National Park Service
U.S. Department of the Interior

Natural Resource Stewardship and Science

Death Valley National Park

Geologic and Soil Resources Inventory Summary



On this page: Photograph facing west across the polygonal salt cracks of Badwater Basin. In the background, the Panamint Range and its extensive bajada rise above the Death Valley floor. NPS photograph.

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Please cite this report as:

Henderson, T. C. 2025. Death Valley National Park: Geologic and soil resources inventory summary. Unpublished report. National Park Service, Fort Collins, Colorado.
https://irma.nps.gov/DataStore/Reference/Profile/2307922.

Abstract

This document summarizes the status of National Park Service (NPS) Geologic Resources Inventory (GRI) and Soil Resource Inventory (SRI) deliverables for Death Valley National Park. It also provides information on current geology and soil resources management concerns with a focus on identified inventory needs related to geologic heritage, geohazards, and related soil features and processes. The purpose of this document is to help park staff prioritize technical assistance or new inventory and assessment funding requests in the near term (roughly 1–5 years).

GRI hosted a baseline scoping meeting for Death Valley National Park in 2002. Baseline bedrock and surficial geologic maps were first delivered to the park in 2014. SRI delivered a legacy soil database to the park in 2012. Several additional Natural Resources Conservation Service (NRCS) soil survey areas encompass the Death Valley region. The most up-to-date soil data for the national park is available through Web Soil Survey.

Death Valley National Park's geologic heritage includes a rich geologic history punctuated by several major glacial and tectonic events. With a geologic record spanning from the Paleoproterozoic to the present, rocks within the national park account for multiple stratotype designations and preserve an invaluable collection of paleontological resources. In the arid Mojave Desert environment, the barren geologic landscape is of outstanding aesthetic value and has been featured in various film productions and inspired many generations of artists. The geologic resources of the park share a diverse cultural history that includes Indigenous Peoples, early prospectors, miners, and geoscientists. The park's geologic and soil resources inventory needs include various data and/or GIS products related to the inventory and monitoring of cultural resources, disturbed lands, fossils, hydrological systems, and stratotypes. Additional needs expressed by park staff or found during literature review are related to geologic resource protection (visitor use), geoscience research, and geologic mapping.

Geologic hazards identified in the national park include abandoned mineral lands, cave and karst features, climate change, flooding (and flash flooding), mass wasting, radon, seismicity, toxicological soil, and volcanic activity. Inventory needs related to geohazards include monitoring strategies to help predict, quantify, and mitigate the damage these processes pose to the national park's geologic and soil resources, infrastructure, visitors, and staff.

Additional guidance for park staff regarding proposal processes and timeframes for the new Inventories and Assessment (I&A) program is available on the GSRI and I&A SharePoint sites.

Table of Contents

Abstract ..... **iii**

Table of Contents ..... **iv**

List of Figures ..... **vi**

List of Tables ..... **vi**

Background of the GSRI **1**
Baseline GSRI Products 1
Geologic Mapping 1
Soil Mapping 2
Possible Future GSRI Products 3

Geologic Setting and History **4**
Park Establishment and Setting 4
Geologic History 4
Proterozoic Assembly and Rifting of Rodinia 4
Snowball Earth 5
Development of the Western Cordillera 5
Nevadan Orogeny 5
Basin and Range Extension 6

Geologic Heritage **8**
Ancient Lakes 8
Indigenous Connections 9
Mining History 9
Metallic Mineral Mining 10
Non-metallic Mineral Mining 10
Stratotypes 11
Death Valley's Alien Landscape and NASA 16
Charles Walcott, Levi Noble, and H. Donald Curry 17
Aesthetic Values 18

Geologic Resource Management Issues and Inventory Needs **19**
Legislatively Required Geologic Inventories 19
Summary of Geologic and Soil Hazards 19
Flooding and Flash Flooding 23
Disturbed Lands 26
Abandoned Mineral Lands 27
Illegal Off-road Vehicles 27
Overgrazing 28
Illegal Marijuana Cultivation 28
Mass Wasting 29
Shrink/swell Soil 31
Cave and Karst 31
Seismicity 32
Climate Change 34
Volcanic Activity 35
Radon 36
Toxicological Soil 36
Geologic Resource Protection 36

Cave and Karst Resources 37
Groundwater Resources 37
Paleontological and Cultural Resources 38
Inventory Needs 38
Prior NRSS-Supported Work **42**
Geologic or Soil Research Permits 42
Previous or Ongoing Technical Assistance Requests 43
Internship Projects 44
Acknowledgements **45**
2002 Scoping Participants 45
2024 Follow-up Meeting Participants 45
Summary Author 46
Summary Review 46
Summary Editing 46
Literature Cited **47**

List of Figures

Figure 1. Block model showing the regional structural configuration of the Basin and Range province...7
Figure 2. Historic mining sites showing talc-rich ore deposits. 11
Figure 3. Dr. Carl Sagan poses with a model of the Viking lander near Mars Hill.....17
Figure 4. An NPS employee surveying an undercut roadway. 25
Figure 5. Photograph of a washed-out segment of Scotty's Castle Road. 26
Figure 6. Illegal off-road tire tracks on the Racetrack. 28
Figure 7. Aerial photograph of an illegal marijuana plot in the remote wilderness of DEVA. 29
Figure 8. Photograph of a car partially buried by a debris flow following August 2022 flooding.....30
Figure 9. Fault scarp located in the alluvial fan immediately south of Badwater. 33
Figure 10. Aerial photograph of Ubehebe Crater.....35

List of Tables

Table 1. Web Soil Survey areas related to DEVA.....2
Table 2. Geologic units and associated stratotypes mapped within the national park. 12
Table 3. Geologic and soil hazards checklist.....20
Table 4. Examples of historic and modern flood events in DEVA. 23
Table 5. Historical (1769–2015) earthquakes measuring above magnitude 5.0 recorded within DEVA..33
Table 6. List of identified geologic and soil resources inventory needs for the national park.....38
Table 7. Research permits related to the geology or soils of DEVA since 2020. 42
Table 8. Technical assistance requests related to the geology or soils of DEVA.....43

Background of the GSRI

The Geologic and Soil Resources Inventory (GSRI) is a new program encompassing the legacy Geologic Resources Inventory (GRI) and Soil Resources Inventory (SRI) programs. To inform park management decisions and planning, GSRI aids in the collection of new data and derives new information from existing data regarding the presence, absence, abundance, distribution, and significance of geologic or soil features or processes.

In the 1990s, the GRI and SRI programs were established as two of the 12 original baseline inventories in the Inventory and Monitoring (I&M) program. These baseline inventories compiled existing information, acquired new information, and helped establish a minimum level of data across more than 270 parks, which served as a common starting point for natural resource monitoring. For both the GRI and SRI, the primary deliverable was a digital (GIS) map. Between the 1990s and early 2020s, GRI scoping summaries, geologic map posters, and GRI reports were also produced for most of the 270 parks. GRI and SRI baseline inventory products are available through the NPS Geodiversity Atlas. These products are designed to enhance stewardship of park resources by providing valuable information about geologic formations, hazards, and links between geology, history, and other natural resources. As of 2024, the I&M program is transitioning from a baseline inventory strategy to a park-proposed inventory strategy.

The GRI and SRI are now unified as one inventory program, the Geologic and Soil Resources Inventory (GSRI), and will be integrated into the new Inventories & Assessment (I&A) Program, in which parks will submit geology- and soil-related project requests in PMIS during the Servicewide Comprehensive Call (SCC). This transition will begin in FY25, with new guidance enacted for GSRI. During this transition period, 13 “priority” parks, including Death Valley National Park, were identified as missing a baseline GRI report.

This GSRI summary serves as a substitute for a baseline GRI report and is intended to support the park’s participation in the new inventories program. As such, it summarizes the status of GRI and SRI deliverables for Death Valley National Park and provides information on current geology and soil resources management concerns with a focus on identified inventory needs. Information in this summary was compiled from existing reports, meetings with park staff, and the best professional judgment from GRI and WASO Geologic Resources Division (GRD) geoscientists.

Baseline GSRI Products

Geologic Mapping

The digital geologic map for the national park is adapted from an unpublished USGS map by Workman et al. (2014) and is available on the NPS DataStore accessed through the Integrated Resource Management Applications (IRMA) portal (see https://irma.nps.gov/DataStore/Reference/Profile/2194553; accessed 22 July 2024). Note that the unpublished digital map is currently restricted to NPS access only. The USGS has projected a published version of this map since at least 2002 and has communicated that the map and GIS data are getting updated, with an eventual goal of publication likely in 2025 at the earliest (Stephanie O’Meara, NPS GSRI, personal communication 17 July 2024). The national park is planning for either GSRI data migration or a new product based on new map availability. As of 2024, the geologic mapping of DEVA

will eventually be refined and integrated into the USGS Geologic Framework of the Intermountain West. The source map used for the current digital geologic map is:

- Workman, J. B., C. M. Menges, C. J. Fridrich, and R. A. Thompson. 2014. Geologic map of Death Valley National Park, California and Nevada: US Geological Survey Scientific Investigations Map SIM-XXXX, unpublished digital data, scale 1:150,000. (GRI Source Map ID 75945).

Soil Mapping

Soil maps provide information on soil types, including scores of different characteristics and management considerations including linear extensibility ("shrink-swell") potential, erosion potential, soil stability, suitability for site development, suitability for recreation development (e.g., trails), and many other topics. Perrone (2023) provides an overview of the use of soil data at the NPS WASO level and lists soil data currently available in the Natural Resources Conservation Service (NRCS) Web Soil Survey website along with NPS-specific uses for the data. The NRCS plans to complete all soil survey areas in the US by 2026 (Thompson et al. 2020).

The most up-to-date soils data for the national park is available via Web Soil Survey, which is updated and maintained regularly. Management-focused maps for the park or potential project areas can be developed on-demand on the website. The Web Soil Survey homepage gives instructions for how to view and download soil data. The Web Soil Survey data are broken down into county-level soil survey areas. Each soil survey area is assigned a code and a name. The national park and surrounding area includes nine soil survey areas that are either complete, forthcoming, or are planned for completion by 2026 (Table 1). To view the soil data on the Web Soil Survey website, use the navigation pane on the left side of the homepage to select the soil survey area or the NPS unit and set it as the "area of interest" using the "AOI" icon along the top of the map. The AOI icon along the top of the screen allows users to select specific areas of the map. Use the "Soil Map" tab at the top to view the soil map and the "Soil Data Explorer" tab to explore detailed soils data (e.g., soil suitability and limitations, soil properties, soil qualities, and ecological sites). See additional Web Soil Survey guidance and FAQs or contact the NRCS state soil scientist for technical assistance.

Additional soil mapping by the NPS SRI was completed for the national park in 2012 and is available on IRMA (https://irma.nps.gov/DataStore/Reference/Profile/2190842; accessed 22 July 2024).

Table 1. Web Soil Survey areas related to DEVA.

Web Soil Survey Area Code	Web Soil Survey Area Name	Status
CA793	Death Valley National Park Area, California and Nevada	Forthcoming
CA663	Inyo County Area, California	Not complete
CA695	Mojave Desert Area, California	Not complete
CA697	National Training Center, Fort Irwin, California	Complete
CA763	Inyo National Forest, Eastern Part, California and Nevada	Complete
CA805	Mojave Desert Area, Northeast Part, California	Complete
CA806	Fish Lake and Deep Springs Valleys Area, California	Complete
NV785	Nye County, Nevada, Southwest Part	Complete
NV796	Esmeralda County Area, Nevada	Complete

Possible Future GSRI Products

As the GSRI becomes integrated into the I&A, future GSRI products will be determined by the project proposals submitted by the parks. Moving forward, the GSRI program will fund inventory projects that include the following:

- Collect new data or derive new information from existing data regarding the presence, absence, abundance, distribution, and significance of geologic heritage, soil features or processes, or geohazards.
- Include features or processes on an individual feature- or landscape-scale.
- Include groups of features or maps of multiple features in a defined area of management needs.
- Are a snapshot in time and may set a baseline for monitoring or assessment.
- Typically include a geospatial (GIS) component.

GSRI project examples:

- Features and processes eligible for funding through the GSRI program include cave/karst, geothermal, paleontological (fossils), landslides and rockfall, other geohazards (e.g., avalanche, permafrost, volcanoes, earthquakes, tsunami, sinkholes), eolian, erosion, soil suitability and limitations for use, soil properties and qualities, ecological site descriptions, and other geologic or soil features or processes of management interest.
- Features and processes covered by other sources of funding and ***not*** eligible for GSRI funding are abandoned mineral lands (AML), orphaned oil and gas wells, coastal processes, coastal storm response, sea level change projections or mitigation, coastal engineering structures, or shoreline sediment movement.
- The GSRI will accept proposals for new baseline map products, such as funding a traditional geologic (bedrock or surficial) or soil mapping effort, especially at new or expanded parks outside the original 270 I&M parks. Parks requesting these products will need to indicate a management need that the baseline data will support.

Geologic Setting and History

Park Establishment and Setting

Death Valley National Park ("DEVA," also referred to as the "national park" herein) is in the Great Basin province of east-central California (Inyo and San Bernardino Counties) and southwest Nevada (Esmeralda and Nye Counties). Originally proclaimed a national monument on 11 February 1933, DEVA was re-designated a national park on 31 October 1994. Encompassing approximately 1,365,030 ha (3,373,063 ac), DEVA is the largest national park in the conterminous US. It preserves a diverse geologic landscape featuring rock formations, fault systems, fault-block mountain ranges, alluvial fans, fossils, cave and karst features, sand dunes, dry lake playas, canyons, intrusive igneous bodies, volcanic craters, and desert springs, including those that are home to the endangered Devils Hole pupfish. The national park features a vast, world-renowned collection of natural resources and was designated a Biosphere Reserve in 1984.

Death Valley National Park is a premier geologic setting to study complex, unique tectonic processes, dynamic erosional forces, and a diverse suite of geologic resources. The national park's extensive rock record stretches back over a billion years and preserves evidence of ancient depositional environments (e.g., shallow seas, lakes, and volcanic fields) and fossils that characterize significant evolutionary stages of life. The vast geologic history of DEVA ranges from Mesoproterozoic Era (~1.8 billion years old) metamorphic rocks exposed in the Black Mountains to modern playa sediments found in the valley basins. Tectonic and erosional processes have played a major role in shaping the rugged topography of the national park and continue to do so today. The famous Badwater Basin is the lowest elevation point in North America at 86 m (282 ft) below sea level, yet it sits adjacent to and within the shadow of Telescope Peak (3,368 m [11,049 ft] above sea level) due to ongoing extensional faulting that causes the basins to subside and mountains to rise.

Geologic History

The geologic history of the national park can be broken down into four significant tectonic episodes that formed its iconic landscape, adorned with fault-block ridges, volcanic ranges, massive canyons, and extensive salt pans. These events include (1) the Proterozoic assembly and rifting of the supercontinent Rodinia (forming the geologic core of North America); (2) multiple global-scale glacial events related to the Neoproterozoic "Snowball Earth"; (3) the development of the Western Cordillera of North America, including various collisional events and the emplacement of the Sierra Nevada batholith; and (4) ongoing Cenozoic extension and volcanism associated with the development of the Basin and Range province. These regional events have not only influenced the geologic evolution of the national park but also large areas of the western United States.

Proterozoic Assembly and Rifting of Rodinia

Some of the oldest rocks in the national park date back to the Paleoproterozoic Era (2.5 billion to 1.6 billion years ago) and consist of undifferentiated metamorphic and igneous assemblages (GSRI geologic map unit **Xmi**) approximately 1.8 billion years old. The geologic history recorded in these rocks is complex, as they have been severely deformed, weathered, and overprinted by subsequent tectonic events. However, this ancient crystalline bedrock forms part of the Mojave Province, one of several constituent crustal blocks that form the core of North America (Whitmeyer and Karlstrom 2007). The Mesoproterozoic and Neoproterozoic rocks of the Pahrump Group mainly consist of sediments that were deposited intermittently during the assembly and breakup of the supercontinent Rodinia approximately 1.2 billion to 600 million years ago

(Fridrich et al. 2012; Mahon et al. 2014a, b). The rifting of Rodinia opened a new ocean basin along the west coast of ancestral North America and the development of a long-lived passive margin. This passive margin accumulated an extensive sequence of marine sedimentary rock and is responsible for the fossiliferous Cambrian, Ordovician, Silurian, and Devonian strata of the national park (see "Paleontological Resources").

Snowball Earth

During the Neoproterozoic (1 billion to 541 million years ago), the rifting of Rodinia was coincident with several global-scale glacial events collectively referred to as "Snowball Earth." These glacial events enveloped the planet and occurred just before the rapid diversification of multicellular life recorded in younger rocks (541 to 485 million years ago) marking the Cambrian explosion (Hoffman and Schrag 2000). Within the national park, formations such as the Neoproterozoic Kingston Peak Formation record evidence of at least two glacial intervals: the Sturtian glaciation (approximately 717 million to 661 million years ago) and the subsequent Marinoan glaciation (approximately 652 million to 635 million years ago; Nelson et al. 2020). The Limekiln Spring Member, Surprise Member, and Wildrose submember of the Kingston Peak Formation all contain clues that suggest glacially influenced sedimentation, including massive diamictites (a lithified sedimentary rock of various clast sizes ranging from clay to boulders), lonestones or dropstones (exotic, oversized stones encased in finer sediment), and faceted to striated clasts (Nelson et al. 2020).

Development of the Western Cordillera

The Late Devonian Era marks a significant tectonic transition along the western boundary of North America. The long-lived passive margin developed into an active subduction zone margin, heralding a new series of orogenic events and continental growth that formed the modern Western Cordillera. As oceanic crust subducted below the western continental margin, small volcanic island chains and terranes (large, exotic landmasses or bodies of rock) converged upon North America, resulting in regional-scale deformation, uplift, and plutonism. Multiple tectonic events have created a complex geologic puzzle, as several older structural features and deposits have been dismembered or offset by more recent Cenozoic extensional faulting (Workman et al. 2002a, b). According to Stevens and Stone (2005) and Stevens et al. (2015), several deformational events impacted east-central California during the Paleozoic and Mesozoic, including the following (in order from oldest to youngest): (1) the Mississippian Antler orogeny; (2) development of the Pennsylvanian–Permian Keeler Basin; (3) the Permian–Triassic Sonoma orogeny; (4) Permian emplacement of the Last Chance thrust and Sierra Nevada–Death Valley thrust system; (5) accretion of the Golconda allochthon in the Middle Triassic; and (6) the Jurassic–Cretaceous Nevadan orogeny and the emplacement of the Sierra Nevada batholith.

Nevadan Orogeny

From the Late Jurassic through the Early Cretaceous (about 160 million to 140 million years ago), the continued subduction of oceanic crust beneath the western margin of North America resulted in the folding, faulting, and uplift of older Precambrian and Paleozoic strata. Simultaneously, subduction also caused widespread volcanism and plutonism associated with the emplacement of the Sierra Nevada batholith. Referred to as the Nevadan orogeny, this episode of compressional mountain building is recorded in several large igneous bodies throughout DEVA, including the Manly Peak pluton (Jurassic), Hunter Mountain batholith (Jurassic), Sylvania Mountains pluton (Jurassic), Hall Canyon pluton (Cretaceous), Skidoo pluton (Cretaceous), Teutonia batholith (Cretaceous), and intrusive rocks of the Owlshead Mountains (Triassic[?]–Jurassic; Workman et al. 2014). High pressures and temperatures within the crust associated with the

Nevadan orogeny and the emplacement of molten rock caused strata within the Funeral Mountains and Panamint Range to undergo metamorphism during the Jurassic and Cretaceous (Workman et al. 2014). Crustal compression related to the Nevadan orogeny continued to affect the Death Valley region until the Eocene, and by the Miocene, a new extensional regime had commenced in association with the development of the Basin and Range (Connors and Covington 2004).

Basin and Range Extension

The Basin and Range physiographic province is characterized by crustal extension and thinning, where large-scale fault zones regionally offset and distort thick sequences of rock (also referred to as "basin and range extension"). These faults form a structural landscape distinguished by horsts (an uplifted block bounded by high-angle normal faults) and grabens (a subsided trough or basin bounded by high-angle normal faults; Figure 1). Early development of the Basin and Range began during the Cenozoic in Utah, and over millions of years has gradually migrated westward to produce areas of greater topographic relief (Fridrich and Thompson 2011; Bryan and Tucker-Bryan 2021). The tilted, fault-block mountains and intervening valley floors that define the national park exemplify younger stages of basin and range extension that began in the central part of Death Valley approximately 14.5 million years ago (Fridrich et al. 2012). According to Fridrich and Thompson (2011) and Fridrich et al. (2012), the Cenozoic strata within the Death Valley region record several unique sedimentary and volcanic basin-fill assemblages. These assemblages can be broken down into three distinct extensional phases (in order from oldest to youngest):

1. Pre-basin-range extension. This initial phase of extension occurred during the late Eocene to middle Miocene (~40 million to 12 million years ago) and created broad, shallow basins but did not form modern basin and range topography. Associated pre-basin-range strata include the Titus Canyon and Hells Gate assemblages.
2. Syn-basin-range extension. Ongoing extension and subsidence that includes basin-fill deposits of the Badwater, Furnace Creek, Navadu, and Owlshead assemblages (about 16 million years ago to present).
3. Post-basin-range extension (≤12 million years ago to present). Deposits formed after the cessation of significant (but not all) faulting. The post-basin-range sequence is typically thin, regardless of geologic age, due to low sedimentation rates attributable to a decline in tectonic subsidence. Post-basin-range deposits are absent in the central Death Valley basin due to active subsidence; however, they are mapped in the surrounding Amargosa Valley, Furnace Creek basin, and Opera House basins.

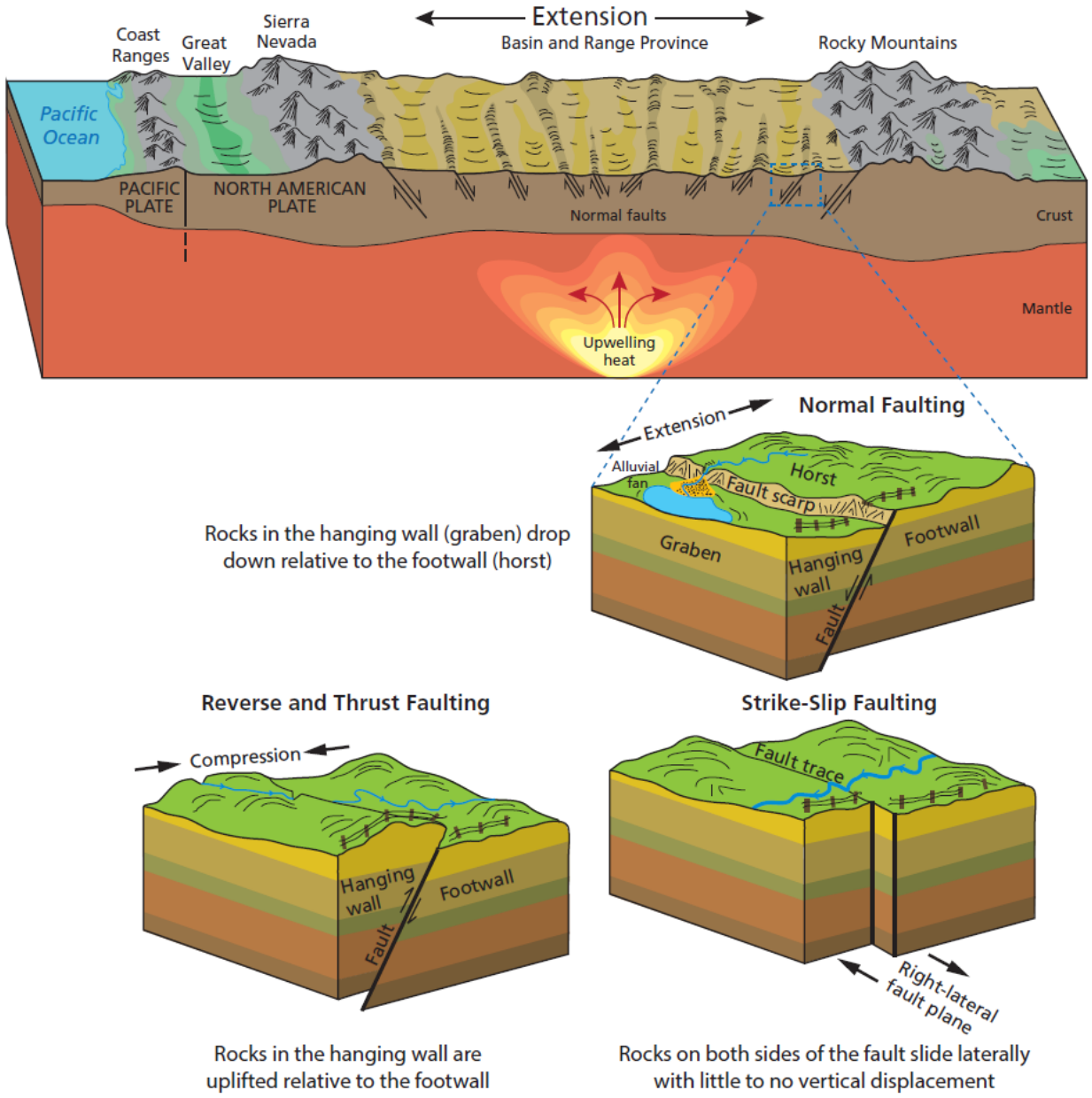


Figure 1. Block model showing the regional structural configuration of the Basin and Range province. The Basin and Range is an area predominantly defined by extension, crustal thinning, and enhanced topographic relief created by normal faulting. However, the geologic framework of DEVA is complex and includes components of reverse or thrust faulting and strike-slip faulting. Active tectonic processes that continuously modify the landscape also pose a known seismic hazard. Figure created by Trista L. Thornberry-Ehrlich (Colorado State University).

Geologic Heritage

Geologic heritage (also called “geoheritage”) evokes the idea that the geology of a place is an integral part of its history and cultural identity. In 2015, the National Park Service's GRD staff, in cooperation with the American Geosciences Institute, published a booklet introducing the American experience of geoheritage, geodiversity, and geoconservation: *America's Geologic Heritage: An Invitation to Leadership*. This publication introduces key principles and concepts of America's geoheritage, which are the focus of ongoing collaboration and cooperation on geologic conservation in the United States. That booklet introduced the American experience of geologic heritage and outlined key principles and concepts, including the following five big ideas:

- America’s geologic landscape is an integral part of its history and cultural identity, and Americans have a proud tradition of exploring and preserving geologic heritage.
- America’s geologic heritage, as shaped by geologic processes over billions of years, is diverse and extensive.
- America’s geologic heritage holds abundant values—aesthetic, artistic, cultural, ecological, economic, educational, recreational, and scientific—for all Americans.
- America’s geologic heritage benefits from established conservation methods developed around the world and within the United States.
- America’s geologic heritage engages many communities, and involvement by individuals will ensure its conservation for future generations.

Ancient Lakes

The Cenozoic rock record at DEVA preserves evidence of cooler climates, previous glaciations, and several pluvial lake systems (lakes formed during periods of enhanced moisture availability) in the Death Valley region. Evidence of these ancient lake settings includes old paludal (peat bog) or lacustrine (lake) deposits (**QTp** and **Ql**) located in Death Valley, Panamint Valley, and Eureka Valley (Machette et al. 2001; Jayko et al. 2008; Knott et al. 2019; Gagnon et al. 2023). Pluvial lakes in the national park—including Lake Manly (Death Valley) and Lake Andrei (Eureka Valley)—began to form during the Late Pliocene approximately 3.5 million years ago and persisted until about 3.3 million years ago and 3.1 million years ago, respectively (Knott et al. 2019; Gagnon et al. 2023). Geologic evidence shows that these lakes also existed at different intervals, approximately 2 million to 1.8 million years ago, 1.3 million to 1 million years ago, and 600,000 years ago (Gagnon et al. 2023). According to Lowenstein et al. (1999), a 186-m (610-ft)-long drill core collected from Badwater Basin preserves a detailed paleoclimate record of the last 200,000 years. Alternating sequences of mud and evaporite deposits within the core represent wet-dry cycles associated with the most recent incarnations of Lake Manly from ~186,000 to 120,000 years ago, and again from about 35,000 to 10,000 years ago (Lowenstein et al. 1999; Miller and Wright 2015). Over the last 25 years, geologists have discovered that the “Lake Manly” from 10,000 years ago would be considered less of a lake and more like a shallow puddle (Dr. Jeffrey Knott, CSU Fullerton, personal communication 20 June 2024). From a cultural perspective, the potential overlap between the existence of Lake Manly and early Indigenous cultures suggests that Death Valley was more hospitable to semi-nomadic hunter-gatherers who came to inhabit the region.

Indigenous Connections

The national park's cultural sites, ethnographic resources, historic structures, and museum collections record more than 10,000 years of human occupation and adaptation to the arid desert landscape. Although widely renowned as one of the hottest and driest areas on the planet, the Death Valley region was much cooler and wetter thousands of years ago, following the last Ice Age. The modern Mojave Desert region once supported large fluvial (river) and lacustrine (lake) settings, and semi-nomadic peoples camped along the shores of the lakes (Bryan and Tucker-Bryan 2021). From time immemorial, the national park has been the ancestral and modern homeland of the Timbisha Shoshone (which translates to "rock paint"), who continue to preserve the land in partnership with the NPS (National Park Service 2017).

According to Bryan and Tucker-Bryan (2021), several geological resources are associated with the national park's cultural sites:

- **Petroglyphs** (depictions carved into rock surfaces): widespread across the national park, these artistic carvings include designs of local fauna (e.g., bighorn sheep, lizards, people) and sets of abstract lines.
- **Pictographs** (depictions painted on rock surfaces): although considered rare, these paintings are found on protected rock surfaces such as overhanging canyon walls and caves. Paint materials often consist of crushed mineral powders or clays.
- **Rock alignments** (long, relatively straight [sometimes serpentine] arrangements of rock): extend across alluvial fan surfaces. With some measuring several hundred feet long, these alignments are speculated to have served as maps or directional guideposts that point toward freshwater spring sources.
- **Geoglyphs** (large-scale alignments of rock): rare and best viewed from the air. These "gardened" or manicured patterns cover large tracts of ground and involve moving some stones into position while clearing others away. In Saline Valley, two notable instances of geoglyphs are present: (1) a series of stone circles considered much too large for shelter purposes; and (2) an eroded human "stick figure." Other reports of smaller geoglyphs have been documented along the alluvial fan below Wildrose Canyon.
- **Camp sites marked by stone circles and stone tools**: Indigenous tools and artifacts commonly consist of chert from Paleozoic formations; quartzite from Neoproterozoic Stirling Quartzite (**Zs**), Cambrian Zabriskie Quartzite (**Cz**), and Ordovician Eureka Quartzite (**Oe**); and chalcedony from Cenozoic volcanic rocks, in addition to shell and bone material (Tweet et al. 2016).

Mining History

For over 150 years, the vast geological resources of the Death Valley region have provoked dreams of mining riches and wealth, and even inspired legends such as the buried silver treasure of the "Lost Gunsight Lode" (Bryan and Tucker-Bryan 2021). Even the park's namesake, "Death Valley," is rumored to have originated from a group of settlers who got lost in the inhospitable valley during California's 1849 gold rush. Though mining is an invaluable part of the national park's historical legacy, early operations left visible scars on the landscape, and in 1976 Congress passed the Mining in the Parks Act, which closed the national park to new mining claims (National Park Service 2017). Although mining resumed in 1980 with stricter

environmental standards, active mining within the national park ended with the Billie Mine's closure in 2005. A detailed account of DEVA's mining history and resources is found in Greene and Latschar (1981).

Among the early prospectors of Death Valley are several notorious and colorful characters that include: (1) Frank "Shorty" Harris, known for some of the region's most famous gold strikes and subsequent gold rushes; (2) Christian Zabriskie, general manager of Pacific Coast Borax Company and namesake of Zabriskie Point; and (3) Pete Aguereberry, a French immigrant who discovered, built, and worked the Eureka Mine—Aguereberry Point bears his name; and (4) Walter Scott, aka "Death Valley Scotty," a prospector, showman, and swindler associated with the legacy of Scotty's Castle (for more information, see https://www.nps.gov/deva/learn/historyculture/people.htm; accessed 22 July 2024).

Metallic Mineral Mining

Several historic mining operations—including gold, silver, lead, copper, antimony, tungsten, and zinc—operated on lands now part of the national park during the late 19th and early 20th centuries. The silver boom came to the Death Valley region first (perhaps driven by prospectors looking for the Lost Gunsight Lode), but soon gold was discovered at Coso in 1860. Subsequently, silver deposits were found at Cerro Gordo in 1867, Panamint City in 1873, Darwin in 1874, and the Modoc in 1875 (Bryan and Tucker-Bryan 2021). Many of these early mining districts were boom-and-bust operations, hindered by a lack of water, fuel, and insufficient technology and transportation. However, a few of these mines were successful and produced a considerable amount of ore, including the mining districts of Rhyolite/Bullfrog, Skidoo, and the Keane Wonder Mine (Miller and Wright 2015).

In recent years, the advent of renewable energy and electric vehicles has spurred interest in the availability of lithium since it is a critical component of modern battery technology. Lake basin deposits, such as those in Death Valley, contain elevated concentrations of lithium that are sometimes one to two orders of magnitude greater than the average continental crust (Gagnon et al. 2023). These elevated lithium concentrations are driven by geothermal enrichment processes, where fluids rich in lithium interact with basin sediments and become progressively concentrated through evaporation (Gagnon et al. 2023).

Non-metallic Mineral Mining

In contrast to metallic mineral mining, non-metallic resources such as talc and borax proved to be extremely profitable. In the 1880s, borax (sodium borate) was first recovered from evaporite minerals scraped from the salt pan of Death Valley, and by the late 1920s, the region had transformed into the world's leading producer (Chappel 1990). Large-scale borate deposits discovered in the Furnace Creek Wash area are found in ancient lake sediments of the Miocene–Pliocene Furnace Creek Formation (**TsF**; Miller and Wright 2015). Early mining companies, such as Harmony Borax Works (later the Pacific Coast Borax Company), are famous for their "Twenty Mule Teams," teams of 18 mules and two horses (the 20 mules are a misnomer) that pulled large wagons hauling borax across the primitive roads to nearby railways. Today, the Harmony Borax site is listed on the National Register of Historic Places. During the 1920s, the Pacific Coast Borax Company played a substantial role in transforming Death Valley from a mining wasteland into a treasured national park. To advocate the idea, Pacific Coast Borax implored NPS Director Stephen Mather and his assistant Horace Albright to visit the area in 1926. Although Mather declined to help due to qualms about his personal and family history (Stephen and his father previously worked for Pacific Coast Borax), his future successor,

Horace Albright, successfully established Death Valley National Monument in 1933 (Bryan and Tucker-Bryan 2021).

The talc deposits in the national park are found within the Mesoproterozoic Crystal Spring Formation (**Yc**). These economic deposits of talc were formed through contact metamorphism as diabase sills intruded basal dolomite horizons approximately 1 billion years ago (Miller and Wright 2015; Van Gosen et al. 2004; Workman et al. 2014). These metamorphosed zones contain talc-tremolite rock that is restricted to a 120 km (75 mi)-long by 24 km (15 mi)-wide belt found within mountain ranges that surround southern Death Valley (Figure 2; Van Gosen et al. 2004). Since 1910, approximately 20 talc ore deposits have been mined in the southern part of DEVA, primarily in Warm Spring Canyon and the Ibex Hills (Miller and Wright 2015; Van Gosen et al. 2004).

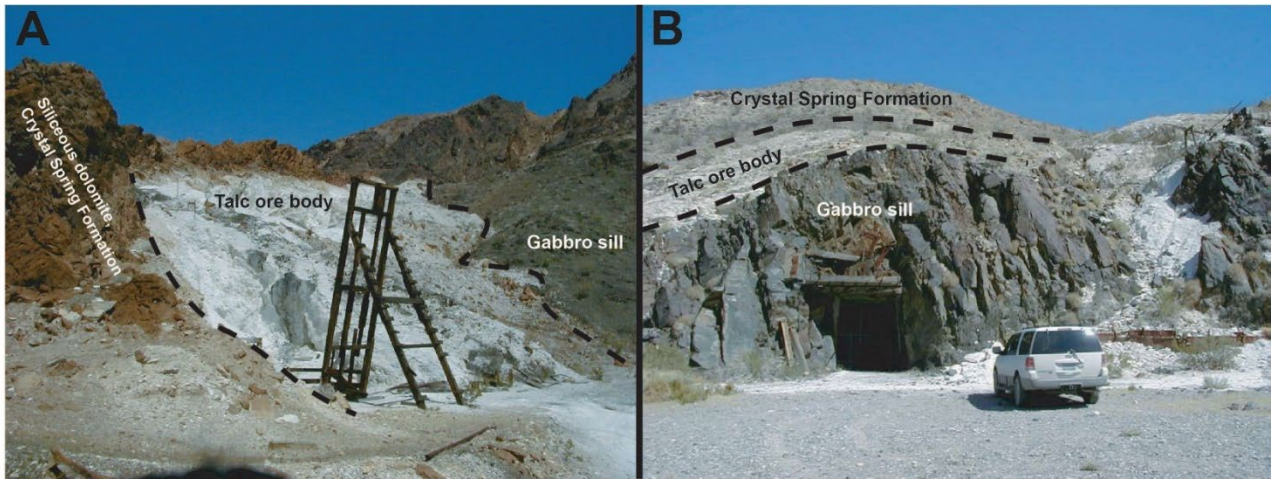


Figure 2. Historic mining sites showing talc-rich ore deposits. Talc-tremolite rocks that contain economic quantities of talc are the product of contact metamorphism as molten rock (gabbro sill) intruded the basal Mesoproterozoic Crystal Spring Formation. Mining sites that show these structural relationships include the A) Pleasanton talc mine; and B) White Point workings near Warm Spring. Figures 5 and 9 from Van Gosen et al. (2004), modified by Tim C. Henderson (Colorado State University).

Stratotypes

Stratotypes are important geologic reference exposures that help identify, define, and correlate geologic units from one location to another. When geologists propose or describe a new layer or body of rock, a stratotype is assigned to exposures containing all (or most) of the unique diagnostic criteria. Stratotypes have significant scientific value and are often easily accessible, world-class locations to study outcroppings of rock. Akin to natural libraries of Earth history, stratotypes preserve meaningful clues to the past and serve as geologic classrooms. The stratotype concept is ingrained in the modern system of geologic nomenclature, as many formal geologic unit names are derived from geologic or geographic features found near stratotype locations. Some particularly recognizable examples from within the National Park System (and their stratotype assignments) include the Permian De Chelly Sandstone (Canyon de Chelly National Monument, Arizona), the Cretaceous Mesaverde Group (Mesa Verde National Park, Colorado), and the Pleistocene Valles Rhyolite (Valles Caldera National Preserve, New Mexico). More information about the various kinds of stratotypes (i.e., lithostratigraphic versus chronostratigraphic) and how to propose or modify them can be

found in the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature 2021) as well as Stamm (2023).

Death Valley National Park contains 45 stratotypes that form a diverse mosaic of geologic units spanning the Neoproterozoic through the Pleistocene (Table 2; Henderson et al. 2021). Currently, the national park contains the third highest number of stratotypes in the National Park System.

Table 2. Geologic units and associated stratotypes mapped within the national park.

The geologic time scale puts the divisions of geologic time in stratigraphic order, with the oldest divisions at the bottom and the youngest at the top. Likewise, rocks and unconsolidated deposits are listed stratigraphically. Units with stratotype designations within the national park are underlined and italicized. GSRI map abbreviations for each time division and GSRI map unit symbols are in parentheses. Only geologic units mapped within the historical park are included. Boundary ages follow the International Commission on Stratigraphy (2023).

Geologic Time Unit	Age	Geologic Units (GSRI map symbol)	Geologic Events
Quaternary (Q) Pliocene (PL)	5.33 million years ago to the present	Youngest alluvium along active channels (**Qayy**) Young alluvium (**Qay**) Young, fine-grained alluvium (**Qayf**) Intermediate-age alluvium (**Qayo**) Undifferentiated younger alluvium (**Qau**) Old alluvium (**Qao**) Undifferentiated alluvium (**QTau**) Oldest alluvium (**QTa**) Landslide block (**QTls**) Playa or salt pan deposits (**Qp**) Eolian deposits (**Qe**) Deposits associated with modern or past groundwater discharge (**Qdt**) Old lacustrine deposits (**Ql**) Old paludal or lacustrine deposits (**QTp**) Confidence Hills Formation (STRATOTYPE) Post-basin-range sedimentary basin-fill deposits (**QTsx**) Post-basin-range rock-avalanche breccia deposits (**QTsx**) Mafic volcanic deposits of the Badwater assemblage (**QTvmB**) Funeral Formation (STRATOTYPE) Sedimentary basin-fill deposits of the Badwater assemblage (**QTsB**) Mormon Point Formation (STRATOTYPE)	Crustal extension continues to impact the landscape of the national park, including recent volcanic activity associated with the eruption of Ubehebe Crater as recently as 300 years ago. During the Pliocene and Quaternary, several pluvial and ephemeral lakes occupied the national park, including Lake Manly (Death Valley) and Lake Andrei (Eureka Valley).

Geologic Time Unit	Age	Geologic Units (GSRI map symbol)	Geologic Events
Miocene (MI) Oligocene (OL) Eocene (E)	23.03 million to 56.0 million years ago	Silicic volcanic deposits of the Furnace Creek assemblage (**TvsF**) Mafic volcanic deposits of the Furnace Creek assemblage (**TvmF**) Silicic intrusive rocks of the Furnace Creek assemblage (**TisF**) Mafic intrusive rocks of the Furnace Creek assemblage (**TimF**) Tectonic mélange of the Furnace Creek assemblage (**TfxF**) Sedimentary basin-fill deposits of the Furnace Creek assemblage (**TsF**) Furnace Creek Formation (STRATOTYPE) Panuga Formation (STRATOTYPE) Sedimentary and volcanic basin-fill deposits of the Furnace Creek assemblage, undivided (**TsvF**) Copper Canyon Formation (STRATOTYPE) Rock-avalanche breccia deposits of the Furnace Creek assemblage (**TsxF**) Silicic volcanic deposits of the Navadu assemblage (**TvsN**) Younger silicic volcanic deposits of the Navadu assemblage (**TvsNy**) Older silicic volcanic deposits of the Navadu assemblage (**TvsNo**) Rhodes Tuff (STRATOTYPE) Mafic volcanic deposits of the Navadu assemblage (**TvmN**) Younger mafic volcanic deposits of the Navadu assemblage (**TvmNy**) Older mafic volcanic deposits of the Navadu assemblage (**TvmNo**) Artist Drive Formation (STRATOTYPE) Sheephead Andesite (STRATOTYPE) Silicic intrusive rocks of the Navadu assemblage (**TisN**) Mafic intrusive rocks of the Navadu assemblage (**TimN**) Tectonic mélange of the Navadu assemblage (**TfxN**) Sedimentary basin-fill deposits of the Navadu assemblage (**TsN**) Navadu Formation (STRATOTYPE) Entrance Narrows Member (STRATOTYPE) Lemoigne Canyon Member (STRATOTYPE) Artist Drive Formation (STRATOTYPE) Sedimentary and volcanic basin-fill deposits of the Navadu assemblage, undivided (**TsvN**) Rock-avalanche breccia deposits of the Navadu assemblage (**TsxN**) Silicic volcanic deposits of the Owlshead assemblage (**TvsO**)	Cenozoic extension in the Death Valley area began during the Eocene approximately 40 million years ago. Early stages of extension formed broad, shallow basins but did not develop the modern basin and range topography defined by tilted fault-block ranges. Basin and range extension that characterizes the national park's geologic landscape began in the central part of Death Valley about 14.5 million years ago. Crustal extension was accompanied by volcanic activity.

Geologic Time Unit	Age	Geologic Units (GSRI map symbol)	Geologic Events
Miocene (MI) Oligocene (OL) Eocene (E) (cont.)	23.03 million to 56.0 million years ago (cont.)	Mafic intrusive rocks of the Owlshead assemblage (**TimO**) Sedimentary basin-fill deposits of the Owlshead assemblage (**TsO**) Silicic volcanic deposits of the Hells Gate assemblage (**TvsH**) Bullfrog Tuff (STRATOTYPE) Mafic volcanic deposits of the Hells Gate assemblage (**TvmH**) Sedimentary basin-fill deposits of the Hells Gate assemblage (**TsH**) Ubehebe Formation (STRATOTYPE) Sedimentary and volcanic basin-fill deposits of the Hells Gate assemblage, undivided (**TsvH**) Sedimentary basin-fill deposits of the Titus Canyon assemblage (**TsT**) Ubehebe Formation (STRATOTYPE) Rock-avalanche breccia deposits of the Titus Canyon assemblage (**TsxT**) Tectonic mélange of the Titus Canyon assemblage (**TfxT**) Titus Canyon Formation (STRATOTYPE)	Cenozoic extension in the Death Valley area began during the Eocene approximately 40 million years ago. Early stages of extension formed broad, shallow basins but did not develop the modern basin and range topography defined by tilted fault-block ranges. Basin and range extension that characterizes the national park's geologic landscape began in the central part of Death Valley about 14.5 million years ago. Crustal extension was accompanied by volcanic activity.
Cretaceous (K) Jurassic (J) Triassic (TR)	251.9 million to 66 million years ago	Younger Mesozoic silicic intrusive rocks (**Kis**) Older Mesozoic silicic intrusive rocks (**Jis**) Sedimentary and volcanic rocks, undivided (**JTRsv**) Oldest Mesozoic silicic intrusive rocks (**JTRis**)	Mesozoic rocks in the national park are the product of large-scale plutonism, volcanic activity, and contractional deformation related to the Nevadan orogeny and the formation of the Sierra Nevada batholith.
Permian (P) Pennsylvanian (PN) Mississippian (M)	358.9 million to 251.9 million years ago	Paleozoic sedimentary rocks, undivided (**PZu**) Permian and Silurian sedimentary rocks, undivided (**PSu**) Owens Valley Group (**Pov**) Bird Spring Formation (**PPNb**) Keeler Canyon Formation (**PPNkc**) Tihvipah Limestone (**PNt;** STRATOTYPE) Mississippian sedimentary rocks, undivided (**Mu**) Leaning Rock Formation (STRATOTYPE) Lee Flat Limestone (STRATOTYPE) Mexican Spring Formation (STRATOTYPE) Perdido Formation (STRATOTYPE) Rest Spring Shale (STRATOTYPE) Santa Rosa Hills Limestone (STRATOTYPE) Stone Canyon Limestone (STRATOTYPE) Tin Mountain Limestone (STRATOTYPE)	The national park experienced a significant number of structural changes following the development of an active margin during the Late Devonian. Several deformational episodes impacted the Death Valley region: (1) the Devonian–Mississippian Antler orogeny; (2) truncation of the continental margin by the Pennsylvanian; and (3) multiple Permian compressional events, including the Sonoma orogeny.

Geologic Time Unit	Age	Geologic Units (GSRI map symbol)	Geologic Events
Devonian (D) Silurian (S) Ordovician (O) Cambrian (C)	538.8 million to 358.9 million years ago	Lost Burro Formation (**Dlb**; STRATOTYPE) Lippincott Member (STRATOTYPE) Quartz Spring Sandstone Member (STRATOTYPE) Hidden Valley Dolomite (**DShv**; STRATOTYPE) Ely Springs Dolomite (**Oes**) Eureka Quartzite (**Oe**) Ordovician and Cambrian sedimentary rocks, undivided (**OCu**) Pogonip Group (**OCp**) Nopah Formation, Bonanza King Formation, and Carrara Formation, undivided (**Cnbc**) Nopah Formation (**Cn**) Bonanza King Formation (**Cb**) Racetrack Dolomite (STRATOTYPE) Monola Formation (**Cm**) Carrara Formation (**Cc**) Echo Shale Member (STRATOTYPE) Pyramid Shale Member (STRATOTYPE) Red Pass Limestone Member (STRATOTYPE) Thimble Limestone Member (STRATOTYPE) Mule Spring Limestone (**Cms**; STRATOTYPE) Saline Valley Formation (**Csv**; STRATOTYPE) Zabriskie Quartzite (**Cz**) Harkless Formation (**Ch**) Poleta Formation (**Cpo**; STRATOTYPE) Wood Canyon Formation and Stirling Quartzite, undivided (**CZws**) Wood Canyon Formation (**CZw**) Campito Formation, undivided (**CZca**) Montenegro Member (**Ccam**) Andrews Mountain Member (**CZcaa**)	From the Neoproterozoic to the Late Devonian, the national park was situated near the continental margin and accumulated a thick passive margin sequence of marine rocks. These rocks preserve a rich array of paleontological resources that record a significant evolutionary history, from stromatolites through vertebrates and land plants. By the Late Devonian, the passive margin of North America had transitioned to an active margin. Compression associated with the Antler orogeny uplifted mountains to the west and north of the national park, and a foreland basin developed in the Death Valley region.

Geologic Time Unit	Age	Geologic Units (GSRI map symbol)	Geologic Events
Neoproterozoic (Z) Mesoproterozoic (Y) Paleoproterozoic (X	2.5 billion to 538.8 million years ago	Deep Spring Formation (**Zd**) Stirling Quartzite (**Zs**) Reed Dolomite (**Zr**) Wyman Formation (**Zw**) Johnnie Formation (**Zj**) Noonday Dolomite (**Zn**) Mahogany Flats Member (STRATOTYPE) Radcliff Member (STRATOTYPE) Sentinel Peak Member (STRATOTYPE) Ibex Formation (**Zn**; STRATOTYPE) Kingston Peak Formation (**Zk**) Beck Spring Dolomite (**Zb**) Horse Thief Spring Formation (**Zh**) Noonday Dolomite and Pahrump Group, undivided (**ZYp**) Crystal Spring Formation (**Yc**) Metamorphic and igneous rocks, undifferentiated (**Xmi**)	Some of the oldest rocks in the national park are severely altered metamorphic and igneous rocks approximately 1.7 billion years old. These rocks were deposited throughout the assembly and rifting of the supercontinent Rodinia. During the Neoproterozoic, rifting coincided with a global glaciation event ("Snowball Earth") that covered most of the Earth. The rifting of Rodinia created a passive margin by the late Precambrian.

Death Valley's Alien Landscape and NASA

The barren, arid desert environment of the national park commonly lacks vegetation, creating an alien-like landscape that mimics geologic settings or processes found elsewhere in the solar system. For several decades, planetary scientists working with the National Aeronautics and Space Administration (NASA) and other academic institutions have performed research, field workshops, and mission trainings (e.g., Viking, Curiosity) at several terrestrial analog sites throughout the Death Valley region. These analog sites are valuable natural laboratories that demonstrate either biological, environmental, or geological conditions similar to those on the Moon, Mars, and beyond. According to several authors (Baldridge et al. 2001, 2004; Farr et al. 2002; Bonaccorsi et al. 2014), these analog sites include Badwater Basin, Mars Hill (south of Furnace Creek), Ubehebe Crater, and Mesquite Flat Sand Dunes. Several decades ago, famous cosmologist Dr. Carl Sagan visited the national park and was photographed with a model of NASA's Viking lander near the area of Mars Hill (Figure 3). Additionally, in partnership with the NPS, NASA participates in several NPS-hosted educational outreach events that review mission trainings and analog studies, including the Death Valley Dark Sky Festival and MarsFest (Bonaccorsi et al. 2014; Jones et al. 2020).

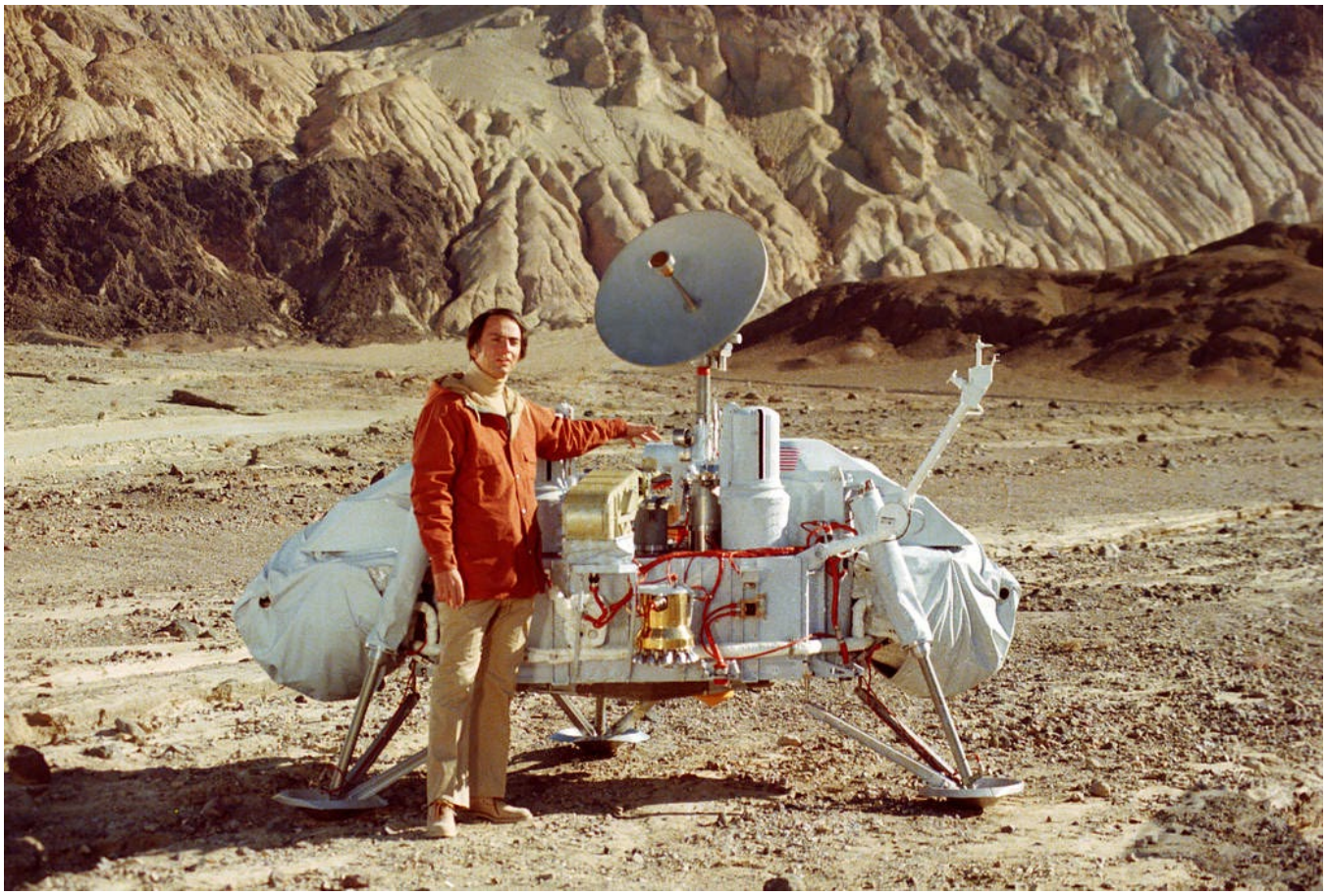


Figure 3. Dr. Carl Sagan poses with a model of the Viking lander near Mars Hill. For several decades, the barren geologic landscape of DEVA has been used as an analog site in preparation for multiple planetary science missions and trainings. NASA photograph.

Charles Walcott, Levi Noble, and H. Donald Curry

Early geologic field investigations performed by Charles Doolittle Walcott, Levi Noble, and H. Donald Curry significantly contributed to the continuously evolving geologic framework of the national park. Walcott, the celebrated paleontologist renowned for the discovery of the Burgess Shale, revealed a scientifically valuable sequence of fossiliferous marine strata in the Waucoba Wash/Waucoba Spring region. Referred to as the Lower Cambrian Waucoban Series, this group of formations (Campito Formation, Poleta Formation, Harkless Formation, Saline Valley Formation, Mule Spring Limestone) preserves a definitive chapter in evolutionary history and contains some of the first appearances of trilobites and other advanced, shelly fauna (Tweet et al. 2016).

Levi Fatzinger Noble is frequently considered to be the “pioneer geologist of Death Valley” and spent considerable years observing and accurately recording many of the major geologic features scattered throughout DEVA (Wright and Troxel 2002). First introduced to the region in 1917, Noble eventually moved to Shoshone in 1931 to begin more systematic studies of the general geology of DEVA. Noble went on to have a long, distinguished career in Death Valley, where he discovered the first evidence of glacial Lake Manly in strandlines on a prominent basalt hill, now known as Shoreline Butte (Machette et al. 2001).

H. Donald Curry served as the first ranger naturalist and geologist at DEVA following its establishment as a national monument in 1933. Curry kept apprised of Noble's geologic investigations in the Death Valley region, and the two men often communicated and collaborated following Curry's arrival to the national park (Wright and Troxel 2002). As a result of his own personal geologic reconnaissance, Curry prepared some of the earliest topographic and geologic maps along the steep western face of the Black Mountains. Located in the southern area of the national park, the Black Mountains are where Curry coined the term "turtlebacks" to describe the complex detachment structures that expose ancient Paleoproterozoic bedrock (Curry 1938, 1954; Santucci et al. 2011). Several fossil trackway localities throughout DEVA—including the notable vertebrate tracks of Copper Canyon—were first investigated and published by Curry in the late 1930s and early 1940s (Curry 1939, 1941; Santucci and Nyborg 1999). Additionally, Curry is credited with the discovery of a titanothere skull in Titus Canyon; a replica of the specimen was formerly on display at the national park's visitor center (Wright and Troxel 2002).

Aesthetic Values

The national park's arid climate, scarce desert vegetation, and rich geologic history combine to form one of the most scenic landscapes in the National Park System. According to DEVA's Foundation Document (National Park Service 2017, p. 4), the national park was established with the purpose of preserving "…exceptional wilderness, scenery, and learning experiences within the nation's largest conserved desert landscape and some of the most extreme climate and topographic conditions on the planet." Much of the scenery in DEVA is inherently geologic in nature, representing an exceptional window into geologic processes and evolving life spanning over 1 billion years. For many decades, the aesthetic beauty of Death Valley has inspired several generations and been featured in various forms of art, including painting, photography, television, and film (see https://www.nps.gov/deva/learn/historyculture/death-valley-in-movies-and-television.htm; accessed 22 July 2024).

Geologic Resource Management Issues and Inventory Needs

This section briefly summarizes the geologic resource management issues, inventory needs, and geologic hazards that have been identified by discussions with DEVA staff. Geologic issues refer to problems related to geologic resources. Inventory needs are highlighted to summarize what is currently known and what is needed to ensure good management of the national park. Geologic hazards refer to notable hazards stemming from geologic features or processes that may require active management. Refer to the Guidance for Resource Management SharePoint for more information regarding geologic resource management.

Legislatively Required Geologic Inventories

The NPS GRD has developed an article series (https://www.nps.gov/articles/series.htm?id=FA0A8F89-CD67-1CCE-5A6608B444E8A7C0; accessed December 2024) that summarizes the laws, regulations, and policies that specifically apply to geologic and soil resources or processes. These protection measures were established to maintain the integrity of these resources or processes while minimizing the impacts of natural or anthropogenic activity.

Summary of Geologic and Soil Hazards

Park resources are not only visitor attractions but can also be potentially hazardous. The Death Valley landscape presents a variety of natural hazards that can pose risks to NPS visitors, staff, facilities, and resources (Table 3). Many of these natural hazards are geologic. Geologic hazards are naturally occurring, dynamic processes that have the potential to cause damage, loss of property, injury, or loss of life. The Addressing Climate Change and Natural Hazards Handbook (NPS 2015, 2023), grounded in NPS Policy Memorandum 15-01 (Jarvis 2015), provides a process and information to help teams and decision-makers identify, avoid, and mitigate risks associated with environmental change hazards and effects on proposed and planned facility investments. The handbook supports NPS planning guidance, policy directives, and executive orders and does not supersede existing mandated compliance processes and policies. Additional guidance for facility management (e.g., Climate-Smart Planning Principles and Recommended Practices; accessed December 2024) has been developed to support effective decision-making.

According to PM 15-01, managers should apply the handbook guidance to identify options to manage natural hazard and climate change risks throughout all levels of facility planning and design. Project teams are required to submit the completed Natural Hazards Checklist (Table 2) as part of Regional and Bureau Investment Review Board submissions. This information can also be used as part of the updated (2024) Automated Investment Review Board (AIRB) submittal process at the Investment Concept (IC) stage. Table 2 includes selected geologic and soils hazards listed in Part 1 of NPS (2023). The GSRI team has added additional hazards where appropriate for the park. If needed, Part 2 of the handbook could inform completion of the checklist, such as whether a hazard is applicable. Contact the NPS GRD with any questions.

Table 3. Geologic and soil hazards checklist.

This summary table is a synthesis of existing GSRI-compiled map data and information, as well as published US Geological Survey and other government agency information. It is suitable for use at park-scale discussions and assessments. It is not a substitute for site-specific investigations or NEPA analysis. Ground-disturbing activities should neither be approved nor denied based on the information here. This table is modeled after the Natural Hazard Checklist (see National Park Service 2015, 2023 and Jarvis 2015). It is meant to provide general information to identify the full range of natural hazard-based risks for the park.

Potential Hazard	**Examples of Risk or Secondary Hazard**	**Best Professional Judgment**	**Information Source(s) Used**
Sea level change	Not applicable	Not applicable	Not applicable
Coastal storm surge or hurricane activity	Large precipitation events that drive flash flooding, debris flows, and erosion Damage or destruction of infrastructure Inoperability of major building systems (e.g., power, sewer, water) or roadways Human injury or casualty	**Known hazard (susceptible to hurricanes)**	https://www.nps.gov/deva/learn/nature/hilary.htm https://www.nps.gov/deva/learn/nature/hurricane-hilary-2023-galleries.htm Reinhart (2024)
Coastal erosion	Not applicable	Not applicable	Not applicable
Flash flood	Sudden rising water (e.g., dry wash, tributary valley, narrow canyons) Enhanced tributary flow regime and erosion capable of carrying large boulders and other debris Damage or destruction of infrastructure Human injury or casualty	**Known hazard**	Crippen (1979, 1981) GSRI GIS hazard layers or flood-related deposits (e.g., “alluvium” and “basin-fill” deposits”) Miller and Wright (2015) Morris et al. (2020) Morris and Welborn (2019) NPS Foundation Document (National Park Service 2017)
Riverine flood	Flooding (i.e., snowmelt, rainfall, flash flooding, etc.) Destruction of infrastructure Stream channel migration Stream bank erosion Human injury or casualty	**Known hazard (extreme)**	Federal Emergency Management Agency (FEMA) Map Service Center US Department of Interior (DOI) Strategic Hazard Identification and Risk Assessment (SHIRA) Risk Mapper Report
Lake and reservoir level change	Not applicable	Not applicable	Not applicable

Potential Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Information Source(s) Used
Earthquake	Falling objects Collapsing structures Inoperability of major building systems (e.g., power, sewer, water) or roadways Trigger to other hazards (e.g., landslides, rock falls, volcanic activity) Water level fluctuations in protected spring environments such as Devils Hole Human injury or casualty	**Known hazard (very high)**	Halford and Jackson (2020) Machette et al. (1999) DOI SHIRA Risk Mapper Report US Geological Survey (USGS) Earthquake Hazard Probability Map (Petersen et al. 2023)
Slope movements (e.g., landslides, rock falls, debris flows)	Rockfalls, landslides, or debris flows often accompany storm events generating large amounts of precipitation Partial constriction of narrow, steep-walled canyons Damage or destruction of park infrastructure Damage to or loss of natural or cultural resource sites or features Human injury or casualty	**Known hazard**	Crippen (1979) DOI SHIRA Risk Mapper Report GSRI GIS hazard layers or slope movement deposits (e.g., “landslide blocks” and “rock-avalanche breccia deposits”) Miller and Wright (2015)
Permafrost	Not applicable	Not applicable	Not applicable
Cave/karst	Sinkholes Surface or ceiling collapse Contamination Abandoned Mineral Lands (AML) features and sites	**Potential hazard (moderate)**	DOI SHIRA Risk Mapper Report
Shrink/swell soils	Not applicable	Not applicable	Not applicable
Tsunami	Not applicable	Not applicable	Not applicable
Volcanic eruption	Lava Flows Pyroclastic flows Ash fall Lahars Toxic gas or steam releases Fire Seismicity Damage to HVAC and other mechanical systems (ash) Damage or destruction to park infrastructure Volcanic ash health hazards if inhaled Human injury or casualty	**Potential hazard (moderate; restricted to Ubehebe Crater region)**	DOI SHIRA Risk Mapper Report Mangan et al. (2019) Miller et al. (1982) Miller (1989) USGS Volcano Hazards Program

Potential Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Information Source(s) Used
Hydrothermal activity	Not applicable	Not applicable	Not applicable
Radon	Health hazard	**Potential hazard (moderate – Zone 2)**	US Environmental Protection Agency (EPA) Map of Radon Zones
Toxicological soil (asbestos[1], arsenic[2], *Bacillus anthracis* [causes anthrax][1], cadmium[1], erionite[1], lead[2], selenium[3], Valley Fever fungus [*Coccidioide*][4])	Health hazard	**[1]Potential hazard (high)** **[2]Potential hazard (very high)** **[3]Potential hazard (low)** **[4]Potential hazard (very low)**	DOI SHIRA Risk Mapper Report Van Gosen et al. (2004)

Flooding and Flash Flooding

Water is a critical resource in the arid Mojave Desert environment of DEVA, and although the national park experiences periods of drought sustained by some of the hottest temperatures on the planet, intense rainstorms can deliver a year's worth of water (average annual rainfall is 5.46 cm [2.15 in]) in a matter of hours. While water availability can be scarce, flood damage can range from minor inconveniences to devastating disasters (Table 4). In mountainous canyon regions, storm events can rapidly result in dramatic changes to streams as steep slopes and sparse vegetation enhance runoff, discharge, and erosion—all factors that increase the susceptibility of flooding, flash flooding, and debris flows (Crippen 1979, 1981; Morris and Welborn 2019; Morris et al. 2020). Roadways and facilities in DEVA are in areas that may be highly susceptible to flood damage, especially transmountain roads that occupy stream channels or roads that follow or cross the easily erodible surfaces of alluvial fan deposits (Crippen 1979). Many popular areas within the national park are subject to flash flooding and debris flows, including Artist Drive, Boundary Canyon, Cottonwood Canyon, Emigrant Canyon, Grapevine Canyon, Mosaic Canyon, Natural Bridge, Trail Canyon, Twenty Mule Team Canyon, Wildrose Canyon, Warm Spring Canyon Road, Titus Canyon Road, and Jubilee Pass Road (Crippen 1979, 1981).

Historic Flooding

Flooding is a recurrent, natural phenomenon that has always been a part of DEVA's history. Following its establishment as a national monument in 1933, the region experienced several major back-to-back flood events in 1934, 1935, 1936, 1938, and 1942 as the Amargosa River inundated portions of the park's early roadway system (see https://dvnha.org/historyminute5/; accessed 22 July 2024). During the early mining era, one of the greatest and perhaps most intriguing floods to have ever occurred in the Panamint Mountains took place in late July 1876 and destroyed the small mining community of Panamint City; the ruins of the town can still be found in Surprise Canyon (Crippen 1981; Wilkerson and Santiago 2016). An account of the event is described in Beebe (1954, para. 32):

> *The whistle of the big mill gave Panaminters scant warning. The waters descended from the towering walls about Panamint in a thundering deluge; a wave variously estimated at from five to seven feet high swept down Main Street headed for the canyon below. Most of Panamint went with it: Munsinger's Brewery, Miss Delia Donoghue's Wyoming Restaurant, the emporium of Harris & Rhine, the Maiden Lane plaisance of Martha Camp's girls. Next morning the noisiest and most remote of all the mining camps of the Old West was found spread over several square miles of wash in Panamint Valley.*

Table 4. Examples of historic and modern flood events in DEVA.

Information provided from National Park Service (2017), Morris and Welborn (2019), Morris et al. (2020), and Death Valley Natural History Association (2023a, b).

Flood Event(s)	Flood-related Damage(s)
Major historic flood in July 1876	SURPRISE CANYON: Destruction of the mining community of Panamint City in the Panamint Range.
Major historic flood events in 1934, 1935, 1936, 1938, 1942	Flooding of early park roads by the Amargosa River; damage to historical resources.
July 1976	SCOTTY'S CASTLE DISTRICT: Flood inundation in areas surrounding Grapevine Canyon and Tie Canyon; floodwaters reportedly incised a channel into the parking lot of Scotty's Castle.

Flood Event(s)	Flood-related Damage(s)
August 2004	FURNACE CREEK JUNCTION: Intense flooding along CA Highway 190 and the Furnace Creek Wash. One vehicle was pushed off the road and flipped near the junction of CA Highway 190 and Dante's View Road. At Zabriskie Point, over a dozen vehicles were washed out or buried in muddy debris; two people died in their vehicle when they could not escape the water.
October 2015	SCOTTY'S CASTLE DISTRICT: Damaged buildings, roads, utility systems (e.g., power, water, sewage), and other infrastructure such as fencing; several hundred historical objects were washed away; burial of the local freshwater spring; generated 1.5–3 m (5–10 ft) of incision in portions of Grapevine Canyon; deposition of mud, gravel, cobbles, and boulders within and surrounding several historic and park administrative buildings; deposition of several feet of sediment across the visitor center parking lot.
July 2021	DEVILS HOLE: Rare flash flooding in Ash Meadows National Wildlife Refuge that deposited mud and rock debris into the pool.
August 2022	Widespread roadway damage, including burial by rock debris; destruction of the Salt Creek boardwalk.
August 2023 (Hurricane Hilary)	Widespread roadway undercutting, collapse, and burial by rock debris; damaged utility system infrastructure.

Modern Flooding

On 19–20 August 2023, remnants of Hurricane Hilary swept through Death Valley and delivered 5.59 cm (2.2 in) of rain, setting a record as one of the wettest and rainiest days in the park. The hurricane caused extensive flash flooding, which undercut roadways, left collapsed pavement surfaces park-wide, and damaged utility system infrastructure (Figure 4). Additionally, debris flows generated by flash floodwaters deposited up to 1.5 m (5 ft) of dirt and rock material along sections of roadway (see https://www.nps.gov/deva/learn/nature/hilary.htm; accessed 22 July 2024). As a result of Hurricane Hilary, major flooding damaged or destroyed roughly 640 km (400 mi) of roads and closed the national park for an unprecedented eight weeks (Reinhart 2024). Residual floodwaters formed a temporary playa lake in Death Valley that persisted for weeks after the hurricane event.



Figure 4. An NPS employee surveying an undercut roadway. In August 2023, Hurricane Hilary swept through the Death Valley region and delivered 5.59 cm (2.2 in) of rain in a matter of hours. The hurricane caused extensive flash flooding, which undercut roadways, left collapsed pavement surfaces, and damaged utility systems. Altogether, Hurricane Hilary damaged or destroyed roughly 640 km (400 mi) of roads and closed the national park for eight weeks. NPS photograph.

Prior to Hurricane Hilary, a major storm event on 5 August 2022 delivered 4.3 cm (1.7 in) of rain in roughly three hours, a deluge of water that caused significant roadway damage, produced massive amounts of rock debris, and destroyed the Salt Creek boardwalk (Death Valley Natural History Associated 2023a, b). Another large flood event that occurred on 18 October 2015 produced 6.91 cm (2.72 in) of rain over a five-hour period and caused considerable damage in the Grapevine Canyon region, which includes the historic Scotty's Castle district (Morris et al. 2020). The resulting flash flood caused an estimated $47 million in damages, as several buildings, roads, utility systems (e.g., power, water, sewage), and other infrastructure were impaired or destroyed; hundreds of historical objects were washed away as far as Mesquite Springs Campground

(Figure 5; National Park Service 2017). The 2015 flood destroyed 20 power poles and 1.6 km (1 mi) of fencing, buried the freshwater spring source to Scotty's Castle, and severely compromised the water pipelines servicing the historical district (National Park Service 2017; Morris et al. 2020). The erosive power of the flood generated approximately 1.5–3 m (5–10 ft) of incision in Grapevine Canyon from near its confluence with Tie Canyon through Castle Gate Bridge to the picnic area adjacent to the parking lot (Morris and Welborn 2019; Morris et al. 2020). Associated debris flows deposited mud, gravel, cobbles, and boulders within and surrounding several historic and park administrative buildings, including several feet of sediment distributed across the visitor center parking lot (Morris et al. 2020).



Figure 5. Photograph of a washed-out segment of Scotty's Castle Road. In October 2015, a major storm produced catastrophic flash flooding, debris flows, and gully incision that damaged buildings, roads, and utility systems in the historic Scotty's Castle district. While certain portions of the roadway were undercut or washed away, others were covered with a veneer of unconsolidated sediment or rock debris—including those in the background. NPS photograph.

Disturbed Lands

Disturbed lands are those park lands where the natural conditions and processes have been directly impacted by development, including facilities, mining, roads, dams, and abandoned campgrounds; agricultural activities such as farming, grazing, timber harvest, and abandoned irrigation ditches; overuse; or

inappropriate use. Restoration returns a site, watershed, or landscape to some previous condition, commonly some desirable historic baseline. Commonly, lands disturbed by natural phenomena such as landslides, earthquakes, floods, and fires are not considered for restoration unless influenced by human activities. Lands disturbed by human activity can cause unwanted and long-lasting problems that affect other resources. Many of these disturbances obliterate soil profiles, exacerbate the invasion of exotic plants, result in contamination of water and soil, and/or cause erosion and sedimentation. These damages, in turn, frequently impair the quality of habitats, disrupt ecosystem functions, and cause problems for parks managing areas as wildlands.

Abandoned Mineral Lands

The extensive mining history associated with the national park has resulted in one of the largest collections of abandoned mineral lands (AMLs) in the National Park System. According to Burghardt et al. (2014), DEVA contains 376 abandoned mining sites (11% of total NPS) and over 16,150 abandoned mining features (44% of total NPS); the Skidoo Mine alone contains 664 individual features and is the biggest site in the NPS. These AMLs exist in various stages of decay and pose a variety of problems for NPS management that include visitor safety, environmental impact, and wildlife habitat.

As prospecting and mining activities rapidly expanded during the late 19th and 20th centuries, several natural, ecological, scenic, scientific, and educational features within the national park were permanently destroyed or severely altered. By the 1970s, surface disturbances created by open pit mines, strip mines, and dump sites were impacting nearly 100 acres of land per year (National Park Service 1976). Over several decades, mining operations stripped away or removed large amounts of vegetation, soil, and desert varnish. Collectively, these mining practices promoted substrate instability and resulted in an acceleration in water and wind erosion (National Park Service 1976). The mining sites scattered throughout DEVA pose a potential threat to human life, as these areas often contain unstable structures or slopes, open pits or shafts, dangerous explosive materials, and sharp metallic or wooden debris.

Illegal Off-road Vehicles

As the largest national park in the conterminous United States, DEVA has more miles of roadway than any other park. However, the expansive road network presents issues with illegal off-road vehicle usage that can (1) leave lasting visible scars; (2) negatively impact vegetation; (3) endanger wildlife; (4) destroy or impair geologic features—including soils, cultural sites, and fossil localities; (5) pollute water sources; (6) destroy designated wilderness; and (7) endanger lives (Figure 6; National Park Service 2017; see https://www.nps.gov/deva/learn/no-driving-off-designated-roads.htm; accessed 22 July 2024). The arid desert environment is fragile and slow to recover from vehicle damage, especially in dune, playa, and saltpan regions that receive little to no water.



Figure 6. Illegal off-road tire tracks on the Racetrack. In the dry, arid Mojave Desert environment, tracks such as these can leave long-lasting scars. Off-road driving is a common management concern at DEVA, as vehicular damage can negatively impact or threaten soils, cultural sites, fossil localities, wilderness, wildlife, and human lives. NPS photograph.

Overgrazing

The Death Valley region is home to several populations of wild, free-roaming livestock and wildlife (e.g., horses, burros, bighorn sheep) that can lead to overgrazing issues and enhanced erosion. Due to a lack of fencing infrastructure, livestock from neighboring lands can trespass across the national park's boundary. According to the national park's Foundation Document (National Park Service 2017), overgrazing by feral burros can dramatically affect vegetation, damage the desert ecosystem, and displace native bighorn sheep. Additionally, trespassing livestock creates social trails that can promote erosion and threaten sensitive cultural and historic sites or features. To help manage wild populations of trespass livestock, the Wild Free-Roaming Horses and Burros Act (Public Law 92-195) gives the NPS authority to remove wild horses and burros from the lands they manage. According to Fleishman et al. (2019), during the 1990s and early 2000s, many wild burros (exact numbers unknown) were removed from DEVA, Mojave National Preserve, and the Lake Mead region.

Illegal Marijuana Cultivation

Illegal marijuana grow operations have been detected within the mountainous regions of DEVA but are difficult to enforce given the massive size and rugged terrain of the park. The illegal cultivation of marijuana negatively impacts the desert landscape, taxes the park's water supply, contaminates water sources,

introduces harmful pollutants or trash, and negatively manipulates the ecosystem by displacing native species with marijuana (Figure 7; National Park Service 2017). Growers often cultivate the land, creating terraced marijuana plots that are supplied with water from artificial catchments that divert the natural flow of water (Death Valley Natural History Association 2023a). Recently, the NPS and its partners cleared an illegal marijuana grow site in Jail Canyon that yielded over 10,000 marijuana plants (an estimated value of $7 million), in addition to trash and hazardous chemicals (Death Valley Natural History Association 2023b).



Figure 7. Aerial photograph of an illegal marijuana plot in the remote wilderness of DEVA. Marijuana cultivation is a major management concern, as growers often introduce poisonous chemicals, disturb natural ecosystems, and divert water resources. NPS photograph.

Mass Wasting

The term “mass wasting” is used to describe downhill movements of rock or soil and includes events such as landslides, slumping, slope creep, rock falls or avalanches, and debris flows. Mass wasting events are driven by natural processes such as erosion, precipitation, flooding, volcanism, and seismicity (earthquakes), but they can also be artificially induced by construction, mining, undercutting, vegetative clearing, and other projects that destabilize the ground.

The dynamic basin and range extension that defines DEVA’s landscape is heavily characterized by mass wasting processes as the valley floors continue to actively subside and fill with debris shed from the surrounding mountains. At high elevations, storm events result in catastrophic flash floods that incise steep-

walled canyons and generate debris flows capable of carrying large boulders; abundant evidence can be readily seen in areas such as Mosaic Canyon. Debris flows can fill or obstruct canyon areas, forcing water to create new incisional outlets or gullies as it transports material downslope toward the valley floor. Additionally, debris flows can undermine the integrity of roadways, causing large-scale pavement collapse, in addition to blanketing surfaces with unconsolidated rock material (Figure 8; Crippen 1979, 1981; Morris and Welborn 2019; Morris et al. 2020). Over the last several years, the national park has been severely affected by the combined action of flash flooding and debris flows, especially those associated with Hurricane Hilary in 2023 and the 2015 storm event that impacted the Scotty's Castle district (see "Flooding and Flash Flooding"). Although debris flows are a natural process that have long transformed DEVA's modern scenery, there is a concern that climate change may enhance the occurrence and intensity of these events, especially as large storms or hurricanes are projected to increase (see "Climate Change").



Figure 8. Photograph of a car partially buried by a debris flow following August 2022 flooding. Major storm events can deliver a year's worth of rainfall in a matter of hours and often cause disastrous flooding, flash flooding, debris flows, and gully incision that damage or destroy roadways, buildings, utility systems, and resources. NPS photograph/M. Gallegos.

In addition to debris flows, the Cenozoic rock record throughout the national park preserves evidence of large rock avalanches and landslides emplaced following the initiation of basin and range tectonism. In mountainous regions, rock avalanches and landslides are well-documented and notorious geologic hazards, typically involving large volumes of rock debris that can rapidly mobilize downslope. In southern Eureka Valley, there is an exceptionally well-preserved and exposed rock-avalanche deposit that sits below the western flank of the Last Chance Range. This avalanche feature consists of pervasively fractured, clast-supported breccia of various sizes, including boulders several meters in diameter (Shaller et al. 2020). The rock-avalanche deposit accounts for nearly 5 million m^3 (175 million ft^3) of debris and can be broken down into a prominent raised lobe bounded by smaller lateral levees (Shaller et al. 2020). The avalanche was sourced from an outcrop of Cambrian strata located to the east in the Last Chance Range and is estimated to have been emplaced during the late Pleistocene based on overlying alluvial surfaces (Schaller et al. 2020). Additional evidence of large rock-avalanche deposits has been reported in the Amargosa Chaos and Sperry Hill basins in the southern region of DEVA (Topping 1993). According to the GSRI GIS data (sourced from Workman et al. 2015), an extensive landslide block deposit (**QTls**) exists in the Panamint Range north of Teakettle Junction. Similar to rock-avalanche deposits, these landslide blocks generally consist of coherent, brecciated deposits recycled from older bedrock. Additional, smaller landslide blocks are scattered across the southern Saline Valley below the northern flank of the Nelson Range (Workman et al. 2014).

To help mitigate the potential impacts of landslide hazards, the California Geological Survey has published a deep-seated landslide susceptibility map that characterizes areas of very high landslide potential (classes VIII, IX, and X) by very steep slopes in hard rocks and moderate to very steep slopes in weak rocks (Wills et al. 2011). Several mountainous regions within DEVA (e.g., Black Mountains, Grapevine Mountains, Owlshead Mountains, Panamint Range) are considered highly susceptible to deep-seated landslide events (Wills et al. 2011).

Shrink/swell Soil

As volcanic ash deposits are weathered, they are physically and chemically altered to swelling clays (minerals such as smectites that expand when water-saturated and contract upon drying) that can pose a significant management issue. As these clay minerals swell and shrink in the presence of water, the constant change in volume can undermine the integrity of the substrate, increase the susceptibility of slope failure, and cause infrastructural problems along roadways. According to Noble (1934) and Denny and Drew (1965), ash beds locally altered to bentonite were historically mined near Shoshone and Bat Mountain along the national park's eastern boundary. Additional swelling clays, such as montmorillonite, have been reported along the Amargosa River Valley by Ericksen et al. (1988).

A comprehensive soil dataset and map for DEVA are forthcoming within the next year and account for nearly 12 million ha (30 million ac). Once completed, soil data obtained from the NRCS Web Soil Survey will be able to provide various soil physical property ratings including linear extensibility, a determination of the shrink-swell potential of soils.

Cave and Karst

Cave and karst resources within the national park are dissolutional features developed within older Paleozoic carbonate rocks in addition to younger evaporite deposits predominantly composed of halite or gypsum. Although DEVA lacks a comprehensive inventory of its cave and karst resources, currently there are at least

two large, explorable caves (the largest is in the Titus Canyon area), in addition to several smaller dissolutional caves or sinkholes scattered across the national park (Graening 2012). In the Devil's Golf Course area, salt pools were once a main visitor attraction and developed as shallow groundwater dissolved away salt deposits to form crystal-lined pools. Prior to NPS management, entrepreneurs blasted holes into the playa beds to create artificial pools to attract tourists.

In the detached Devils Hole Unit, Devils Hole represents the collapsed upper portion of a flooded, spring-fed cave system (Shepard et al. 2000). As the protected environment of the endangered Devils Hole pupfish (*Cyprinodon diabolis*), Devils Hole is part of the Ash Meadows Complex, a collection of desert uplands and over 30 spring-fed oases that were designated a national wildlife refuge in 1984. As a window into the regional groundwater aquifer, Devils Hole is over 152 m (500 ft) deep, and its true depth and extent remain unknown (Richard Friese, DEVA hydrologist, personal communication May 2024). Critical, spring-fed environments such as Devils Hole are sensitive habitats that are susceptible to floods, debris flows, seismically induced seiches (standing waves that oscillate in enclosed spaces), increased groundwater usage (e.g., mining, agriculture, tourism, residential development), and vandalism.

In addition to naturally formed cave and karst features, DEVA includes an anthropogenic sinkhole feature related to the collapse of the Texas Spring tunnel. Developed by miners during the late 1920s or 1930s, the Texas Spring tunnel represents an abandoned groundwater well that was formerly part of DEVA's eastern hydrologic infrastructure (Pistrang and Kunkel 1964). Collapsed portions of the tunnel are considered hazardous (Richard Friese, DEVA hydrologist, personal communication May 2024).

Seismicity

Located in the Basin and Range physiographic province of eastern California, DEVA is part of a dynamic, seismically active region transected by an elaborate system of fault structures, including strike-slip, normal, oblique-slip (faults that incorporate components of strike-slip and normal displacement), and thrust faults (see Figure 1). Displacement along these faults can be observed along several scarp exposures, including those along the alluvial fan just south of Badwater (Figure 9). According to seismic hazard models by Petersen et al. (2023), the national park occupies a region of very high to high seismic probability compared to the rest of the country. Several seismic monitoring sites are installed within the national park as part of the California Geological Survey California Strong Motion Instrumentation Program (CSMIP). These sites include (in order of increasing latitude) Shoshone, Furnace Creek, and Grapevine (see https://www.conservation.ca.gov/cgs/smip/; accessed 22 July 2024). Although the Death Valley region is generally considered to be an area of high seismic potential, the history of earthquake activity is relatively sparse, with most of the perceived ground motion originating from earthquake clusters around the margin of the national park (Machette et al. 1999). According to the California Geological Survey, one of the largest earthquakes recorded in proximity to DEVA included a magnitude 7.6 event that occurred on 26 March 1872 (see https://maps.conservation.ca.gov/cgs/; accessed 22 July 2024). The earthquake epicenter was located in Owens Valley, approximately 5 km (3 mi) southeast of Manzanar National Historic Site. The earthquake was followed by aftershocks measuring 6.8 (26 March 1872), 6.3 (3 April 1872), and 6.8 (11 April 1872); these events were also centered within Owens Valley to the west of DEVA. According to historical (1769–2015) earthquake data from the California Geological Survey, there have been at least six recorded earthquakes in DEVA that have measured above a magnitude 5.0 event (Table 5; see https://maps.conservation.ca.gov/cgs/; accessed 22 July 2024).

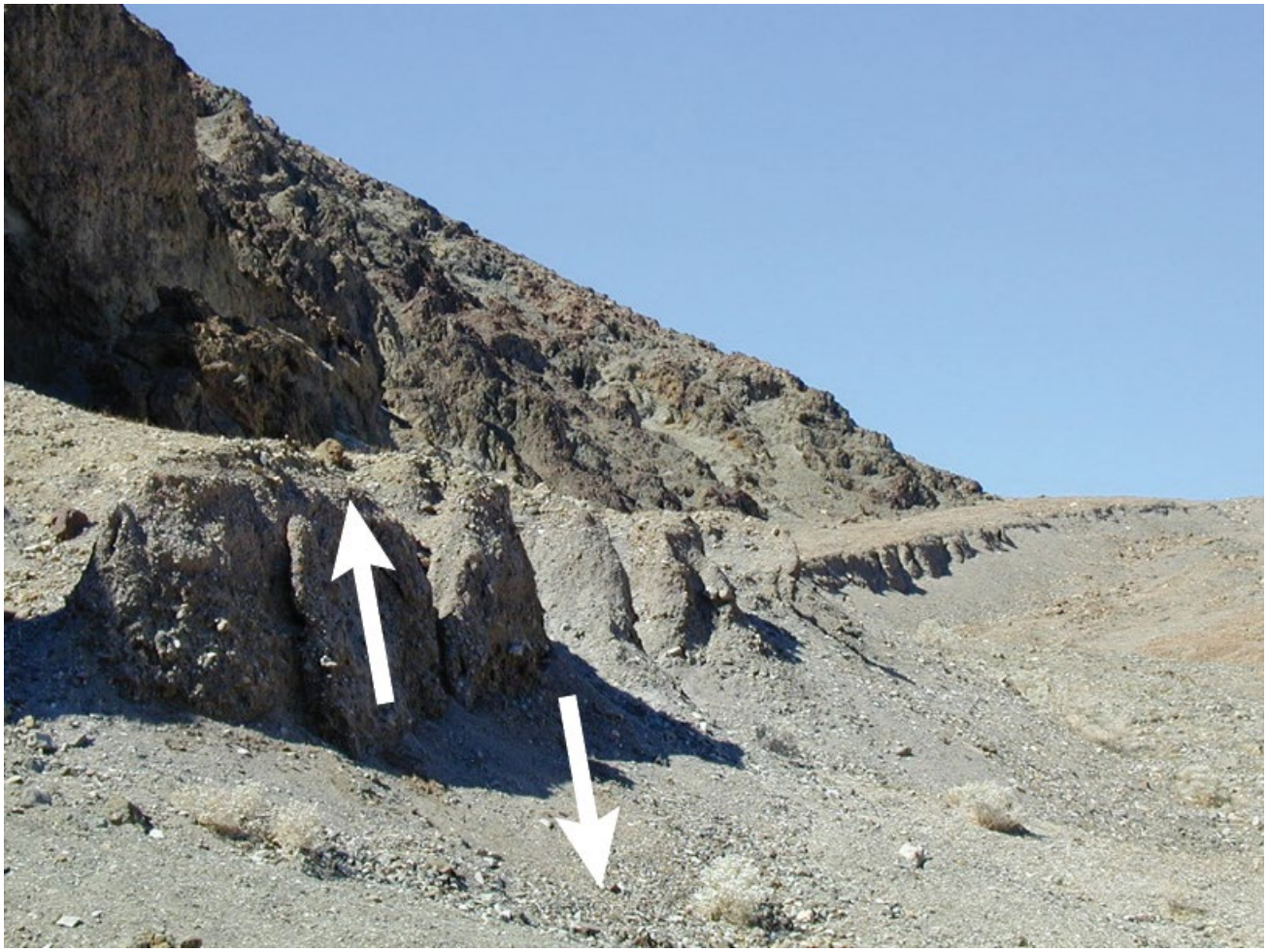


Figure 9. A fault scarp located in the alluvial fan immediately south of Badwater. Exposed near the canyon mouth, the scarp offsets Quaternary alluvial fan deposits and indicates that the valley floor is still actively subsiding. Arrows indicate the relative sense of displacement along the scarp. NPS photo.

Table 5. Historical (1769–2015) earthquakes measuring above magnitude 5.0 recorded within DEVA. Data provided from the California Geological Survey/California Department of Conservation Data Viewer.

Date	Magnitude	Epicenter Location
4 November 1911	6.0	Panamint Range near Butte Valley
13 June 1939	5.0	Grapevine Mountains east of Scotty's Castle
11 November 1949	5.6	Northeastern Saline Range, about 7 km (4.3 mi) west of Eureka Dunes
14 June 1945	5.0	East of the Last Chance Range, approximately 9 km (5.6 mi) north of Ubehebe Crater
17 May 1993	6.1	Northernmost Saline Range
19 May 1993	5.0	Northeastern Saline Range, about 11 km (6.8 mi) northwest of Eureka Dunes

Protected geologic resources, such as Devils Hole, host sensitive habitats that are susceptible to regional-scale seismic events, including those originating thousands of miles away. On 5 December 2024, a magnitude 7.0 earthquake originated off the coast of northern California approximately 805 km (500 mi) northwest of Devils Hole. Within minutes of the quake, water began sloshing around within the pool environment of Devils Hole. Seismically induced waves called seiches reached nearly 0.6 m (2 ft) high and

disrupted the shallow shelf—the main spawning area of the endangered Devils Hole pupfish (https://www.nps.gov/deva/learn/news/devils-hole-seiche-2024-12-05.htm; accessed 10 December 2024). Seiche disturbances not only impact the spawning grounds of the pupfish but can also destroy eggs and remove dietary algae growing along the pool's shallow carbonate rocks (Chaudoin 2014; Chaudoin et al. 2015). The 28 July 2021 Alaskan Chignik earthquake was a magnitude 8.2 event that was centered along the Alaskan Peninsula. Despite the epicenter being more than 3,700 km (2,300 mi) away, the earthquake generated a seiche within Devils Hole that caused water levels to fluctuate and redistribute flash flood debris that had been deposited only a couple of days prior. An additional 7.6 magnitude earthquake struck the Mexican states of Colima and Michoacán on 19 September 2022. Even though the epicenter was over 2,400 km (1,500 mi) away, the shockwave triggered a seiche that included waves approximately 1.2 m (4 ft) tall.

Climate Change

Although climate change planning is beyond the scope of this GSRI summary, a discussion of it is included because of the potential disruption it may cause to the national park's geologic resources. Considered one of the most inhospitable places on Earth, the national park is well-known for its arid climate and record-breaking heat. As DEVA continues to record increasing average temperatures, projected climate change scenarios include several significant threats to the national park's infrastructure (e.g., buildings, roadways, trails), archeological or cultural resources, and natural resources (e.g., geologic, biological, hydrological). The climate at the national park is already changing; since 1970, the park has warmed at a rate of 3.8° C (6.8° F) per century (Climate Change Response Program 2024). All future climate model projections include temperatures above the recent historical average (1979–2012), and average annual precipitation is projected to be highly variable (Climate Change Response Program 2024). Projected increases in several variables (e.g., air temperatures, evaporation rates, extreme drought, extreme precipitation) may negatively affect aquifer recharge, spring or seep persistence, as well as water quality. These modifications to water availability are likely to impact additional geologic processes (e.g., floods, landslides, mudslides, erosion), in addition to ecological processes (e.g., invasive species, phenology), visitation, and park management procedures (Climate Change Response Program 2024).

As the climate continues to shift, there is an expected increase in the frequency, intensity, and duration of both droughts and storm events (National Park Service 2017). Projected increases in temperature are likely to stress the regional groundwater aquifer, which may limit water availability and negatively impact sensitive spring-fed environments—including Devils Hole and the endangered Devils Hole pupfish. Large storm events, including those that occurred in August 2023 (Hurricane Hilary), August 2022, and October 2015, produced devastating flash floods and debris flows that caused widespread infrastructure damage and threatened sensitive ecosystems, resources, and lives.

In summary, climate change manifestations that may intensify geologic hazards include the following:

- More frequent and intense droughts
- More frequent and intense storms, including tropical storms or hurricanes
- More frequent and intense flash flooding and debris flows
- Decreased water availability as groundwater sources dissipate
- Increased erosion and susceptibility to paleontological and cultural resources

Volcanic Activity

Volcanism has occurred at various times throughout the geologic history of DEVA, including (1) the intrusion of Mesoproterozoic diabase sills in the basal Crystal Spring Formation; (2) widespread Mesozoic plutonism and volcanism; and (3) ongoing Cenozoic plutonism and volcanism associated with basin and range extension (Connors and Covington 2004; Van Gosen et al. 2004; Workman et al. 2014). Volcanic events are sometimes violent natural occurrences and can directly or indirectly endanger human lives, infrastructure, or resources through a combination of (1) flowage phenomena (e.g., debris avalanches, debris flows, pyroclastic flows, pyroclastic surges, directed blasts, lava flows, lava domes, floods); (2) eruption of tephra; (3) emission of volcanic gases; and (4) volcanically induced seismicity (Miller 1989). In the northern part of DEVA, the Ubehebe volcanic center—which includes the famous Ubehebe Crater—consists of at least 14 overlapping craters that formed during a series of explosions about 2,100 years ago as rising magma encountered the groundwater table (Figure 10; Champion et al. 2018; Valentine et al. 2022). Characterized as a maar-style eruption, the hot molten rock instantly flashed water into steam, producing an explosion that blasted rock and lava high into the air and blanketed a 39 km^2 (15 mi^2) area with ash (Mangan et al. 2019).

Although there is no visual evidence to suggest magma still resides beneath the Ubehebe volcanic center (e.g., fumaroles, hot springs, or areas of high heat flow), the area remains on California's list of threatening volcanoes because of its geologic youth and past explosivity (Mangan et al. 2019). According to Miller (1989), there is a 10-km (6.2-mi) radius hazard zone surrounding Ubehebe Crater that accounts for potential future stream blasts or pyroclastic surges. Future geophysical investigations can likely determine subsurface conditions below the volcanic center and help assess the likelihood of future eruptions.



Figure 10. Aerial photograph of Ubehebe Crater. Located in the northern part of DEVA, the crater is listed on California's list of threatening volcanoes due to its geologic youth (about 2,100 years old) and previous explosive history. NPS photograph/Birgitta Jansen.

Radon

Radon is a naturally occurring gas created by the radioactive decay of the element radium. Although radon is usually present in small amounts in soil and rocks, some types of rock (i.e., volcanic rocks, granites, dark shales, phosphate-rich rocks, and metamorphic rocks) have the potential to produce above-average amounts of radon gas, which is a known health risk (Otton 1992). According to the US Environmental Protection Agency (EPA) map of radon zones, the Death Valley region is identified as a zone of moderate potential (zone 2) for elevated indoor radon levels.

Toxicological Soil

According to the DOI SHIRA risk mapper report, the soils of the national park include potentially hazardous elemental abundances of asbestos or erionite (fibrous silicate minerals), arsenic, cadmium, lead, and selenium, Valley Fever fungus (*Coccidioides*), and *Bacillus anthracis*—a naturally occurring soil pathogen known to cause anthrax. Naturally occurring asbestos or erionite occurs in certain geologic settings (e.g., those containing ultramafic rocks, serpentinite, or fibrous amphibole) and can introduce health issues if disturbed by natural erosion or anthropogenic activities. Although asbestos-bearing talc-tremolite rocks have been mined in the region surrounding DEVA, the national park's talc-tremolite deposits remain to be evaluated for their asbestos potential (Van Gosen et al. 2004). Inhalation of fine airborne particles of asbestos or erionite can introduce various respiratory illnesses, including mesothelioma and other types of cancer. Soil maps show that potentially hazardous concentrations of arsenic, cadmium, lead, and selenium occur within the top 5 cm (2 in) of soil based on 2010 sampling (DOI SHIRA). For more information on naturally occurring arsenic, cadmium, lead, and selenium, in addition to their potential health impacts, visit the US Department of Health and Human Services Agency for Toxic Substances and Disease Registry (see https://www.atsdr.cdc.gov/; accessed 22 July 2024).

Valley Fever is an infection caused by a fungus that lives in soils throughout the southwestern United States and parts of Mexico, Central America, and South America. More information about Valley Fever can be found at the US Centers for Disease Control and Prevention's Valley Fever website (https://www.cdc.gov/valley-fever/hcp/clinical-overview/index.html; accessed 22 July 2024). Anthrax is a rare, naturally occurring disease caused by the bacteria *Bacillus anthracis* that can cause severe illness to both people and livestock who are exposed to spores. For more information on the public health risks associated with anthrax, visit the US Centers for Disease Control and Prevention's anthrax website (see https://www.cdc.gov/anthrax/about/index.html; accessed 22 July 2024).

Geologic Resource Protection

The core responsibility of the NPS is to preserve and protect park resources, processes, systems, and values unimpaired for present and future generations. According to National Park Service (2006), the NPS will preserve and protect geologic resources, features, and processes as integral components of park natural systems. The goals of the NPS are to (1) assess the impacts of natural processes and human activities on geologic resources; (2) maintain and restore the integrity of existing geologic resources; (3) integrate geologic resources management into NPS operations and planning; and (4) interpret geologic resources for the benefit and enjoyment of park visitors (National Park Service 2006). Various management protection policies applicable to geologic resources, features, and processes are included in National Park Service (2006) and are also organized at the following website: https://home.nps.gov/subjects/geology/geoheritage-nps-management-policies.htm (accessed 22 July 2024).

Cave and Karst Resources

According to a cave faunal survey by Graening (2012), DEVA contains at least nine identified caves that include (in alphabetical order): Crack-'n-Mound Cave, Dirty Crack Cave, Furnace Cave (aka Squacky's Cave), Gnomes Grotto, Keave Travertine Cave, No Snakes Cave, Sponge Cave, Titus Canyon Cave (aka Great Western Mine Cave or Leadfield Cave), and Wallboard Cave. Perhaps the best-studied cave within the park is Titus Canyon Cave, which was discovered in either 1925 or 1926 by miners operating out of the town of Leadfield (Ek and Rogers 2011). Since its discovery, Titus Canyon Cave has been known to contain delicate speleothems and passageways lined with spectacular crystalline aragonite minerals. According to Ek and Rogers (2011, p. 4), the crystalline cave decoration is "…arguably one of the more impressive aragonite displays in the country." Unfortunately, since the 1920s, multiple incidents of vandalism have been reported from Titus Canyon Cave, and the NPS has been forced to continuously improve or upgrade vandal-resistant gates at both the lower and upper cave entrances (Ek and Rogers 2011; Graening 2012).

For additional information regarding cave and karst resource laws, regulations, and policies, the NPS GRD developed the following summary article: https://www.nps.gov/articles/caves-and-karst-systems-legal-instruments.htm (accessed 22 July 2024).

Groundwater Resources

In the arid Mojave Desert environment, groundwater is a critical resource that helps sustain ecosystems and drive landscape processes. Although DEVA receives an average of 5 cm (2 in) of rain per year, the national park contains approximately 1,000 springs, seeps, and streams that are sustained by a complex regional carbonate aquifer (National Park Service 2017). These groundwater resources are impacted by several natural and anthropogenic processes, including evaporation, drought, rainfall, floods, debris flows, seismicity, groundwater consumption or diversion, climate change, and potential radionuclide transport.

As one of the hottest environments on the planet, evaporative loss in DEVA is roughly 200 times greater than the rate of precipitation (National Park Service 2017). Periods of drought stress the availability of water. However, large storm events can rapidly and destructively deliver a year's worth of water in a matter of hours, generating flash floods and debris flows that can damage or destroy groundwater springs (see "Mass Wasting"). Deep groundwater pools such as Devils Hole are susceptible to seismically induced seiches—even from large earthquake epicenters over 3,700 km (2,300 mi) away (see "Seismicity"). Increased groundwater consumption or diversion (e.g., mining, agriculture, renewable energy, residential development, illegal marijuana cultivation) both within and surrounding DEVA stresses the regional groundwater system, introduces sources of possible contamination or degradation, and threatens sensitive habitats such as Devils Hole. During the 1960s and 1970s, groundwater development in the Ash Meadows area near Devils Hole conflicted with the preservation of the endangered Devils Hole pupfish, a concern that resulted in a landmark 1976 US Supreme Court decision (*Cappaert v. United States*) in favor of protecting federal water rights (National Park Service 2017; Halford and Jackson 2020). As the temperature continues to increase at the national park, projected climate change will likely exacerbate the threats stressing the groundwater resources of the region (see "Climate Change").

The national park shares the same regional groundwater flow system as the nearby Nevada National Security Site (the "Nevada Test Site"). For several decades, underground nuclear testing at the Nevada Test Site introduced radionuclide (radioactive forms of elements) contamination into the groundwater system (Halford

and Jackson 2020; see https://www.usgs.gov/mission-areas/water-resources/science/radionuclides; accessed 22 July 2024). Park management is aware of the issues regarding potential radionuclide transport, but recent scientific literature strongly suggests it is not a major concern for the national park's groundwater resources (Richard Friese, DEVA hydrologist, personal communication May 2024).

Paleontological and Cultural Resources

The national park's paleontological and cultural resources are invaluable and provide a unique window into the geological and historical past of the Death Valley region. The national park contains one of the most diverse and significant fossil records in the National Park System and the nation (National Park Service 2017). The rocks in DEVA preserve a nearly continuous geologic record from the Proterozoic to the Cenozoic. Fossils contained within these rocks show how simple stromatolites evolved into complex invertebrates, vertebrates, and plants. Certain areas within the national park—notably Copper Canyon—contain a rich assemblage of vertebrate fossils and trackways of birds, camels, horses, cats, and proboscideans that are of considerable scientific value. A detailed summary of DEVA's stratigraphy, fossils, and depositional settings can be found in Table 2 of Tweet et al. (2016). Cultural resources of the national park encompass the human occupation of the Death Valley region, including Indigenous cultures, prospectors, miners, and early settlers. Both paleontological and cultural resources at DEVA are invaluable, as they record life's evolutionary and adaptive responses to climate change in one of the most extreme environments on the planet.

Natural and anthropogenic processes threaten these sensitive resources, including flash floods, debris flows, fire, seismicity, climate change, trespass livestock, illegal off-road vehicles, illegal marijuana cultivation, and park construction or maintenance projects (National Park Service 2017). Although dynamic erosional processes can aid in the discovery of paleontological and cultural resources, they also have the potential to bury, destroy, or expose them to looting, vandalism, or neglect.

For additional information regarding paleontological resource laws, regulations, and policies, the NPS GRD developed the following summary article: https://www.nps.gov/articles/paleontolosy-legal-instruments.htm (accessed 22 July 2024).

Inventory Needs

The following table (Table 6) presents several geologic and soil resources inventory needs that were identified during the 2024 follow-up meeting, in NPS planning documents, or through literature review.

Table 6. List of identified geologic and soil resources inventory needs for the national park.

Subject	Inventory Need(s)	Reference(s)
Climate change	Climate change vulnerability assessment	National Park Service (2017)
Climate change	Park sustainability plan with integrated climate change considerations	National Park Service (2017)
Cultural resources	Cultural resources management plan with integrated climate change considerations. Cultural resource data management protocols should focus on maintaining a GIS database, as well as complete and digitize legacy data. Additionally, cultural resource condition assessments should be updated to support stewardship planning and meeting national goals.	National Park Service (2017)

Subject	Inventory Need(s)	Reference(s)
Cultural resources	Enter cultural resources, especially mine sites and ruins, into the Facility Management Software System database.	National Park Service (2017)
Cultural resources	Complete GIS predictive model for cultural resources	National Park Service (2017)
Cultural resources	Update museum collections management plan	National Park Service (2017)
Cultural resources	Updated cultural landscape inventory and report for Scotty's Castle	National Park Service (2017)
Cultural resources	Scotty's Castle/Grapevine Developed Area preservation plan, including flood mitigation	National Park Service (2017)
Cultural resources	Damage assessment of Scotty's Castle District archeological sites	National Park Service (2017)
Cultural resources	Historic mining site management and preservation plan	National Park Service (2017)
Cultural resources	Additional cultural resource surveys focusing on developed areas, roads (especially California State Route 190), rights-of-way, and utility corridors. Approximately 3% of the park has been surveyed for archeological and cultural resources. Many of these surveys date to the 1950s and 1960s and are inadequate by current standards. Many developed and non-developed areas of the national park lack adequate survey information. Completed surveys would greatly assist park managers to make well-informed decisions, avoid unnecessary project delays, and protect the cultural resources of the park.	National Park Service (2017)
Disturbed lands	Burro management plan and additional data. Feral burros flourish in the desert conditions of the park, with the population continuing to increase over time. The burros damage the desert ecosystem by overgrazing scant plant resources and trampling riparian areas. Replicated, long-term enclosure studies that control for soil type, vegetation type, and burro density have the potential to provide strong inferences about the effects of burros on soils and vegetation.	National Park Service (2017); Fleishman et al. (2019)
Disturbed lands	Abandoned mineral lands inventory. Focus on completing comprehensive inventory of AML sites that categorizes high, medium, and low priority mitigation needs and estimate the resources needed to address priority issues (e.g., hazards, reclamation issues, etc.).	National Park Service (2017)
Disturbed lands	Mining sites survey	National Park Service (2017)
Disturbed lands	Additional studies to examine pollution dose-response relationships in sensitive park resources, including monitoring mercury and other toxic contaminants.	National Park Service (2017); 2024 follow-up meeting
Flooding	Flood hazard and mitigation plan. A comprehensive, digital flood hazard map could help managers with park planning and future development.	National Park Service (2017); 2024 follow-up meeting
Flooding	Flood risk assessment of the Zabriskie Point. The high-visitation area is often impacted by fluvial processes which may impact further development.	Connors and Covington (2002)
Geologic resource protection	Geologic resource stewardship strategy	National Park Service (2017)
Geologic resource protection	GIS layer for illegal incidents, including vandalism and off-road vehicle use in wilderness	National Park Service (2017)

Subject	Inventory Need(s)	Reference(s)
Geologic resource protection	Climbing and canyoneering management plan	National Park Service (2017)
Geologic resource protection	Copper Canyon management plan. An investigation in Fall 2023 utilized LiDAR in three sections of Copper Canyon. Additional photogrammetry work was completed. Management plan needs to address and monitor anthropogenic disturbances such as looting, vandalism, etc.	National Park Service (2017); 2024 follow-up meeting
Geologic resource protection	Visitor-use management plan. Visitation is rapidly increasing while staff capacity remains limited. Resource degradation will continue to occur due to off-road vehicle use and other visitor activities.	National Park Service (2017)
Geoscience research	Faults in the Scotty's Castle district need to be better mapped and investigated (e.g., recurrence intervals) due to the potential instability in this culturally resource-rich area.	Connors and Covington (2002)
Geoscience research	Sand dunes in the national park need more research on their origins, development, and movement history.	Connors and Covington (2002)
Hydrology	Water utility plan	National Park Service (2017)
Hydrology	Texas Spring restoration plan. The Texas Spring tunnel is an abandoned groundwater well that has partially collapsed and fallen into disrepair. Any restoration efforts should include mitigation of deterioration of Texas Spring tunnel.	National Park Service (2017) Richard Friese (DEVA hydrologist, personal communication May 2024) JaneAnne Stockton (DEVA physical science technician, personal communication 16 January 2025)
Hydrology	Devils Hole pupfish management plan that addresses possible flood impacts (e.g., debris flows) and seismically induced seiches	National Park Service (2017)
Hydrology	New hydrologic models. The national park seeks an expansion and refinement of groundwater modeling, especially to the east of the park boundary.	National Park Service (2017); 2024 follow-up meeting
Hydrology	Incorporate the USGS lower carbonate aquifer model to simulate how withdrawals from wells affect future water resources elsewhere.	National Park Service (2017)
Hydrology	Delineate new wetland conditions	National Park Service (2017)
Hydrology	Hydrological investigation of Nevares Peak	Connors and Covington (2002)
Mapping	Comprehensive bedrock and surficial geologic maps of the national park	Connors and Covington (2002); 2024 follow-up meeting
Mapping	Correlation of geologic maps to other natural resource themes such as vegetation, archeology, and mining	Connors and Covington (2002)
Mapping	GIS layers for all types of geology (e.g., springs, geothermal, soils, volcanic data, paleontological resources, mining sites)	National Park Service (2017)
Mapping	Accurate elevation data (LiDAR)	National Park Service (2017); 2024 follow-up meeting
Mapping	Continuously update aerial imagery	National Park Service (2017)

Subject	Inventory Need(s)	Reference(s)
Mass wasting	Mass wasting hazard and mitigation plan. Detailed geologic and topographic map data (e.g., geomorphology, debris flow, LiDAR) could help guide decision-making to relocate or reroute infrastructure away from destructive zones.	2024 follow-up meeting
Mass wasting	GIS layer(s) of landscape changes post-2015 flood (debris flows, etc.)	National Park Service (2017)
Paleontological resources	Update the national park's paleontological inventory to include all reported fossil localities.	2024 follow-up meeting
Paleontological resources	Update the paleontological monitoring program to address fossil resource sensitivity with respect to climate change projections.	2024 follow-up meeting
Stratotype resources	Baseline condition and stability assessment, including unstable slope management program evaluation and photogrammetry	Henderson et al. (2021)
Stratotype resources	Establish routine monitoring plan to identify threats or impacts.	Henderson et al. (2021)
Stratotype resources	Work toward establishing stratotypes for several formally named units mapped within the national park (e.g., Neoproterozoic Sourdough Limestone Member 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).	Henderson et al. (2021)

Prior NRSS-Supported Work

Geologic or Soil Research Permits

As a premiere natural laboratory, Death Valley National Park has issued a significant number of research permits related to various geologic and soil science themes, including geochemistry, geohazards, paleontology, sedimentology, stratigraphy, structural geology, and volcanism. Table 7 is a select list of completed or ongoing research projects related to the geology or soils of the national park since 2020. These items are located on the NPS Research Permit and Reporting System of IRMA (see https://irma.nps.gov/RPRS/Search; accessed 22 July 2024) but may require government access or assistance.

Table 7. Research permits related to the geology or soils of DEVA since 2020.

Year(s)	Title	Author
2020, 2021, 2022	Ubehebe Crater cluster in Death Valley National Park: a key to understanding explosive phreatomagmatic eruptions	Judy Fierstein
2020	Geologic and paleontological reconnaissance of Pleistocene Rogers Beds	Kathleen Springer
2020	Investigating debris flow erosion in Saline Valley	Fiona Clubb
2020	Investigation of Neoproterozoic glacial deposits of the Kingston Peak Formation	Kelsey Lamothe
2020	Field-based structural and micro-structural analysis of the Boundary Canyon Fault, Funeral Mountains	Elizabeth Miller
2020	The evolution of seafloor colonization and exceptional preservation in early Paleozoic shallow marine environments	Lidya Tarhan
2020	Geology and geochemistry of the ca. 9 Ma Trail Canyon volcanic sequence, Panamint Range	James Calzia
2020	California Geological Survey – the California Strong Motion Instrumentation Program (CSMIP) seismic instrumentation adjacent to Furnace Creek district ranger station and Grapevine ranger station	Hamid Haddadi
2020, 2021	Evaluating Pleistocene Climate Change using Oxygen Isotope of Nitrate in the Confidence Hill formation, Death Valley California	Greg Michalski
2020, 2023	Strain accumulation across the Eastern California Shear Zone (ECSZ) at latitude 36 degrees-30 minutes	Jerry Svarc
2021	Investigating the Quaternary slip histories of normal faults within the Eastern California Shear Zone	Peter Haproff
2021, 2023	Using meandering channels in Death Valley to determine the role of bank cohesion for unvegetated rivers on Earth and Mars	Madison Douglas
2021, 2022, 2023, 2024	USGS Geologic Framework of the Intermountain West – Cenozoic stratigraphy	Theresa Schwartz
2021	Spatial variability in aeolian abrasion	Mackenzie Day
2021	Pennsylvanian–Permian mixed carbonate-siliciclastic deposition along the continental slope of western Laurentia	Eric Stauffer
2021, 2022	Holocene strain release on the Northern Death Valley Fault	Nadine Reitman
2021, 2023	Alluvial fans and lakes in Death Valley National Park, Miocene to present	Terence Blair
2021	Visiting the Cucumungo Canyon alluvial fan in Eureka Valley, CA near the Last Chance Mountain Range	Jacob Adler
2021	Correlation of ignimbrites in Death Valley National Park (Titus Canyon and Ubehebe Formations) to source calderas in central Nevada: implications for paleotopography and tectonics	Henry Christopher

Year(s)	Title	Author
2022	Parameters and factors controlling modern stromatolites in spring-fed streams in Death Valley National Park	Torrey Nyborg
2022	Neoproterozoic to early Paleozoic coevolution of environment and life recorded in southwestern Laurentia	Francis Macdonald
2022	Geology of deep rifts, their faults, and sedimentary basins	Ivar Midtkandal
2022	Geological study of the Pennsylvanian and Permian outcrops in Death Valley National Park	Caitlin Leslie
2022	Geologic map of surficial deposits along the Saline Valley fault system	Sofia Marino
2023	Evolution and kinematics of faulting in the Amargosa Chaos, Death Valley, California	Marli Miller
2023	Bacterial profile of the rhizosphere in the high drought habitat soil of Death Valley	Salme Timmusk
2023	Gaia's exhalation from the 2019 Ridgecrest earthquake in Death Valley	Ira Leifer
2023	Debris flows, erosion, and sedimentation resulting from exceptional precipitation over Death Valley during Hurricane Hilary	Josh West
2023	Rainbow Canyon and Panamint Valley (Death Valley National Park): reconnaissance in response to the flood of August 20, 2023	Jeffrey Nittrouer
2023	Death Valley after Hurricane Hilary: a study of desert landscape re-equilibration after extreme events	Mackenzie Day
2024	Sedimentological and stratigraphic framework of the Pennsylvanian and early Permian outcrops of the Keeler/Darwin Basin, east-central California	Joshua Malone
2024	Using stable isotope and trace element analyses to investigate pluvial lake formation in Badwater Basin, Death Valley National Park	Zach Perzan
2024	Paleontological resource survey for the environmental services for the repairs to Titus Canyon Road damaged by flooding at Death Valley National Park Project	Alyssa Bell
2024	Determining the extent of contact metamorphism in the Funeral Mountains	Suzanne Mulligan

Previous or Ongoing Technical Assistance Requests

The following table (Table 8) contains a list of previous or ongoing technical assistance requests submitted to the GRD related to the geology or soils of the national park. These items are located on the NPS Solution for Technical Assistance Requests (STAR) of IRMA (see https://irma.nps.gov/STAR/; accessed 22 July 2024) but may require government access or assistance.

Table 8. Technical assistance requests related to the geology or soils of DEVA.

Year(s)	Title	Program Area
2010	Cave resource inventory	Geologic Features, Processes, and Hazards
2011	Death Valley geospatial soils coverage	Soil Resources Management
2012	Develop paleontological resources management plan	Geologic Features, Processes, and Hazards
2012	Review of draft SUP from Inyo Country to use in park sand and gravel pits	Energy and Mineral Development
2012	Explain NPS mining regulations, policies, and laws to IRS examiners who are auditing a recent donation of mining claims to Death Valley National Park	Energy and Mineral Development
2017	Develop paleontological resources management plan	Caves, Paleontology, and other Geologic Features

Year(s)	Title	Program Area
2017	Provide regulatory and policy assistance with external and internal mining operation and use of Sourdough Springs water	Energy and Mineral Development
2019	Assist with two mining operations [Keystone Mine and Crater Mine]	Energy and Mineral Development
2020	2018 support for paleontological activities at Death Valley National Park	Caves, Paleontology, and other Geologic Features
2023	Paleontological resource monitoring plan for Copper Canyon fossil tracksite	Caves, Paleontology, and other Geologic Features
2023	Photogrammetry of unique or sensitive fossil tracks and trackways at Copper Canyon, Death Valley National Park	Caves, Paleontology, and other Geologic Features
2024	Photogrammetry of unique or sensitive fossil tracks and trackways at Copper Canyon, Death Valley National Park	Caves, Paleontology, and other Geologic Features
2024	Replace Salt Creek boardwalk and repair associated parking lot and access road	Caves, Paleontology, and other Geologic Features
2024	Repair flood-damaged Titus Canyon Road	Caves, Paleontology, and other Geologic Features
2024	Regulatory policy assistance for sand, gravel, and other mining	Mining and Minerals

Internship Projects

Nearly a dozen geoscience-based internship positions have been previously filled at DEVA through a variety of programs, including Public Land Corps Hiring Authority as well as Direct Hire Authority. These internships have assisted the national park with various projects addressing geoscience themes, including ecology, education and interpretation, hydrology, and natural resource management.

Acknowledgements

The GSRI team thanks the participants of the 2002 scoping meeting and the 2024 follow-up meeting for their assistance in this inventory. The lists of participants reflect the names and affiliations of these participants at the time of the meeting and call. Additional thanks to Trista L. Thornberry-Ehrlich for producing the DEVA GSRI poster and some of the figures in this summary report.

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Literature Cited

These references are cited in this summary document. Contact the GRD for assistance in obtaining them.

Baldridge, A. M., J. D. Farmer, and J. E. Moersch. 2001. Remote sensing of terrestrial analogs for evaporite basins on Mars: Analysis of ground truth. Eos (Fall Supplement) 82, abstract P22B-0550.

Baldridge, A. M., J. D. Farmer, and J. E. Moersch. 2004. Mars remote-sensing analog studies in the Badwater Basin, Death Valley, California. Journal of Geophysical Research 109(12). https://doi.org/10.1029/2004JE002315

Beebe, L. 1954. Panamint: suburb of Hell. American Heritage 6(1). https://www.americanheritage.com/panamint-suburb-hell

Bonaccorsi, R., A. J. P. Jones, T. Baldino, L. V. Bleacher, and C. P. McKay. 2014. MarsFest: an annual planetary analog event hosted by Death Valley National Park. 45th Lunar and Planetary Science Conference March 17–21, 2014, The Woodlands, Texas, abstract 2904.

Bryan, T. S., and B. Tucker-Bryan. 2021. The explorer's guide to Death Valley National Park (4th ed.). University Press of Colorado, Louisville, Colorado.

Burghardt, J. E., E. S. Norby, and H. S. Pranger, II. 2014. Abandoned mineral lands in the National Park System—comprehensive inventory and assessment. Natural Resource Technical Report NPS/NRSS/GRD/NRTR—2014/906. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2215804

Champion, D. E., A. Cyr, J. Fierstein, and W. Hildreth. 2018. Monogenetic origin of Ubehebe Crater maar volcano, Death Valley, California: paleomagnetic and stratigraphic evidence. Journal of Volcanology and Geothermal Research 354:67–73.

Chappel. G. 1990. Ryan, California: the curious case of the "portable" borate mining camp near Death Valley. Pages 158–166 *in* Barker, L. R., and A. E. Huston, editors. Death Valley to Deadwood; Kennecott to Cripple Creek. Proceedings of the 1989 Historic Mining Conference, Death Valley National Monument, California. https://archive.org/details/DeathValleytoDead005

Chaudoin, A. L. 2014. Video and visual surveys of spawning in Devils Hole pupfish *Cyprinodon diabolis.* Master's thesis. University of Arizona, Tucson.

Chaudoin, A. L., O. G. Feuerbacher, S. A. Bonar, and P. J. Barrett. 2015. Underwater videography outperforms above-water videography and in-person surveys for monitoring the spawning of Devils Hole pupfish. North American Journal of Fisheries Management 35:1252–1262. https://doi.org/10.1080/02755947.2015.1094155

Climate Change Response Program. 2024. Death Valley National Park climate futures summary. National Park Service. Fort Collins, CO. https://irma.nps.gov/DataStore/Reference/Profile/2303520

Connors, T., and S. Covington. 2004. Death Valley National Park geologic resources management issues scoping summary (revised). National Park Service, Geologic Resources Division, Lakewood, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2250147

Crippen, J. R. 1979. Potential hazards from floodflows and debris movement in the Furnace Creek area, Death Valley National Monument, California–Nevada. US Geological Survey Open-File Report 79-991. https://irma.nps.gov/DataStore/Reference/Profile/95357

Crippen, J. R. 1981. Potential hazards from floodflows in Wildrose Canyon, Death Valley National Monument, California–Nevada. US Geological Survey Open-File Report 81-407. https://irma.nps.gov/DataStore/Reference/Profile/511832

Curry, H. D. 1939. Tertiary and Pleistocene mammal and bird tracks in Death Valley. Bulletin of the Geological Society of America, 50(12):1971–1972.

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

Curry, D. 1938. "Turtleback" fault surfaces in Death Valley, California (abs.). Geological Society of America Bulletin 49, 1875.

Curry, D. 1954. Turtlebacks in the central Black Mountains, Death Valley, California. Pages 53–59 *in* R. H. Jahns, editor. Geology of Southern California. California Division of Mines Bulletin 170.

Death Valley Natural History Association. 2023a. Puff, puff, kill a national park. Telescope Quarterly FY2023 Q1.

Death Valley Natural History Association 2023b. Marijuana grow clean-up. Telescope Quarterly FY2023 Q2.

Ek, D. A., and B. Rogers. 2011. Timeline/chronology for Titus Cave, Death Valley National Park. Unpublished document. National Park Service.

Ericksen, G. E., J. W. Hosterman, and P. S. Amand. 1988. Chemistry, mineralogy and origin of the clay-hill nitrate deposits, Amargosa River valley, Death Valley region, California, USA. Chemical Geology 67:85–102.

Farr, T. G., S. Arcone, R. E. Arvidson, V. Baker, N. G. Barlow, D. Beaty, M. S. Be11, D. D. Blankenship, N. Bridges, G. Briggs, M. Bulmer, F. Carsey, S. M. Clifford, R. A. Craddock, P. W. Dickerson, N. Duxbury, G. L. Galford, J. Garvin, J. Grant, J. R. Green, T. K. P. Gregg, E. Guinness, V. L. Hansen, M. H. Hecht, J. Holt, A. Howard, L. P. Keszthelyi, P. Lee, P. D. Lanagan, R. C. F. Lentz, D. W. Leverington, L. Marinangeli, J. E. Moersch, P. A. Morris-Smith, P. Mouginis-Mark, G. R. Olhoeft, G. G. Ori, P. Paillou, J. F. Reilly II, J. W. Rice, Jr., C. A. Robinson, M. Sheridan, K. Snook, B. J. Thomson, K. Watson, K. Williams, and K. Yoshikawa. 2002. Terrestrial analogs to Mars. Pages 35–76 *in* M. V. Sykes, editor. The future of solar system exploration, 2003–2013. Astronomical Society of the Pacific Conference Series 272.

Fleishman, E.,C. Albano, B. A. Bradley, T. G. Creech, C. Curtis, B. G. Dickson, C. W. Epps, E. E. Hegeman, C. Hoglander, M. Leu, N. Shaw, M. W. Schwartz, A. VanCuren, and L. Z. Zachmann. 2019. Natural resource condition assessments for six parks in the Mojave Desert Network. Natural Resource Report NPS/MOJN/NRR—2019/1959. National Park Service, Fort Collins, Colorado. https://irma.nps.gov/DataStore/Reference/Profile/2265461

Fridrich, C. J., and R. A. Thompson. 2011. Cenozoic tectonic reorganizations of the Death Valley region, southeast California and southwest Nevada. US Geological Survey Professional Paper 1783. https://pubs.usgs.gov/pp/1783/

Fridrich, C. J., R. A. Thompson, J. L. Slate, M. E. Berry, and M. N. Machette. 2012. Geologic map of the southern Funeral Mountains including nearby groundwater discharge sites in Death Valley National Park, California and Nevada. US Geological Survey Scientific Investigations Map 3151. https://pubs.usgs.gov/sim/3151/

Gagnon, C. A., K. L. Butler, E. Gaviria, A. Terrazas, A. Gao, T. Bhattacharya, D. F. Boutt, L. A. Munk, and D. E. Ibarra. 2023. Paleoclimate controls on lithium enrichment in Great Basin Pliocene–Pleistocene lacustrine clays. GSA Bulletin 135:11–12.

Graening, D. O. 2012. Faunal biodiversity assessment of subterranean habitats of California – investigator's annual report part 2: Mojave Desert region. California State University, Sacramento, California. National Park Service study# MOJA-00240 and DEVA-00260.

Greene, L. W., and J. A. Latschar. 1981. Death Valley National Monument historic resource study: a history of mining (volumes I and II). National Park Service Historic Preservation Branch, Denver, Colorado. https://www.nps.gov/parkhistory/online_books/deva/index.htm

Halford, K. J., and T. R. Jackson. 2020. Groundwater characterization and effects of pumping in the Death Valley regional groundwater flow system, Nevada and California, with special reference to Devils Hole. US Geological Survey Professional Paper 1863. https://pubs.usgs.gov/publication/pp1863

Henderson, T. C., V. L. Santucci, T. Connors, and J. Tweet. 2021. National Park Service geologic type section inventory: Mojave Desert Inventory & Monitoring Network. Natural Resource Report. National Park Service. Fort Collins, Colorado. https://doi.org/10.36967/nrr-2289952

Hoffmann, P. F., and D. P. Schrag. 2000. Snowball earth. Scientific American, 282(1):68–75. https://www.jstor.org/stable/26058566

Jarvis, J. E. 2015. Addressing climate change and natural hazards for facilities. Policy Memorandum 15-01 to All Employees (National Park Service), 20 January 2015. US Department of the Interior, National Park Service, Washington DC Support Office, Washington DC. https://www.nps.gov/policy/PolMemos/policymemoranda.htm

Jayko, A. S., R. M. Forester, D. S. Kaufman, F. M. Phillips, J. C. Yount, J. McGeehin, and S. A. Mahan. 2008. Late Pleistocene lakes and wetlands, Panamint Valley, Inyo County, California. Pages 151 – 184 *In* Reheis, M. C., R. Hershler, and D. M. Miller (eds.). Late Cenozoic drainage history of the southwestern Great Basin and lower Colorado River region: geologic and biotic perspectives. Geological Society of America Special Paper 439.

Jones, A. J. P., B. Stewart, P. Taylor, and R. R. Joaquin. 2020. Death Valley Dark Sky Festival: NASA science engagement in a national park. Abstract# 3005, 51st Lunar and Planetary Science Conference March 2020, The Woodlands, Texas.

Knott, J. R., E. Wan, A. L. Deino, M. Casteel, M. C. Reheis, F. M. Phillips, L. Walkup, K. McCarty, D. N. Manoukian, and E. Nunez, Jr. 2019. Lake Andrei: a Pliocene pluvial lake in Eureka Valley, eastern California. Pages 125–142 *in* S. W. Starratt, and M. R. Rosen, editors. From saline to freshwater: the diversity of western lakes in space and time. Geological Society of America Special Paper 536.

Knott, J. R., E. Wan, A. L. Deino, M. Casteel, M. C. Reheis, F. M. Phillips, L. Walkup, K. McCarty, D. N. Manoukian

Lowenstein, T. K., J. Li, C. Brown, S. M. Roberts, T.-L. Ku, S. Luo, and W. Yang. 1999. 200 k.y. paleoclimate record from Death Valley salt core. Geology 27(1):3–6. https://doi.org/10.1130/0091-7613(1999)027%3C0003:KYPRFD%3E2.3.CO;2

Machette, M. N., C. N. Martinez, A. J. Crone, K. M. Haller, and G. D'Addezio. 1999. Geologic and seismic hazards investigations of the Cow Creek area, Death Valley National Park, California. US Geological Survey Open-File Report 99-155. https://pubs.usgs.gov/publication/ofr99155

Machette, M. N., M. L. Johnson, and J. L. Slate (editors). 2001. Quaternary and Late Pliocene geology of the Death Valley region: recent observations on tectonics, stratigraphy, and lake cycles (guidebook for the 2001 Pacific Cell—Friends of the Pleistocene fieldtrip), US Geological Survey Open-File Report 01-0051. https://pubs.usgs.gov/of/2001/ofr-01-0051/

Mahon, R. C., C. M. Dehler, P. K. Link, K. E. Karlstrom, and G. E. Gehrels. 2014a. Detrital zircon provenance and paleogeography of the Pahrump Group and overlying strata, Death Valley, California. Precambrian Research 251.

Mahon, R. C., C. M. Dehler, P. K. Link, K. E. Karlstrom, and G. E. Gehrels. 2014b. Geochronologic and stratigraphic constraints on the Mesoproterozoic and Neoproterozoic Pahrump Group, Death Valley, California: a record of the assembly, stability, and breakup of Rodinia. GSA Bulletin 126(5-6). https://www.researchgate.net/publication/262141723_Geochronologic_and_stratigraphic_constraints_on_the_Mesoproterozoic_and_Neoproterozoic_Pahrump_Group_Death_Valley_California_A_record_of_the_assembly_stability_and_breakup_of_Rodinia

Mangan, M., J. Ball, N. Wood, J. L. Jones, J. Peters, N. Abdollahian, L. Dinitz, S. Blankenheim, J. Fenton, and C. Pridmore. 2019. California's exposure to volcanic hazards. US Geological Survey Scientific Investigations Report 2018–5159. https://doi.org/10.3133/sir20185159

Miller, C. D. 1989. Potential hazards from future volcanic eruptions in California. US Geological Survey Bulletin 1847. https://pubs.usgs.gov/bul/1847/

Miller, C. B., and L. A. Wright. 2015. Geology of Death Valley National Park (3rd ed.). Kendall Hunt Publishing, Dubuque, Iowa.

Miller, C. D., D. R. Mullineaux, D. R. Crandell, and R. A. Bailey. 1982. Potential hazards from future volcanic eruptions in the Long Valley-Mono Lake area, east-central California and southwest Nevada; a preliminary assessment. US Geological Survey Circular 877. https://pubs.usgs.gov/publication/cir877

Morris, C. M., and Welborn, T. L. 2019. Flood-inundation mapping of a steep, gravel desert stream in Death Valley National Park, California. *In* Proceedings of SEDHYD 2019: Conferences on Sedimentation and Hydrologic Modeling (vol. 1), Reno, Nevada. https://www.sedhyd.org/2019/#sedhyd-2019-proceedings

Morris, C. M., T. L. Welborn, and J. T. Minear. 2020. Delineation of flood-inundation areas in Grapevine Canyon near Scotty's Castle, Death Valley National Park, California. US Geological Survey Scientific Investigations Report 2020-5082. https://pubs.usgs.gov/publication/sir20205082

National Park Service. 1976. The mining situation in Death Valley National Monument. Death Valley National Park publications, informal report. https://www.npshistory.com/publications/deva/index.htm#documents

National Park Service. 2006. National Park Service management policies. National Park Service, US Department of the Interior, Washington, DC. https://www.nps.gov/orgs/1548/upload/ManagementPolicies2006.pdf

National Park Service. 2015. Addressing climate change and natural hazards: facility planning and design considerations, January 2015. Level 3 Handbook. National Park Service, Park Planning Facilities and Lands, Construction Program Management Division, Denver, Colorado. https://www.nps.gov/dscw/publicforms.htm#df

National Park Service. 2017. Foundation document, Death Valley National Park, California, Nevada (February 2017). DEVA 143/136699. Denver Service Center, Denver, Colorado. https://www.npshistory.com/publications/foundation-documents/index.htm

National Park Service. 2023. Addressing climate change and natural hazards handbook: checklist for assessment of environmental change and effects on National Park Service facilities, version 2, April 2023. NPS Park Planning, Facilities, and Lands Directorate. Washington, DC.

National Park Service and American Geosciences Institute. 2015. America's geologic heritage: an invitation to leadership. NPS 999/129325. National Park Service, Geologic Resources Division, Denver, Colorado, and American Geosciences Institute, Alexandria, Virginia. https://www.nps.gov/subjects/geology/americas-geoheritage.htm

Nelson, L. L., E. F. Smith, E. B. Hodgin, J. L. Crowley, M. D. Schmitz, and F. A. Macdonald. 2020. Geochronological constrains on Neoproterozoic rifting and onset of the Marinoan glaciation from the Kington Peak Formation in Death Valley, California. Geology 48(11):1083–1087. https://doi.org/10.1130/G47668.1

Noble, L. F. 1934. Rock formations of Death Valley, California. Science 80(2069):173–178.

North American Commission on Stratigraphic Nomenclature. 2021. North American Stratigraphic Code. Stratigraphy 18(3):153–204. https://ngmdb.usgs.gov/Geolex/stratres

Otton, J. K. 1992. The Geology of Radon. US Geological Survey Unnumbered Series, General Interest Publication. https://www.usgs.gov/publications/geology-radon

Petersen, M. D., A. M. Shumway, P. M. Powers, E. H. Field, M. P. Moschetti, K. S. Jaiswal, K. R. Milner, S. Rezaeian, A. D. Frankel, A. L. Llenos, A. J. Michael, J. M. Altekruse, S. K. Ahdi, K. B. Withers, C. S. Mueller, Y. Zeng, R. E. Chase, L. M. Salditch, N. Luco, K. S. Rukstales, J. A. Herrick, D. L. Girot, B. T. Aagaard, A. M. Bender, M. L. Blanpied, R. W. Briggs, O. S. Boyd, B. S. Clayton, C. B. DuRoss, E. L. Evans, P. J. Haeussler, A. E. Hatem, K. L. Haynie, E. H. Hearn, K. M. Johnson, Z. A. Kortum, N. S. Kwong, A. J. Makdisi, H. B. Mason, D. E. McNamara, D. F. McPhillips, P. G. Okubo, M. T. Page, F. F. Pollitz, J. L. Rubinstein, B. E. Shaw, Z-K. Shen, B. R. Shiro, J. A. Smith, W. J. Stephenson, E. M. Thompson, J. A. Thompson Jobe, E. A. Wirth, and R. C. Witter. 2023. The 2023 US 50-State National Seismic Hazard Model: overview and implications. Earthquake Spectra. https://journals.sagepub.com/doi/10.1177/87552930231215428

Pistrang, M. A., and F. Kunkel. 1964. A brief geologic and hydrologic reconnaissance of the Furnace Creek Wash area, Death Valley National Monument, California. US Geological Survey Water Supply Paper 1779-Y. https://pubs.usgs.gov/publication/wsp1779Y

Reinhart, B. J. 2024. Hurricane Hilary. National Hurricane Center Tropical Cyclone Report. https://www.nhc.noaa.gov/data/tcr/index.php?season=2023&basin=epac

Santucci, V. L., and T. Nyborg. 1999. Paleontological resource management, systematic recording, and preservation of vertebrate tracks within Death Valley National Park, California. San Bernardino County Museum Association Quarterly 46(2):21–26.

Santucci, V. L., T. Nyborg, P. H. Buchheim, and K. E. Nick. 2011. Vertebrate paleontology of Death Valley National Park, California. Pages 127-155 In Bonde, J. W., and R. C. Milner (editors). Field Trip Guidebook for the 71st Annual Meeting of the Society of Vertebrate Paleontology, Las Vegas, Nevada. Nevada State Museum Paleontological Papers Number 1. https://irma.nps.gov/DataStore/Reference/Profile/2256497

Shaller, P. J., M. Doroudian, and M. W. Hart. 2020. The Eureka Valley landslide: evidence of a dual failure mechanism for a long-runout landslide. Lithosphere 2020(1). https://doi.org/10.2113/2020/8860819

Shepard, W. D., D. W. Blinn, R. J. Hoffman, and P. T. Kantz. 2000. Algae of Devils Hole, Nevada, Death Valley National Park. Western North American Naturalist 60(4):410-419. https://www.researchgate.net/publication/280000500_Algae_of_Devils_Hole_Nevada_Death_Valley_National_Park

Stamm, N. R. 2023. Suggestions for proposing changes in nomenclature in papers submitted to "Stratigraphic Notes". Pages 3–16 *in* Orndorff, R.C., N. R. Stamm, and D. R. Soller, editors. Stratigraphic notes—Volume 1, 2022: US Geological Survey Professional Paper 1879–1. https://doi.org/10.3133/pp1879v1

Stevens, C. H., and P. Stone. 2005. Interpretation of the Last Chance thrust, Death Valley region, California, as an early Permian décollement in a previously undeformed shale basin. Earth-Science Reviews 73(1–4):79–101.

Stevens, C. H., P. Stone, and R. T. Magginetti. 2015. Regional implications of new chronostratigraphic and paleogeographic data from the early Permian Darwin Basin, east-central California. Stratigraphy 12(2). https://www.micropress.org/microaccess/stratigraphy/issue-319/article-1944

Topping, D. J. 1993. Paleogeographic reconstruction of the Death Valley extended region: evidence from Miocene large rock-avalanche deposits in the Amargosa Chaos Basin, California. GSA Bulletin 105 (9):1190–1213.

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.

Valentine, G. A., J. Fierstein, and J. D. White. 2022. Pyroclastic deposits of Ubehebe Crater, Death Valley, California, USA: ballistics, pyroclastic surges, and dry granular flows. Geosphere 18(6):1926–1957. https://pubs.geoscienceworld.org/gsa/geosphere/article/18/6/1926/618754/Pyroclastic-deposits-of-Ubehebe-Crater-Death

Van Gosen, B. S., H. A. Lowers, and S. J. Sutley. 2004. A USGS study of talc deposits and associated amphibole asbestos within mined deposits of the southern Death Valley region, California. US Geological Survey Open-File Report 2004-1092. https://pubs.usgs.gov/of/2004/1092/

Whitmeyer, S. J., and K. E. Karlstrom. 2007. Tectonic model for the Proterozoic growth of North America. Geosphere 3(4). https://doi.org/10.1130/GES00055.1

Wilkerson, G., and J. Santiago. 2016. Geology and mineral development history of the northern Death Valley region: from Matarango Museum to Saline Valley Hot Spring. US Bureau of Land Management and Buena Vista Museum of Natural History Field Guide.

Wills, C. J., F. G. Perez, and C. I. Gutierrez. 2011. Susceptibility to deep-seated landslides in California. California Geological Survey map sheet 58. https://www.researchgate.net/publication/263118543_Susceptibility_to_Deep-Seated_Landslides_in_California

Wright, L. A., and B. W. Troxel. 2002. Levi Noble; geologist; his life and contributions to understanding the geology of Death Valley, the Grand Canyon, and the San Andreas fault. US Geological Survey Open-File Report 2002-422. https://pubs.usgs.gov/publication/ofr02422

Workman, J. B., C. M. Menges, W. R. Page, E. B. Ekren, P. D. Rowley, and G. L. Dixon. 2002a. Tectonic map of the Death Valley ground-water model area, Nevada and California. US Geological Survey Miscellaneous Field Studies Map MF-2381-B. https://pubs.usgs.gov/mf/2002/mf-2381/

Workman, J. B., C. M. Menges, W. R. Page, E. M. Taylor, E. B. Ekren, P. D. Rowley, G. L. Dixon, R. A. Thompson, and L. A. Wright. 2002b. Tectonic map of the Death Valley ground-water model area, Nevada and California. https://pubs.usgs.gov/mf/2002/mf-2381/

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