geology 48(5):526–531.

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

Beard, L. S., R. E. Anderson, R. G. Bohannon, R. J. Brady, S. B. Castor, E. M. Duebendorfer, J. E. Faulds, T. J. Felger, K. A. Howard, M. A. Kuntz, and V. S. Williams. 2007. Preliminary geologic map of the Lake Mead 30' x 60' quadrangle, Clark County, Nevada, and Mohave County, Arizona. U.S. Geological Survey, Reston, Virginia. Open-File Report 2007-1010. Scale 1:100,000. Available at: https://pubs.usgs.gov/of/2007/1010/ (accessed October 25, 2021).

Bell, G. L., Jr., J. S. Tweet, and V. L. Santucci. 2016. Great Basin National Park: Paleontological resource inventory. Natural Resource Report NPS/GRBA/NRR—2016/1285. National Park Service, Fort Collins, Colorado.

Beratan, K. K., J. Hsieh, and B. Murray. 1999. Pliocene-Pleistocene stratigraphy and depositional environments, southern Confidence Hills, Death Valley, California. Pages 298–300 *in* L. A. Wright and B. W. Troxel, editors. Cenozoic basins of the Death Valley region. Geological Society of America. Boulder, Colorado. Special Paper 333.

Best, M. G., E. H. McKee, and P. E. Damon. 1980. Space-time composition patterns of late Cenozoic mafic volcanism, southwestern Utah and adjoining areas: American Journal of Science 280:1035–1050.

Billingsley, G. H., M. L. Harr, and J. L. Wellmeyer. 2000. Geologic map of the upper Parashant Canyon and vicinity, Mojave County, northwestern Arizona. U.S. Geological Survey, Reston, Virginia. Miscellaneous Field Studies Map 2343. Scale 1:31,680. Available at: https://pubs.usgs.gov/mf/2000/2343/ (accessed October 25, 2021).

Billingsley, G. H., D. L. Block, and H. C. Dyer. 2006. Geologic map of the Peach Springs 30' X 60' Quadrangle, Coconino and Mohave counties, northwestern Arizona. U.S. Geological Survey, Reston, Virginia. Scientific Information Map 2900. Scale 1:100,000. Available at: https://pubs.usgs.gov/sim/2006/2900/ (accessed October 25, 2021).

Blair, W. N., and A. K. Armstrong. 1979. Hualapai Limestone Member of the Muddy Creek Formation: the youngest deposit predating the Grand Canyon, southeastern Nevada, and northwestern Arizona. U.S. Geological Survey, Washington, D.C. Professional Paper 1111. Available at: https://pubs.er.usgs.gov/publication/pp1111 (accessed October 25, 2021).

Bonde, A., V. L. Santucci, J. S. Tweet, E. Eichenberg, and B. Moore. 2018. Lake Mead National Recreation Area: Paleontological resources inventory. Natural Resource Report NPS/LAKE/NRR— 2018/1618. National Park Service, Fort Collins, Colorado.

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.

Byers, F. M., Jr., W. J. Carr, P. P. Orkild, W. D. Quinlivan, and K. A. Sargent. 1976. Volcanic suites and related cauldrons of Timber Mountain-Oasis Valley caldera complex, southern Nevada. U.S. Geological Survey, Washington, D.C. Professional Paper 919. Available at: https://pubs.er.usgs.gov/publication/pp919 (accessed October 25, 2021).

Carlisle, D., R. M. Kettler, and S. C. Swanson. 1980. Geological study of uranium potential of the Kingston Peak Formation, Death Valley region, California. U.S. Department of Energy, Grand Junction, Colorado. GJBX 37(81). Available at: https://www.osti.gov/biblio/6732937 (accessed October 25, 2021).

Curry, H. D. 1941. Mammalian and avian ichnites in Death Valley. Geological Society of America Bulletin 52(12, Part 2):1979.

Drewes, H. 1963. Geology of the Funeral Peak Quadrangle, California, on the east flank of Death Valley. U.S. Geological Survey, Washington, D.C. Professional Paper 413. Available at: https://pubs.er.usgs.gov/publication/pp413 (accessed October 25, 2021).

Drewes, H. D., and A. R. Palmer. 1957. Cambrian rocks of southern Snake Range, Nevada. Bulletin of the American Association of Petroleum Geologists 41(1):104–120.

Dunne, G. C. 1977. Geology and structural evolution of Old Dad Mountain, Mojave Desert, California. Geological Society of America Bulletin 88(6):737–748.

Dunne, G. C., R. M. Gulliver, and C. H. Stevens. 1981. Correlation of Mississippian shelf-to-basin strata, eastern California. Geological Society of America Bulletin 92(1):I1–I4, II1–II38.

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.

Farmer, G. L., A. F. Glazner, H. G. Wilshire, J. L. Wooden, W. J. Pickthorn, and M. Katz. 1995. Origin of late Cenozoic basalts at the Cima volcanic field, Mojave Desert, California. Journal of Geophysical Research 100(B5):8399–8415.

Fenneman, N. M. 1946. Physical divisions of the United States (map). U.S. Geological Survey, Washington, D.C. Unnumbered. Scale 1:7,000,000. Available at: https://pubs.er.usgs.gov/publication/70207506 (accessed October 25, 2021).

Fleck, R. J., J. M. Mattinson, C. J. Busby, M. D. Carr, G. A. Davis, and B. C. Burchfiel. 1994. Isotopic complexities and the age of the Delfonte volcanic rocks, eastern Mescal Range, southeastern California. Geological Society of America Bulletin 106(10):1242–1253.

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

Graham, J. P. 2014. Great Basin National Park: Geologic resources inventory report. Natural Resource Report NPS/NRSS/GRD/NRR—2014/762. National Park Service, Fort Collins, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/2206957 (accessed October 25, 2021).

Greene, R. C., and R. J. Fleck. 1997. Geology of the northern Black Mountains, Death Valley, California. U.S. Geological Survey, Reston, Virginia. Open-File Report 97-79. Available at: https://pubs.er.usgs.gov/publication/ofr9779 (accessed October 25, 2021).

Hall, W. E., and E. M. MacKevett. 1958. Economic geology of the Darwin Quadrangle, Inyo County, California. California Division of Mines and Geology, Sacramento, California. Special Report 51.

Hall, W. E., and E. M. MacKevett. 1962. Geology and ore deposits of the Darwin quadrangle, Inyo County, California. U.S. Geological Survey, Washington, D.C. Professional Paper 368. Available at: https://pubs.er.usgs.gov/publication/pp368 (accessed October 25, 2021).

Hazzard, J. C. 1954. Rocks and structure of the northern Providence Mountains, San Bernardino County, California. Pages 27–35 *in* R. H. Jahns, editor. Geology of southern California. California Division of Mines, Sacramento, California. Bulletin 170, chapter 4.

Hazzard, J. C., and J. F. Mason. 1936. Middle Cambrian formations of the Providence and Marble Mountains, California. Geological Society of America Bulletin 47(2):229–240.

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 October 25, 2021).

Hunt, C. B., and D. R. Mabey. 1966. Stratigraphy and structure, Death Valley, California. U.S. Geological Survey, Washington, D.C. Professional Paper 494-A. Available at: https://pubs.er.usgs.gov/publication/pp494A (accessed October 25, 2021).

Johnson, E. A. 1971. Geology of a part of the southeastern side of the Cottonwood Mountains, Death Valley, California. Dissertation. Rice University, Houston, Texas.

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 October 25, 2021).

Knott, J. R., A. M. Sarna-Wojcicki, C. E. Meyer, J. C. Tinsley, III, S. G. Wells, and E. Wan. 1999. Late Cenozoic stratigraphy and tephrochronology of the western Black Mountains piedmont, Death Valley, California: Implications for the tectonic development of Death Valley. Pages 345–366 *in* L. A. Wright, and B. W. Troxel, editors. Cenozoic Basins of the Death Valley Region. Geological Society of America, Boulder, Colorado. Special Paper 333.

Knott, J. R., A. M. Sarna-Wojcicki, M. N. Machette, and R. E. Klinger. 2005. Upper Neogene stratigraphy and tectonics of Death Valley—A review. Earth-Science Reviews 73(1–4):245–270.

Langenheim, R. L., Jr., and H. Tischler. 1960. Mississippian and Devonian paleontology and stratigraphy, Quartz Spring area, Inyo County, California. University of California Publications in Geological Sciences 38(2):89–150.

Longwell, C. R. 1936. Geology of the Boulder Reservoir floor. Geological Society of America Bulletin 47(9):1393–1476.

Longwell, C. R. 1963. Reconnaissance geology between Lake Mead and Davis Dam, Arizona-Nevada. U.S. Geological Survey, Washington, D.C. Professional Paper 374-E. Available at: https://pubs.er.usgs.gov/publication/pp374E (accessed October 25, 2021).

Marvin, R. F., and S. W. Dobson. 1979. U.S. Geological Survey radiometric ages; Compilation "B". Isochron/West 26:3–32.

McAllister, J. F. 1952. Rocks and structure of the Quartz Spring area, northern Panamint Range, California. California Division of Mines and Geology, Sacramento, California. Special Report 25. Scale 1:19,200.

McAllister, J. F. 1955. Geology of mineral deposits in the Ubehebe Peak Quadrangle, Inyo County, California. California Division of Mines and Geology, Sacramento, California. Special Report 42.

McAllister, J. F. 1956. Geologic map of the Ubehebe Peak Quadrangle, California. U.S. Geological Survey, Washington, D.C. Geologic Quadrangle Map 95. Available at: https://ngmdb.usgs.gov/Prodesc/proddesc_383.htm (accessed October 25, 2021).

McAllister, J. F. 1970. Geology of the Furnace Creek borate area, Death Valley, Inyo County, California. California Division of Mines and Geology, Sacramento, California. Map Sheet 14. Scale 1:24,000.

McNair, A. H. 1951. Paleozoic stratigraphy of part of northwestern Arizona. Bulletin of the American Association of Petroleum Geologists 35(3):503–541.

Misch, P., and J. C. Hazzard. 1962. Stratigraphy and metamorphism of Late Precambrian rocks in central northeastern Nevada and adjacent Utah. Bulletin of the American Association of Petroleum Geologists 46(3):289–343.

Murphy, F. M. 1932. Geology of a part of the Panamint Range, California. California Journal of Mines and Geology 28(3):329–356.

Nelson, C. A. 1962. Lower Cambrian-Precambrian succession, White-Inyo Mountains, California. Geological Society of America Bulletin 73(1):139–144.

Noble, L. F. 1941. Structural features of the Virgin Spring area, Death Valley, California. Bulletin of the Geological Society of America 52(7):941–999.

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):118–25.

Palmer, A. R., and R. B. Halley. 1979. Physical stratigraphy and trilobite biostratigraphy of the Carrara Formation (lower and middle Cambrian) in the southern Great Basin. U.S. Geological Survey, Washington, D.C. Professional Paper 1047. Available at: https://pubs.er.usgs.gov/publication/pp1047 (accessed October 25, 2021).

Petterson, R., A. R. Prave, B. P. Wernicke, and A. E. Fallick. 2011. The Neoproterozoic Noonday Formation, Death Valley region, California. Geological Society of America Bulletin 123(7–8):1317–1336.

Reynolds, M. W. 1971. Stratigraphy and structural geology of the Titus and Titanothere Canyon areas, Death Valley, California. Dissertation. University of California-Berkeley, Berkeley, California.

Sawyer, D. A., R. J. Fleck, M. A. Lanphere, R. G. Warren, D. E. Broxton, and M. R. Hudson. 1994. Episodic caldera volcanism in the Miocene southwestern Nevada volcanic field; revised stratigraphic framework, $^{40}Ar/^{39}Ar$ geochronology, and implications for magmatism and extension. Geological Society of America Bulletin 106(10):1304–1318.

Scott, E., K. B. Springer, and J. C. Sagebiel. 2017. The Tule Springs local fauna: Rancholabrean vertebrates from the Las Vegas Formation, Nevada. Quaternary International 443(A):105–121.

Snow, J. K. 1990. Cordilleran orogenesis, extensional tectonics, and geology of the Cottonwood Mountains area, Death Valley region, California and Nevada. Dissertation. Harvard University, Cambridge, Massachusetts.

Snow, J. K., and D. R. Lux. 1999. Tectono-sequence stratigraphy of Tertiary rocks in the Cottonwood Mountains and northern Death Valley area, California and Nevada. Pages 17–64 *in* L. A. Wright and B. W. Troxel, editors. Cenozoic basins of the Death Valley region. Geological Society of America. Boulder, Colorado. Special Paper 333.

Springer, K. B., J. S. Pigati, C. R. Manker, and S. A. Mahan. 2018a. The Las Vegas Formation. U.S. Geological Survey, Reston, Virginia. Professional Paper 1839. Available at: https://pubs.er.usgs.gov/publication/pp1839 (accessed October 25, 2021).

Springer, K. B., J. S. Pigati, and E. Scott. 2018b. The geology and paleontology of Tule Springs Fossil Beds National Monument, Nevada. U.S. Geological Survey, Reston, Virginia. Fact Sheet 2018–3038. Available at: https://pubs.er.usgs.gov/publication/fs20183038 (accessed October 25, 2021).

Stevens, C. H., D. Klingman, and P. Belasky. 1995. Development of the Mississippian carbonate platform in southern Nevada and eastern California on the eastern margin of the Antler foreland basin. Pages 175–186 *in* S. L. Dorobek and G. M. Ross, editors. Stratigraphic evolution of foreland basins. Society for Sedimentary Geology, Tulsa, Oklahoma. Special Publication 52.

Stevens, C. H., D. S. Klingman, C. A. Sandberg, P. Stone, P. Belasky, F. G. Poole, and J. K. Snow. 1996. Mississippian stratigraphic framework of east-central California and southern Nevada with revision of Upper Devonian and Mississippian stratigraphic units in Inyo County, California. U.S. Geological Survey, Reston, Virginia. Bulletin 1988-J. Available at: https://pubs.er.usgs.gov/publication/b1988J (accessed October 25, 2021).

Stock, C. and F. Bode. 1935. Occurrence of lower Oligocene mammal bearing beds near Death Valley, California. Proceedings of the National Academy of Sciences 21(10):571–579.

Thornberry-Ehrlich, T. 2009. Manzanar National Historic Site Geologic Resources Inventory Report. Natural Resource Report NPS/NRPC/GRD/NRR—2009/130. National Park Service, Denver, Colorado. Available at: https://irma.nps.gov/DataStore/Reference/Profile/662742 (accessed October 25, 2021).

Tocci, A. M., V. L. Santucci, J. Tweet, K. B. Springer, and E. Scott. 2018. Joshua Tree National Park: paleontological resources inventory. Natural Resource Report NPS/JOTR/NRR—2018/1813. National Park Service, Fort Collins, Colorado.

Troxel, B. W. 1982. Basin facies (Ibex Formation) of the Noonday Dolomite, southern Saddle Peak Hills, southern Death Valley, California. Pages 43–48 *in* J. D. Cooper, B. W. Troxel, and L. A. Wright, editors. Geology of selected areas in the San Bernardino Mountains, western Mojave Desert, and southern Great Basin, California. Geological Society of America, Cordilleran Section, Guidebook Fieldtrip 9. Death Valley Publishing Co., Shoshone, California.

Tweet, J. S., V. L. Santucci, and T. Connors. 2016. Paleontological resource inventory and monitoring: Mojave Desert Network. Natural Resource Report NPS/MOJN/NRR—2016/1209. National Park Service, Fort Collins, Colorado.

Walcott, C. D. 1908. Nomenclature of some Cambrian Cordilleran formations. Pages 1–12 *in* C. D. Walcott. Cambrian geology and paleontology. Smithsonian Miscellaneous Collections 53. Available at: https://repository.si.edu/handle/10088/23377 (accessed October 25, 2021).

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 October 25, 2021).

Wright, L. A., J. H. Kramer, C. P. Thornton, and B. W. Troxel. 1984a. Type sections of two newly-named volcanic units of the central Death Valley volcanic field, eastern California, Appendix 1. Page 21–24 *in* L. A. Wright and B. W. Troxel. Geologic map and sections of the north 1/2 Confidence Hills 15' quadrangle, Inyo County, California. California Division of Mines and Geology, Sacramento, California. Map Sheet 34.

Wright, L. A., E. G. Williams, and B. W. Troxel. 1984b. Type section of the newly-named Proterozoic Ibex Formation, the basinal equivalent of the Noonday Dolomite, Death Valley region, California. Page 25–31 *in* L. A. Wright and B. W. Troxel. Geologic map and sections of the north 1/2 Confidence Hills 15' quadrangle, Inyo County, California. California Division of Mines and Geology, Sacramento, California. Map Sheet 34.

Yonkee, W. A., C. D. Dehler, P. K. Link, E. A. Balgord, J. A. Keeley, D. S. Hayes, M. L. Wells, C. M. Fanning, and S. M. Johnston. 2014. Tectono-stratigraphic framework of Neoproterozoic to Cambrian strata, west-central U. S.; protracted rifting, glaciation, and evolution of the North American Cordilleran margin. Earth-Science Reviews 136:59–95.

Appendix A: Source Information for GRI Maps of MOJN Parks

DEVA

- GMAP 75945: Workman, J. B., C. M. Menges, C. J. Fridrich, and R. A. Thompson. 2014. Geologic map of Death Valley National Park, California and Nevada. U.S. Geological Survey, Reston, Virginia. Scientific Investigations Map XXXX, unpublished digital data. Scale 1:150,000.

GRBA

- GMAP 7455: Miller, E. L., and the Stanford Geological Survey. 2007 (mapping 1993 to 1997). Geologic map of Great Basin National Park and environs, southern Snake Range, Nevada. Stanford Geological Survey, Stanford, California. Scale 1:24,000.

JOTR

- GMAP 75652: Powell, R. E., J. C. Matti, and P. M. Cossette. 2014. Joshua Tree National Park, Riverside and San Bernardino Counties, California: U.S. Geological Survey, Administrative Report for National Park Service, Geologic Map database version 2.0. Scale 1:100,000.

LAKE

- GMAP 75657: Beard, S., T. J. Felger, P. K. House, and K. A. Howard. In press. Geologic map of the Lake Mead National Recreation Area, Nevada and Arizona. U.S. Geological Survey, Reston, Virginia. Open-File Report XXXX-XXXX. Scale 1:62,500 and 1:100,000.

MANZ

- GMAP 1920: Stone, P., G. C. Dunne, J. G. Moore, and G. I. Smith. 2000. Geologic map of the Lone Pine 15' quadrangle, Inyo County, California. U.S. Geological Survey, Reston, Virginia. Geologic Investigations Series 2617. Scale 1:62,500. Available at: https://pubs.usgs.gov/imap/2617/ (accessed October 25, 2021).

MOJA

- GMAP 74819: Theodore, T. G., editor. 2007. Geology and mineral resources of the East Mojave National Scenic Area, San Bernardino County, California. U.S. Geological Survey, Reston, Virginia. Bulletin 2160. Scale 1:125,000. Available at: https://pubs.usgs.gov/bul/b2160/ (accessed October 25, 2021).

PARA

- GMAP 4151: Billingsley, G. H., D. L. Block, and H. C. Dyer. 2006. Geologic map of the Peach Springs 30' X 60' Quadrangle, Coconino and Mohave Counties, northwestern Arizona. U.S. Geological Survey, Reston, Virginia. Scientific Information Map 2900. Scale 1:100,000. Available at: https://pubs.usgs.gov/sim/2006/2900/ (accessed October 25, 2021).
- GMAP 4152: Billingsley, G. H., and J. L. Wellmeyer. 2004. Geologic map of the Mount Trumbull 30' X 60' quadrangle, Mohave and Coconino Counties, northwestern Arizona. U.S.

Geological Survey, Reston, Virginia. Geologic Investigations Series Map 2766. Scale 1:100,000. Available at: https://pubs.usgs.gov/imap/i2766/ (accessed October 25, 2021).

- GMAP 1174: Billingsley, G. H., and J. B. Workman. 2000. Geologic map of the Littlefield 30' x 60' quadrangle, Mohave County, northwestern Arizona. U.S. Geological Survey, Reston, Virginia. Geologic Investigations Map 2628. Scale 1:100,000. Available at: https://pubs.usgs.gov/imap/i2628/ (accessed October 25, 2021).

TUSK

- GMAP 29565: Bell, J. W., A. R. Ramelli, C. M. dePolo, F. Maldonado, and D. L. Schmidt. 1999. Geologic map of the Corn Creek Springs Quadrangle, Nevada. Nevada Bureau of Mines and Geology, Reno, Nevada. Map 121. Scale 1:24,000.
- GMAP 76014: Ramelli, A. R., W. R. Page, C. R. Manker, and K. B. Springer. 2012. Preliminary geologic map of the Corn Creek Springs NW Quadrangle, Clark County, Nevada. Nevada Bureau of Mines and Geology, Reno, Nevada. Open-File Report 12-7. Scale 1:24,000.
- GMAP 76015: Ramelli, A. R., W. R. Page, C. R. Manker, and K. B. Springer. 2011. Geologic map of the Gass Peak SW Quadrangle, Clark County, Nevada. Nevada Bureau of Mines and Geology, Reno, Nevada. Map 175. Scale 1:24,000.
- GMAP 29445: Bell, J. W., A. R. Ramelli, and S. J. Caskey. 1998. Geologic map of the Tule Springs Park Quadrangle, Nevada. Nevada Bureau of Mines and Geology, Reno, Nevada. Map 113. Scale 1:24,000.

Appendix B: Geologic Time Scale

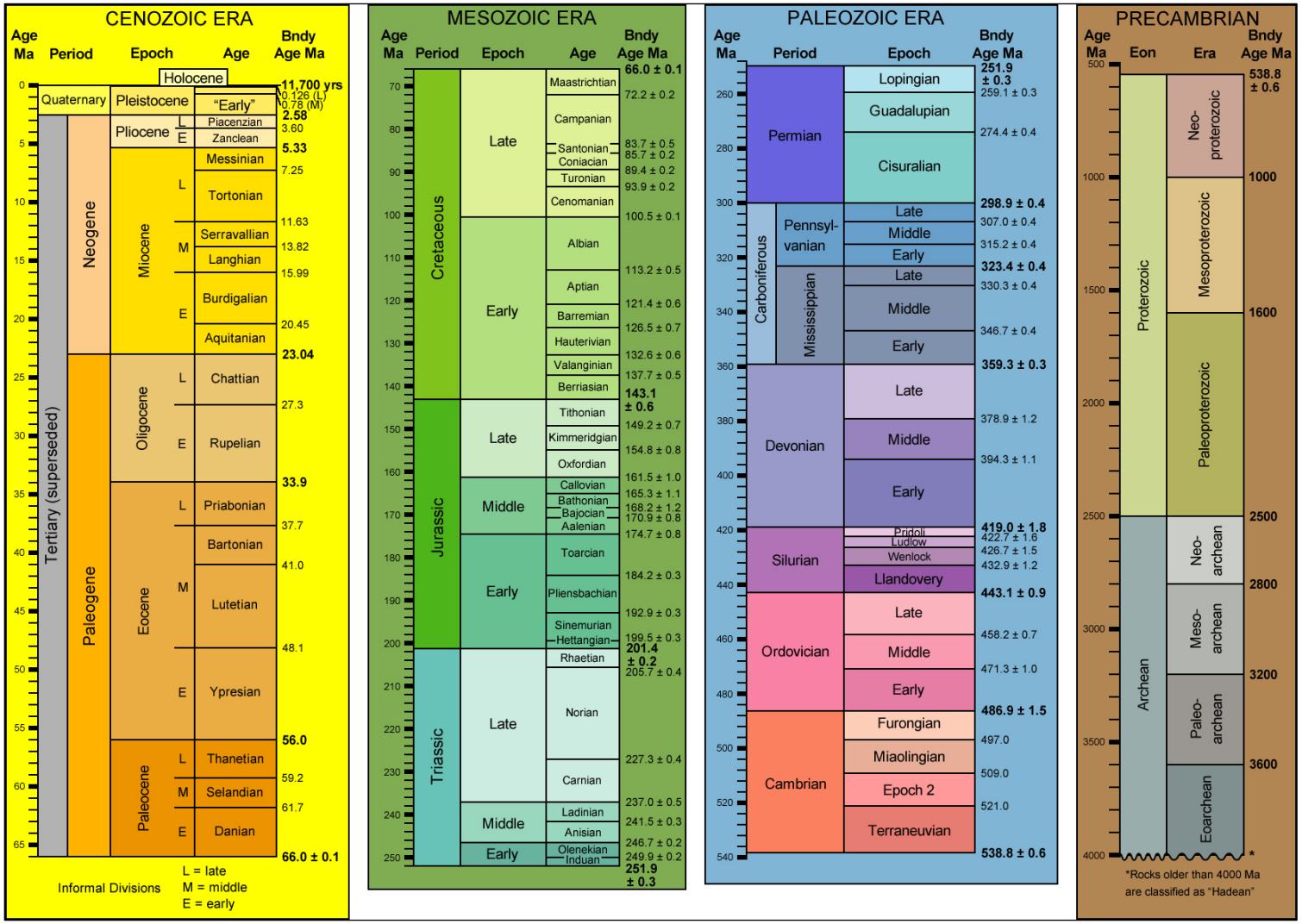


Figure B1. Geologic Time Scale. **Ma**=Millions of years old. **Bndy Age**=Boundary Age. Layout after 1999 Geological Society of America Time Scale (https://www.geosociety.org/documents/gsa/timescale/timescl-1999.pdf). Dates after Gradstein et al. (2020).

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