National Park Service
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Natural Resource Stewardship and Science

Sequoia and Kings Canyon National Parks

Geologic and Soil Resources Inventory Summary



On this page: Rocky spires of the Sierra Nevada rise above boulder deposits adorned with streams and vegetation—including the famous giant sequoia (*Sequoiadendron giganteum*). NPS photograph / Daniel Jeffcoach

Sequoia and Kings Canyon National Parks

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Abstract

This document summarizes the status of National Park Service (NPS) Geologic Resources Inventory (GRI) and Soil Resource Inventory (SRI) deliverables for Sequoia and Kings Canyon National Parks. 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. This document is intended to assist park staff with prioritizing technical assistance or new inventory and assessment funding requests in the near term (roughly 1–5 years).

GRI hosted a baseline scoping meeting for Sequoia and Kings Canyon National Parks in 2002. Baseline bedrock and surficial geologic maps were delivered to the park in 2010. SRI delivered an updated legacy soil database and map in 2015, and an additional Natural Resources Conservation Service (NRCS) soil survey area encompasses the recreation area. The most up-to-date soils data for Sequoia and Kings Canyon National Parks is available on Web Soil Survey.

The geologic heritage of Sequoia and Kings Canyon National Parks is subdivided into several categories that include (1) Indigenous resources (e.g., bedrock mortars, campsites, shelters, pictographs, projectile points, hearths, hunting blinds, lithic fragments, and ceramic sherds); (2) the geologic record of the giant sequoia; (3) early geologic exploration of the southern Sierra Nevada; (4) historic mining and timber industries; and (5) stratotypes. These geoheritage connections all relate to the complex geologic history of the Sierra Nevada region, which has been heavily influenced by multiple stages of tectonic deformation and igneous activity followed by uplift, exhumation, and glaciation. The geologic and soil resources inventory needs for the national parks include various data and/or GIS needs related to the inventory and monitoring of cave and karst resources, cultural resources, disturbed lands, fossils, geothermal resources, glaciers, groundwater, soils, stratotypes, and visitor use. Additional mapping needs have been expressed regarding detailed glacial and floodplain studies, park-wide LiDAR, and the generation of a high-resolution digital elevation model for the national parks.

Geologic hazards identified in the national parks include cave and karst development, debris flows, disturbed lands (e.g., historic overgrazing, trespass livestock, illegal marijuana cultivation), flooding, mass wasting (e.g., avalanches, landslides, rockfalls), permafrost, radon, seismicity, shrink-swell soils, and toxicological soil. Most, if not all, of these geohazards may be exacerbated by the effects of climate change. Inventory needs related to geohazards address monitoring strategies to help predict, quantify, and mitigate the damage these processes pose to the geologic and soil resources of the national parks.

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.

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Background of the GSRI

The Geologic and Soil Resources Inventory (GSRI) facilitates the collection of new data, or derives new information from existing data, regarding the presence, absence, abundance, distribution, and significance of geologic or soil features or processes to inform park management decisions and planning.

In the 1990s, the NPS Geologic Resources Inventory (GRI) and Soil Resource Inventory (SRI) programs were established as two of the original 12 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. As of 2024, the I&M program was 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 Pea Ridge National Military 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 national park’s participation in the new inventories program. As such, it summarizes the status of GRI and SRI deliverables for SEKI 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

Geology

Geologic maps for SEKI are stored on the NPS Datastore and consist of 14 component maps and one compiled map. Many of these quadrangles reflect several decades of diligent work performed by USGS geologists Paul C. Bateman, James G. Moore, and Thomas W. Sisson. The GSRI first digitized these maps in 2013 and recently migrated the datasets in 2022. These maps can be found online using the Integrated Resource Management Applications (IRMA; https://irma.nps.gov/DataStore/Reference/Profile/2194498) and are listed below. Additional GSRI documents include the NPS Scoping Report (National Park Service 2002).

Component Maps

- Digital Geologic-GIS Map of the Big Pine 15’ Quadrangle, California (Bateman et al. 1965)
- Digital Geologic-GIS Map of the Blackcap Mountain 15’ Quadrangle, California (Bateman 1965)
- Digital Geologic-GIS Map of the Giant Forest 15’ Quadrangle, California (Sisson and Moore 1994)

- Digital Geologic-GIS Map of the Kern Peak 15' Quadrangle, California (Moore and Sisson 1985)
- Digital Geologic-GIS Map of Manzanar National Historic Site and Vicinity, California (Stone et al. 2000)
- Digital Geologic-GIS Map of the Marion Peak 15' Quadrangle, California (Moore 1978)
- Digital Geologic-GIS Map of the Mount Goddard 15' Quadrangle, California (Bateman and Moore 1965)
- Digital Geologic-GIS Map of the Mount Pinchot 15' Quadrangle, California (Moore 1963)
- Digital Geologic-GIS Map of the Mount Whitney 15' Quadrangle, California (Moore 1987)
- Digital Geologic-GIS Map of the Olancha 15' Quadrangle, California (du Bray and Moore 1985)
- Digital Geologic-GIS Map of the Southwestern Sequoia National Park, California (7.5' map; Sisson and Moore 2013)
- Digital Geologic-GIS Map of the Tehipite Dome 15' Quadrangle, California (Moore and Nokleberg 1992)
- Digital Geologic-GIS Map of the Triple Divide Peak 15' Quadrangle, California (Moore and Sisson 1987a)
- Digital Glacial Geologic-GIS Map Showing Limits of Tahoe Glaciation in Sequoia and Kings Canyon National Parks, California (Moore and Mack 2008)

Compiled Maps

- Digital Geologic-GIS Map of Sequoia and Kings Canyon National Parks and Vicinity, California Sensitive Digital Geologic-GIS Map of Sequoia and Kings Canyon National Parks, California (access limited to NPS management)

Soils

Soil maps provide information on soil types, including scores of different characteristics and management considerations, such as 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 SEKI 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. SEKI includes five soil survey areas that are partially completed (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 of Interest ('AOI')" tab. Under the "National Park Service" dropdown menu, select SEKI to view the soil data for the national parks. The AOI icon along the top of the screen allows users to

select specific areas of the map and generate detailed soils data (e.g., soil suitability and limitations, soil properties, soil qualities, and ecological sites). Use the "Soil Map" tab at the top to view the soil map and the "Soil Data Explorer" tab to view additional soil data, including linear extensibility and suitability for development. See additional Web Soil Survey guidance and FAQs or contact the NRCS state soil scientist for technical assistance. A legacy soil map database was first completed for SEKI by the SRI in 2012 (last updated in 2015) and is available on IRMA (https://irma.nps.gov/DataStore/Reference/Profile/2190304).

In addition to the Web Soil Survey, the NRCS has a complete set of soil samples from SEKI. It is believed this soil collection represents the most complete set of soil types that transect the Sierra Nevada (Paul Hardwick, NPS SEKI, written communication April 2025).

Table 1. Web Soil Survey areas related to the national parks.

Web Soil Survey Area Code	Web Soil Survey Area Name	Status
CA660	Tulare County, California	Partially Completed
CA732	Inyo National Forest, Western Part, California	Partially Completed
CA740	High Sierra Area, California	Partially Completed
CA760	Sequoia National Forest Parts of Fresno, Kern, and Tulare Counties, California	Partially Completed
CA792	Sequoia and Kings Canyon National Parks, California	Partially Completed

Possible Future GSRI Products

As the GSRI becomes integrated into the I&A program, 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 the baseline data will support.

Geologic Setting and History

Park Establishment and Setting

Sequoia and Kings Canyon National Parks ("SEKI"; also referred to as the "national parks" herein) are two jointly managed, contiguous national parks located in the southern Sierra Nevada in Tulare and Fresno counties, California. Both Sequoia National Park and Kings Canyon National Park (formerly General Grant National Park) were established in 1890 and encompass a combined 350,443 ha (865,964 ac) of Sierran ecosystem featuring high mountains, rugged foothills, deep canyons, marble cave networks, glaciers, and protected giant sequoia groves—the largest trees in the world (National Park Service 2016b). Sharp-crested peaks and ridges in SEKI form part of the Great Western Divide and the Sierra Nevada crest, including Mount Whitney (4,418 m [14,494 ft]), the tallest mountain in the lower 48 states. The national parks protect the alpine headwaters of several major rivers, including three designated Wild and Scenic Rivers. These rivers are a critical source of water that provides ecological, geological, recreational, and societal value. The cultural history of SEKI includes Indigenous societies spanning the last 8,000 years, which utilized the region's geologic resources for numerous purposes, including domestic (e.g., shelters, campsites), hunting (e.g., projectile points, hunting blinds), culinary (e.g., bedrock mortars), artistic, and spiritual practices (National Park Service 2016b).

The national parks are located in the Sierra Nevada province of California, a mountainous region defined by an uplifted and tilted fault block roughly 645 km (400 mi) long (Figure 1). The geology of SEKI is the product of multiple stages of tectonic collision, volcanism, plutonism (the intrusion and crystallization of molten rock), uplift, glaciation, and fluvial incision. The bedrock underlying SEKI is characteristic of the province; it is made up of intrusive and volcanic rocks from the Mesozoic Era, with additional Paleozoic to early Mesozoic metamorphic rocks that have been worn away by erosion. Surficial rocks mapped throughout the national parks include unconsolidated glacial, eolian (wind-driven), fluvial (river), and mass wasting (e.g., avalanches, landslides, rockfalls) deposits that record modern erosional processes that continue to shape the landscape.

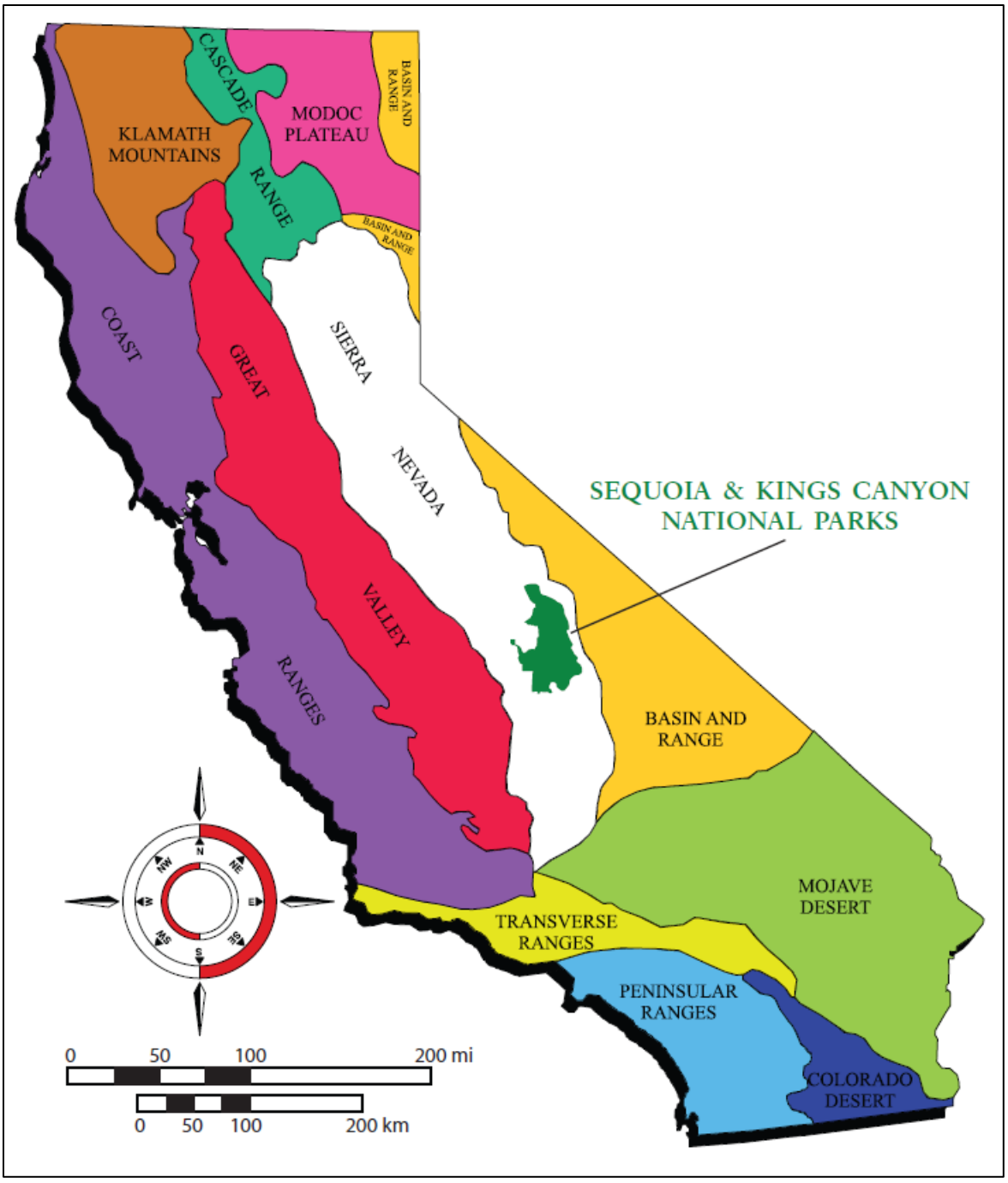


Figure 1. Map of California showing major physiographic provinces and the location of SEKI. The national parks occupy the Sierra Nevada province, an uplifted and tilted fault block roughly 645 km (400 mi) long. The bedrock of SEKI is characteristic of the province and predominantly consists of crystalline intrusive rocks of Mesozoic age. Figure modified by Timothy C. Henderson (Colorado State University) after California Geological Survey (2002).

Geologic History

Sequoia and Kings Canyon National Parks share a complex geologic history that is reflected in a diverse assemblage of features and resources that include voluminous granitic bedrock, marble caves, ore deposits, deep canyons, rugged alpine peaks, and glacial valleys. The modern landscape of east-central California records several major geologic episodes that include (1) Paleozoic–early Mesozoic deformation and

plutonism; (2) widespread Cretaceous plutonism and volcanism associated with the emplacement of the Sierra Nevada batholith (a large igneous intrusion made of several plutons); (3) Cenozoic uplift of the Sierra Nevada and Tertiary–Quaternary volcanism; and (4) Cenozoic glaciation. These regional events influenced the geologic evolution of the Sierra Nevada national parks, including neighboring Yosemite National Park and Devils Postpile National Monument, as well as large areas of the western United States.

Ongoing research and mapping efforts continue to shed light on the geologic age, nomenclature, and evolution of the national parks. For example, a recent article by Greene et al. (2024) provides a revised geologic map and structural interpretation of the Mineral King region of SEKI based on refined U-Pb zircon dating; these new radiometric ages extend the oldest deposits within the national parks to the Permian Era (approximately 275 million years ago).

Paleozoic–Early Mesozoic Sedimentation and Deformation

The oldest rocks in SEKI date back to the Paleozoic and early Mesozoic Eras and include metamorphic rocks that were originally deposited in marine or volcanic settings along the ancient western margin of North America. Over millions of years, these rocks were subjected to intense temperature and pressure conditions associated with tectonic collisions (e.g., Mississippian Antler orogeny, Early Triassic Sonoma orogeny, Late Jurassic Nevadan orogeny) and plutonism (Bateman 1988). Marine sediments, including mudstone, siltstone, sandstone, and limestone, were transformed into quartzite, phyllite, schist, hornfels (metamorphic rocks baked by magmatic intrusion), and marble; metavolcanic rocks include altered lava flows, tuffs, and breccias (Moore et al. 1994; Sisson and Moore 2013). Today, these metamorphic units are surrounded or intruded by plutonic rock and form isolated masses called "roof pendants." The national parks contain several metamorphic roof pendants named after geographic areas within their boundaries; these include (1) the Mineral King pendant; (2) Sequoia pendant; (3) Sheep Ridge pendant; (4) Tule River pendant; (5) South Fork Kaweah pendant; (6) Boyden Cave pendant; (7) Logger Point pendant; (8) Redwood Mountain pendant; (9) Big Baldy pendant; (10) Lake Kaweah pendant; (11) Goddard pendant; and (12) Oak Creek pendant (Moore and Sisson 1987b; Moore and Nokleberg 1992; Moore et al. 1994; Sisson and Moore 1994, 2013). These roof pendants are possibly erosional remnants of overlying "roof" or host rocks that were intruded by younger Mesozoic plutons (Sisson and Moore 2013).

The Sierra Nevada Batholith

Throughout the Sierra Nevada region, tectonic collisional events facilitated and were accompanied by multiple pulses of Mesozoic plutonism that resulted in the emplacement of the Sierra Nevada batholith. It is important to note that the Sierra Nevada and the Sierra Nevada batholith are different entities. The Sierra Nevada is a mountain range that originated during the Cenozoic Era by westward tilting and uplift of the Earth's crust, whereas the Sierra Nevada batholith is the part of the range composed of almost-continuous Mesozoic plutonic rock (Bateman 1988). During the Mesozoic, the subduction of oceanic crust (Farallon Plate) below the western margin of North America (North American Plate) facilitated three magmatic "flare-ups," each lasting about 20 million to 40 million years during the Triassic (230 million to 205 million years ago), Jurassic (170 million to 150 million years ago), and Cretaceous (120 million to 80 million years ago; Figure 2; Ardill et al. 2024). The batholith forms the predominant bedrock of the national parks and is comprised of a wide range of granitoid rocks (coarse-grained igneous rocks rich in silica [SiO2] such as granite, granodiorite, tonalite, leucogranite) with smaller intrusions of mafic rock (rocks lacking silica that

are rich in Fe and Mg), including diorite and gabbro (Chen and Moore 1982; Moore and Sisson 1987b; Sisson and Moore 2013).

The individual pulses or flare-ups associated with the Sierra Nevada batholith each contain distinctive lithologies, distributions, and structural features that record a complex interplay of tectonics and pluton emplacement. Older Triassic and Jurassic intrusive and metaigneous rocks are generally found adjacent to various roof pendants and typically show more extensive shearing, jointing, and post-magmatic alteration compared to younger Cretaceous plutons (Moore and Sisson 1987b). Another defining characteristic of these older granitic rocks is that they are commonly crosscut by numerous mafic dikes associated with the Jurassic Independence dike swarm (roughly 148 million years ago; Moore 1963, 1978, 1981, 1987; Chen and Moore 1982; Moore and Sisson 1985, 1987b). The dike swarm is an extensive system of vertical dikes formed by crustal extension and serves as an important geologic marker because of its regional distribution and relatively short period of injection (Carl and Glazner 2002). Younger Cretaceous intrusive rocks are the product of widespread plutonism that forms the bulk of the Sierra Nevada batholith and typically lacks any evidence of post-emplacement deformation. Geochemical and radiometric data indicate the Sierra Nevada batholith was emplaced sequentially from west to east and generally became more silica-rich and lighter-colored through time (Chen and Moore 1982; Sisson and Moore 1994; Ardill et al. 2024). Several plutonic rocks within SEKI belong to genetically related, nested successions or assemblages referred to as intrusive suites; these suites formed from a common magma source as it evolved through fractional crystallization (a process where magma chemistry evolves as minerals crystallize out of melt). All intrusive suites mapped within or partially within SEKI—including the Mount Whitney, Sequoia, Mitchell Peak, and Palisade Crest intrusive suites—are also stratotype resources (see poster; see also “Stratotypes”).

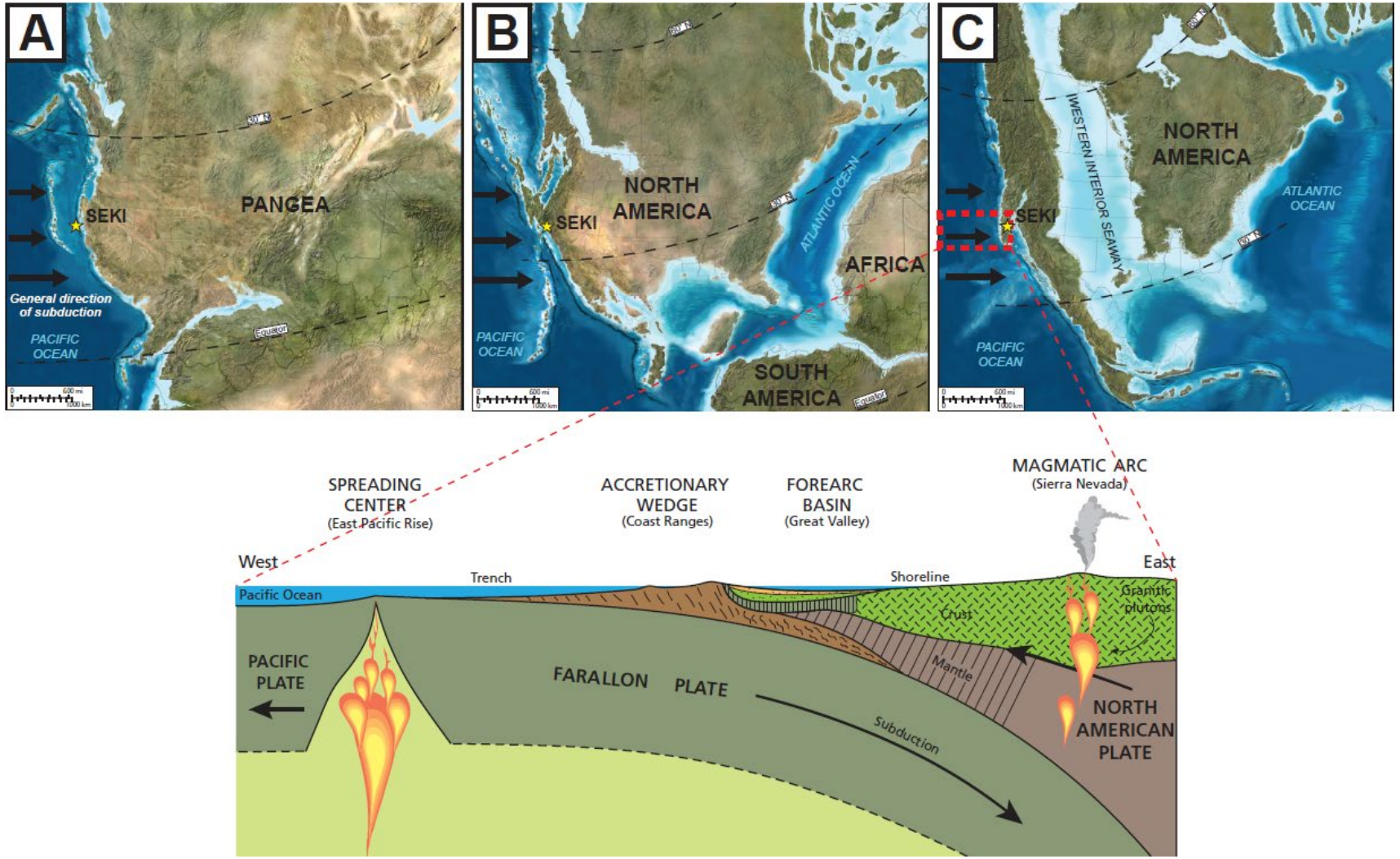


Figure 2. Paleogeographic reconstructions of North America during the Mesozoic Era. The emplacement of the Sierra Nevada batholith was driven by the subduction of the Farallon Plate beneath the western margin of North America. Intrusive rocks that form the batholith were created during three magmatic pulses that occurred during (A) the Late Triassic, about 220 million years ago; (B) Late Jurassic, approximately 150 million years ago; and (C) Late Cretaceous, about 85 million years ago. The inset cross section depicts the subduction of the Farallon Plate beneath the North American Plate and the generation of magma that formed the Sierra Nevada batholith. North American Key Time Slices © 2013 Colorado Plateau Geosystems Inc., modified by Tim C. Henderson (Colorado State University). Figure cross section created by Trista L. Thornberry-Ehrlich (Colorado State University).

Cenozoic Uplift of the Sierra Nevada and Volcanism

As plutonism related to the Sierra Nevada batholith ceased roughly 80 million years ago, it was followed by an extensive period of erosion and exhumation that removed a considerable portion of the overlying bedrock and left behind scattered remnants or roof pendants (Sisson and Moore 1984). Some authors have speculated that normal faulting responsible for uplifting the front range of the Sierra Nevada commenced within the last 25 million years and continued episodically to the present (Figure 3; Sisson and Moore 1984; Brown and Schaible 2008; Figueroa and Knott 2010; Hammond et al. 2012; Lee et al. 2022). However, the history of uplift and westward tilting to form the Sierra Nevada is still controversial and up for debate. The timing of normal fault development coincides with 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).

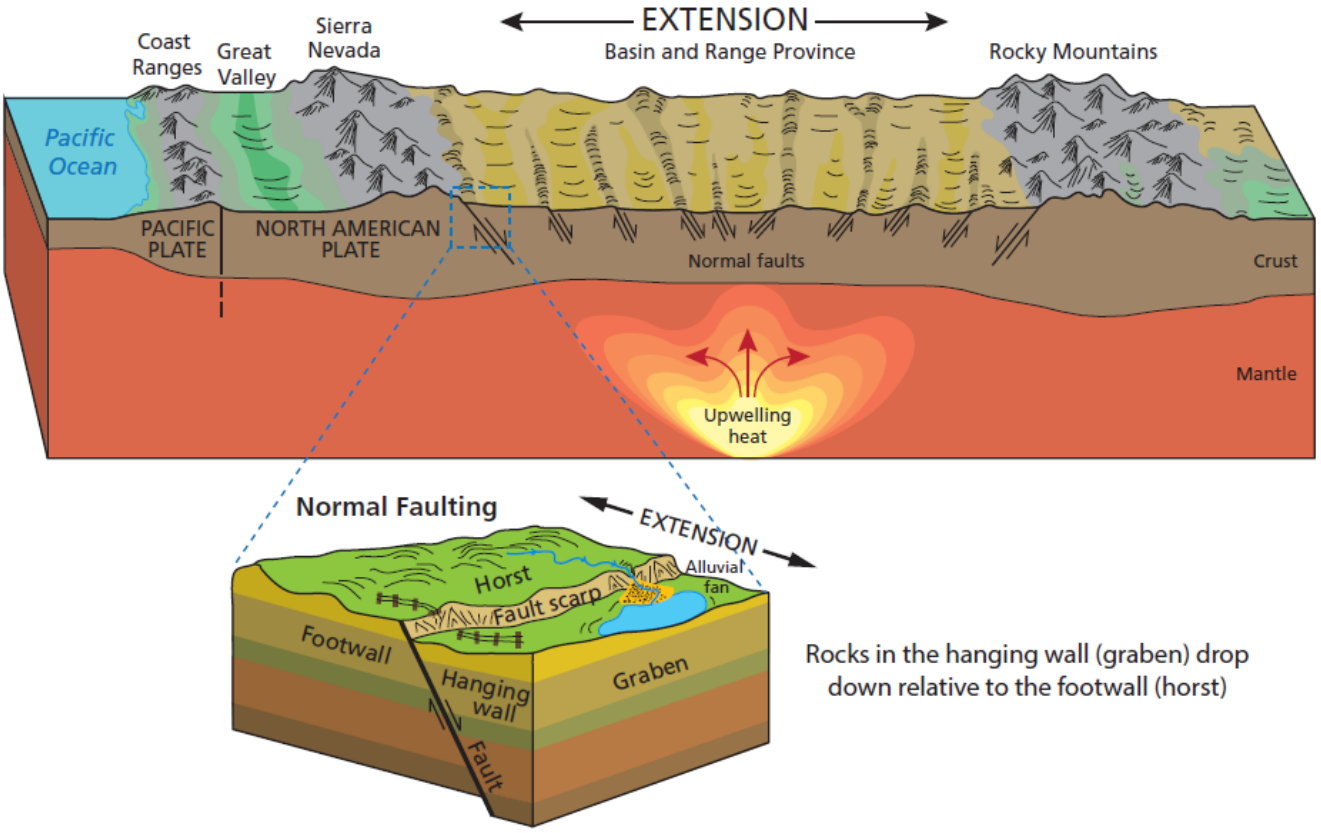


Figure 3. Block model showing the regional structural configuration of the western United States. The national parks are located in the Sierra Nevada province, an uplifted and tilted crustal block predominantly composed of Mesozoic intrusive bedrock. Regional-scale normal faulting along the Sierra Nevada crest (inset) began roughly 25 million years ago and continues to uplift the mountains relative to the surrounding Great Valley and Basin and Range provinces. Active tectonic processes continuously modify the landscape of SEKI and pose a known seismic hazard. Figure created by Trista L. Thornberry-Ehrlich (Colorado State University).

Scattered around the national parks are numerous late Tertiary or Quaternary lava flows, cinder cones, and pyroclastic deposits (QTv) that record a resurgence of volcanic activity in the Sierra Nevada region. Basaltic lava flows, dikes, and volcanic necks (conduits or plugs) located near Tehipite Dome and along the Middle Fork Kings River (including Windy Peak) are related to the San Joaquin-Kings volcanic field, which erupted during the Pliocene Epoch approximately 4.5 million to 3 million years ago (Moore and Sisson 1987b;

Moore and Nokleberg 1992). Younger Quaternary volcanic deposits are mapped immediately east of SEKI along portions of the Sierra Nevada crest and Golden Trout Creek. Although located outside the national parks, these rocks are a valuable window to the past and represent an important phase in the geologic evolution of the area. Sizable cinder cones and lava flows were sourced from volcanic vents associated with some of the normal faults located along the front range of the Sierra Nevada crest, notably near the cities of Big Pine and Aberdeen (Moore 1963; Moore and Sisson 1987b). Radiometric dating of these deposits reveals several pulses of volcanism in the Pleistocene spanning roughly 1.2 million years. Some of the youngest volcanic rocks mapped along Golden Trout Creek remain to be dated but show no signs of glaciation (which extensively occurred over 14,000 years ago) and are estimated to have formed between 10,000 and 5,000 years ago (Moore and Sisson 1985; 1987b).

Cenozoic Glacial History

Glaciers have repeatedly advanced and retreated across the Sierra Nevada region over the last several million years and are responsible for various glacial features and deposits in SEKI. The alpine landscape of the national parks has been extensively sculpted by vast ice sheets to form deep canyon systems, craggy peaks, hanging valleys, U-shaped valleys, cirques, and an extensive collection of lakes. The glacial history of SEKI is fragmentary, as older evidence of previous glaciations is commonly destroyed or obscured by subsequent ice advances. However, multiple Quaternary glacial events are recorded in till deposits (unconsolidated rock and sediment of glacial origin), moraines (ridges of till), rock glaciers (tongues of rock debris with cores of ice), and erratics (ice-transported boulders) that were left behind when glaciers receded. The latest periods of extensive ice cover in the Sierra Nevada include (1) the Tahoe glaciation, defined by two stages ranging from 170,000–130,000 and 70,000 years ago; and (2) the Tioga glaciation, approximately 28,000–14,000 years ago (Moore and Mack 2008; Moore and Moring 2013). Both the Tahoe and Tioga glaciations covered about half the area of SEKI, albeit the Tioga event was slightly less extensive. The youngest glacial deposits in SEKI are products of two glacial stages: the Pleistocene Recess Peak (13,000 years ago) and the late Holocene Matthes (“Little Ice Age”; circa 1450–1850 A.D.). These ice advances were restricted to high elevation (3,050 m [>10,000 ft]) slopes and cirques (Moore and Sisson 1985; Santucci and Kenworthy 2007; Sisson and Moore 2013).

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. The booklet includes 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.

The Geologic Record of the Giant Sequoia

According to SEKI’s foundation document (National Park Service 2016b), the parks preserve more than 40% of the world’s giant sequoia (Sequoiadendron giganteum) grove area, including the four largest trees on Earth. For generations, the giant sequoia of the Sierra Nevada have influenced the American perception of nature and conservation, with natural groves considered a national treasure afforded the protection of various federal, state, local, and tribal agencies. Although known by Indigenous cultures for thousands of years, the giant sequoia was first “discovered” in the central Sierra Nevada by English botanist John Lindley in 1853. Although the fossil distribution of Sequoiadendron giganteum is restricted to Quaternary floras of the Sierra Nevada region where they currently occur, the earliest fossil record of the genus Sequoiadendron comes from early middle Miocene (approximately 18.5 million years ago) sediments of western Nevada (Lowe 2014).

The geologic record reveals that some of the oldest ancestral sequoia trees date back to the Jurassic and Cretaceous Periods from localities in Bohemia, China, Russia, northeast Asia, south-central Kansas, coastal New Jersey, and Staten Island, New York (Lowe 2014; KellerLynn 2021). The modern subfamily Sequoioideae (commonly referred to as redwoods) includes species that survived the Cretaceous–Paleogene (formerly the Cretaceous–Tertiary) mass extinction event that ended the Age of the Dinosaurs roughly 66 million years ago. Cenozoic genera of sequoia (e.g., Metasequoia, Taxodium, and Glyptostrobus) were dominant members of Paleocene coal-forming swamps and coastal wetland areas of the mid-continent of North America, where the final remnants of the Cretaceous Western Interior Seaway (approximately 100 million to 66 million years ago) were being filled in through sedimentation (Lowe 2014; Slattery et al. 2015). During the Eocene Period, approximately 56 million to 33.9 million years ago, ancient sequoias were part of plant communities surrounding paleolakes nestled in the volcanic terrain of the Okanagan Highlands in

northeastern Washington and southern British Columbia. Within the National Park System, ancestral species of sequoia (Sequoia magnifica) are fantastically preserved as upright tree stumps within the volcaniclastic strata of the Eocene Sepulcher and Lamar River Formations in northern Yellowstone National Park, Wyoming (Wheeler 2024); additional Eocene fossil localities, including Sequoia affinis, are located in Florissant Fossil Beds National Monument, Colorado (Lowe 2014). In his book The Fossils of Florissant (Meyer 2003, p. 86), retired NPS paleontologist Herbert W. Meyer suggests that Sequoia affinis "…may have been the ancestor of the modern Sequoiadendron giganteum." For more information about fossil sequoias within the NPS and worldwide, please see tables 1 and 2 of KellerLynn (2021).

Indigenous Connections

For several millennia following the Pleistocene Ice Age, early human inhabitants of the southern Sierra Nevada navigated the rugged, alpine landscape and hunted, harvested, and adapted to the environment. The Indigenous history preserved in SEKI extends back 8,000 years and is recorded in remnant campsites, shelters, hunting blinds, pictographs (rock paintings), and artifacts that include projectile points, bedrock mortars, lithic fragments, and ceramic sherds (National Park Service 2016b). Caves within the national parks—notably Crystal Cave and Kaweah Cave—are rumored to have served as protective shelters or important ceremonial sites for possibly thousands of years (Panek and Despain 2013). Additionally, obsidian fragments discovered in multiple SEKI caves are believed to be of Indigenous origin (Santucci and Kenworthy 2007).

Several Indigenous groups are associated with the southern Sierra Nevada region of the national parks, some of which have living descendants that continue to protect and steward the lands of SEKI (National Park Service 2016b; see also https://www.nps.gov/seki/learn/historyculture/native-americans.htm; accessed September 2024).

Hospital Rock

In Sequoia National Park, Hospital Rock is a popular site along the Middle Fork of the Kaweah River that was once an Indigenous village known as *Pah-din*, which translates as the "place to go through." Granitic bedrock surrounding the Hospital Rock area served many purposes, including shelter, healing, and a place for ceremonies. The picnic area and river are littered with numerous boulders sourced from Moro Rock that are up to several meters in diameter and were deposited during major rockfalls, landslides, and avalanches. Some of these boulders contain bedrock mortars (circular holes or depressions) that were used to grind and process food (Figure 4). The namesake Hospital Rock is one of these giant landslide boulders that has subsequently cracked and split apart since coming to rest; the flat face of the boulder now contains pictographs made with a red iron-oxide mineral paint (Figure 5; Moore et al. 1994; Sisson and Moore 1994). Additional cultural remnants that record the village include fire pits and obsidian artifacts.



Figure 4. Photograph of bedrock mortars near Hospital Rock. The depressions or holes in the crystalline granitic bedrock were formed by Indigenous Peoples who used the geology to grind and process food. NPS photograph.



Figure 5. Hospital Rock. The Indigenous pictographs on the flat face of Hospital Rock were created using a red oxide mineral paint. NPS photograph.

Historic Mining and Timber Industries

Mining

Prior to the establishment of the national parks, the colorful mineralized rocks that now comprise SEKI's foothill region inspired several mining bonanzas that attracted the attention of prospectors during the late 19th century. Early mineral exploration of the Mineral King area did not begin until 1873, when James Crabtree and associates discovered silver-rich ore deposits and filed a claim for the White Chief Mine, named after its location in the headwaters of White Chief Creek (National Park Service 1995; Sisson and Moore 2013). Although discoveries in the Mineral King region are among the most notable in Sequoia National Park, other mines include those along Triple Divide Peak and above Lone Pine Creek. Additional mines were established near Cataract Creek, Windy Peak, and Cedar Grove in Kings Canyon National Park (see https://www.nps.gov/seki/learn/nature/mine_assess.htm; accessed September 2024). As the name would imply, the Mineral King area of Sequoia National Park represents a historic boom-and-bust mining region where dreams of wealth ended in hardship and failure. Meager amounts of silver, combined with numerous avalanches, brought an end to the mining dreams of Mineral King by the early 1880s.

From a geologic perspective, the discoveries of precious metals (e.g., gold [including the famous 1849 gold rush], silver, copper, and zinc) within the Sierra Nevada are a product of ancient plutonic processes related to the emplacement of the Sierra Nevada batholith. Serving as a vast "heat engine," the batholith mobilized

superheated fluids containing high amounts of metal that later mineralized to become concentrated ore deposits. Additionally, mining resources such as tungsten skarn deposits were formed by contact metamorphism as plutons invaded carbonate bedrock (Bateman 1988). All sizable mines and prospects in the Mineral King area are in or associated with Paleozoic marbles (**MZmr**) that have been metamorphosed to dark reddish-brown rocks known as tactite or skarn; additional tungsten-rich skarn deposits are known from the nearby Tungsten Hills and Bishop tungsten districts. Other minerals reported from the Mineral King area include minute amounts of gold, chalcopyrite (copper-iron sulfate), pyrrhotite (iron sulfide), and stibnite (antimony sulfide; Bateman 1988; Sisson and Moore 2013).

Timber

Before the establishment of the national parks, timber companies logged large swaths of privately owned, old-growth forests to profit from vast tracts of giant sequoia and pinewood trees. According to Harrison (2013), approximately 25–30% of the original distribution of giant sequoia was logged throughout the Sierra Nevada, in addition to at least 80% of the old-growth conifer forest. The historic timber industry began as small-scale, sporadic operations in the 1860s and detrimentally expanded into major enterprises that reached their peak from 1880 to 1900 (Figure 6; Cook 1955). The progressive deforestation of the Sierra Nevada negatively impacted the environment by decreasing species habitat and diversity while promoting forest fragmentation. Additionally, the clearing of forest removed vital anchoring vegetation, which promoted surface erosion, gully development, and mass wasting susceptibility (see “Disturbed Lands” and “Mass Wasting”). Despite the growth of the timber industries, several of the more inaccessible tree groves remained protected due to the immense size of the trees, rough topography, inclement weather conditions, and bulky logging machinery (Cook 1955). Logging activities inspired the creation of Yosemite National Park, Sequoia National Park, and General Grant National Park (precursor to Kings Canyon National Park) in 1890 to protect and conserve some of the remaining giant sequoia groves. For the next 26 years, until the inception of the National Park Service in 1916, park management largely consisted of cavalry troops patrolling for poaching, illegal timber harvesting, and issues related to increasing visitation (Parsons 1994). As the last logging operations ceased following WWI, the giant sequoia groves of SEKI have expanded and are now protected for the benefit and inspiration of future generations.



Figure 6. Historic photograph of giant sequoia timber harvesting. During the late 19th and early 20th centuries, the expansion of the timber industry led to the widespread deforestation of the Sierra Nevada and prompted the establishment of several national parks, including SEKI and Yosemite National Park. NPS photograph.

Early Geologic Exploration of the Southern Sierra Nevada

During the summer of 1864, the Whitney Survey of the California Geological Survey made the first scientific expedition into the remote southern Sierra Nevada, including the drainages of the Kings, Kern, and San Joaquin Rivers of SEKI (Moore et al. 1994). The survey expedition—and the famous Mount Whitney—are named after Josiah D. Whitney, the second state geologist and chief of the California Geological Survey from 1860 to 1874. Today, the current route of King Canyon Highway (California State Route 180) closely follows the path of the 1864 expedition, which entered the mountains from Visalia, traveled through Millwood, and encountered the giant sequoia trees at General Grant Grove (Moore et al. 1994). Among the field survey party were William Brewer (party chief), Charles Hoffman (topographer), James Gardiner (geologist), Clarence King (geologist who later became the first USGS Director), and Dick Cotter (packer); several alpine peaks, including Mount Brewer, Mount Clarence King, and Mount Gardiner, bear their names.

Over 150 years ago, naturalist John Muir explored Kings Canyon National Park during 1875–1877 and was deeply inspired by its geologic origins and beauty. Located along the Kings River is Muir Rock, a large granitic boulder overlooking the river where Muir would give speeches about the glacial origins of the canyon. During his visit to the park, Muir wrote the following description of Kings Canyon:

> *In the vast Sierra wilderness far to the southward of the famous Yosemite Valley, there is a yet grander valley of the same kind. It is situated on the south fork of King's River, above the most extensive groves and forests of the giant sequoia, and beneath the shadows the highest mountains in the range, where the cañons are deepest and the snow-laden Pus are crowded most closely together. It is called the Big King's River Cañon, or King's River Yosemite, and is reached by way of Visalia, the nearest point on the Southern Pacific Railroad, from which the distance is about forty-five miles, or by the Kearsarge Pass from the east side of the range. It is about ten miles long, half a mile wide, and the stupendous rocks of purplish gray granite that form the walls are from 2,500 to 5,000 feet in height, while the depth of the valley beloved the general surface of the mountain mass from which it has been carved is considerably more than a mile. Thus it appears that this new Yosemite is longer and deeper, and lies embedded in grander mountains, than the well-known Yosemite of the Merced. Their general characters, however are wonderfully alike, and they bear the same relationship to the fountains of the ancient glaciers above them.* (Muir 1891, p. 77).

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).

Sequoia and Kings Canyon National Parks contain 12 stratotypes that represent a diverse mosaic of plutonic rocks that comprise large portions of the Sierra Nevada batholith. These igneous units include lithodemes (igneous or metamorphic rocks that are mappable similar to sedimentary formations) and intrusive suites that span the Jurassic and Cretaceous Periods (Table 2; Henderson et al. 2021). Stratotype designations within SEKI reflect decades of geologic mapping, reconnaissance, and research performed by USGS geologists Paul C. Bateman, James G. Moore, and Thomas W. Sisson (see "Baseline GSRI Products").

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

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 parks 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 national parks are included. Boundary ages follow the International Commission on Stratigraphy (2023).

Geologic Time Unit	Age	Geologic Units (GSRI map symbol)	Geologic Events
Quaternary (Q)	2.6 million years ago to the present	Tufa (**Qtf**) Active alluvium (**Qa**) Eolian sand (**Qs**) Younger lake deposits (**Qly**) Rock glaciers (**Qr**) Older alluvial deposits, grouped (**Qoa**) Slope deposits, grouped (**Qs**) Glacial deposits, grouped (**Qg**)	During the Cenozoic, the activation of regional normal faults uplifted the Sierra Nevada relative to Owens Valley and promoted downward fluvial incision responsible for SEKI's deep canyon systems. These faults are still actively uplifting the Sierra Nevada today and are associated with rejuvenated Tertiary–Quaternary volcanic activity that extruded lava flows, pyroclastic deposits, and cinder cones within and surrounding the national parks. Over the last several million years, ice sheets have repeatedly advanced and retreated across SEKI, sculpting the landscape into a diverse collection of glacial features, including craggy peaks or ridges, cirques, U-shaped valleys, hanging valleys, and thousands of lakes.

Geologic Time Unit	Age	Geologic Units (GSRI map symbol)	Geologic Events
Tertiary (T)	66.0 million to 2.58 million years ago	Quaternary or Tertiary volcanics, grouped (**QTv**)	During the Cenozoic, the activation of regional normal faults uplifted the Sierra Nevada relative to Owens Valley and promoted downward fluvial incision responsible for SEKI's deep canyon systems. These faults are still actively uplifting the Sierra Nevada today and are associated with rejuvenated Tertiary–Quaternary volcanic activity that extruded lava flows, pyroclastic deposits, and cinder cones within and surrounding the national parks.
Cretaceous (K)	145 million to 66 million years ago	Cretaceous intrusive rocks, grouped (**Ki**) Mount Whitney Intrusive Suite (STRATOTYPE) Whitney Granodiorite (STRATOTYPE) Paradise Granodiorite (STRATOTYPE) Evolution Basin Alaskite (STRATOTYPE) Lamarck Granodiorite (STRATOTYPE) Mitchell Intrusive Suite (STRATOTYPE) Mitchell Peak Granodiorite (STRATOTYPE) Sequoia Intrusive Suite (STRATOTYPE) Giant Forest Granodiorite (STRATOTYPE) Inconsolable Quartz Monzonite (STRATOTYPE) Cretaceous metaigneous rocks, grouped (**Kmi**)	Mesozoic plutonic rocks are the predominant bedrock in the national parks and formed by three major magmatic pulses associated with the emplacement of the Sierra Nevada batholith. As the oceanic Farallon Plate subducted below the western margin of the North American Plate, widespread plutonism resulted in a diverse array of granitoid rocks (e.g., granite, granodiorite, leucogranite, tonalite) and minor mafic intrusions.
Jurassic (J)	201.3 million to 145 million years ago	Cretaceous and/or Jurassic intrusive rocks, grouped (**KJi**) Cretaceous and/or Jurassic metaigneous rocks (**KJmi**) Jurassic intrusive rocks, grouped (**Ji**) Palisade Crest Intrusive Suite (STRATOTYPE) Tinemaha Granodiorite (STRATOTYPE) Jurassic volcanic rocks, grouped (**Jv**) Jurassic metaigneous rocks, grouped (**Jmi**)	Mesozoic plutonic rocks are the predominant bedrock in the national parks and formed by three major magmatic pulses associated with the emplacement of the Sierra Nevada batholith. As the oceanic Farallon Plate subducted below the western margin of the North American Plate, widespread plutonism resulted in a diverse array of granitoid rocks (e.g., granite, granodiorite, leucogranite, tonalite) and minor mafic intrusions.
Triassic (TR)	251.9 million to 201.3 million years ago	Jurassic and/or Triassic intrusive rocks (**JTRi**) Jurassic and/or Triassic metaigneous rocks (**JTRmi**) Jurassic and/or Triassic metamorphic rocks, grouped (**JTRm**) Mesozoic metamorphic rocks, grouped (**MZmr**) Mesozoic metaigneous rocks, grouped (**MZmi**)	Mesozoic plutonic rocks are the predominant bedrock in the national parks and formed by three major magmatic pulses associated with the emplacement of the Sierra Nevada batholith. As the oceanic Farallon Plate subducted below the western margin of the North American Plate, widespread plutonism resulted in a diverse array of granitoid rocks (e.g., granite, granodiorite, leucogranite, tonalite) and minor mafic intrusions.

Geologic Time Unit	Age	Geologic Units (GSRI map symbol)	Geologic Events
Paleozoic (PZ)	541.0 million to 251.9 million years ago	Mesozoic and/or Paleozoic pelitic hornfels and schist (**MZPZhs**) Mesozoic and/or Paleozoic calc-hornfels (**MZPZch**) Paleozoic biotite schist (**PZbs**) Paleozoic pelitic hornfels and quartzite (**PZph**) Paleozoic marble, grouped (**PZm**) Paleozoic pelitic hornfels and interbeds of marble (**PZphm**)	The oldest rocks within the national parks are Paleozoic and early Mesozoic metamorphic units that were originally deposited in marine or volcanic settings along the ancient western margin of North America. These rocks are intensely deformed and were subjected to multiple pulses of tectonic collision and plutonism.

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 SEKI staff. Geologic resource management 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 SEKI. Geologic hazards refer to notable hazards stemming from geologic features or processes that may require active management. Refer to the Guidance for Geologic Resource Management SharePoint for more information regarding geologic resource management.

Geologic Hazards

Geologic resources are not only visitor attractions but may also be potentially hazardous. The landscape of both national parks presents various natural hazards that threaten NPS visitors, staff, facilities, and resources (Table 3). Many of these natural hazards are geologic. Geologic hazards are naturally occurring, dynamic geologic processes that have the potential to cause damage, loss of property, and/or injury and loss of life. In the rugged, alpine landscape of the Sierra Nevada, geologic peril often takes the form of floods, debris flows, and mass wasting events such as landslides, rockfalls, or avalanches. A recent geohazard assessment report by Capps et al. (2024) covers select areas within Sequoia National Park and includes many of the geologic hazards described in this chapter. A key takeaway message from Capps et al. (2024, p. 14) states that, "*Landslides, debris flows, and rockfall will continue to be problematic for SEKI for the foreseeable future as the landscape evolves due to existing conditions, climate change, wildfire, and severe weather. SEKI facilities have an elevated probability of future problems because of these geohazards and the location of facilities in vulnerable areas.*"

The Addressing Climate Change and Natural Hazards Handbook (National Park Service 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) 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 3) 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 3 includes selected geologic and soil hazards listed in Part 1 of National Park Service (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 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; Jarvis 2015). It is meant to provide general information to identify the full range of geologic hazard-based risks for the national parks.

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Sources of Geohazard Information
Earthquake	Falling objects Collapsing structures Inoperability of major utility systems (e.g., power, sewer, water) Trigger to other hazards (e.g., landslides, rockfalls, avalanches) Human injury or casualty	**Known Hazard (very high; DOI SHIRA)**	Austin (2012) Brown and Schaible (2008) McJunkin and Bedrossian (1980) US Department of Interior (DOI) Strategic Hazard Identification and Risk Assessment (SHIRA) Risk Mapper Report US Geological Survey (USGS) Earthquake Hazard Probability Map (Petersen et al. 2023)
Slope movements (e.g., avalanche, landslide, rockfall)	Downhill movements of soil, rock, snow, or ice can destabilize and entrain debris, including large trees Large-scale landslide events can obstruct watersheds and create temporary dams; breaching of dams can lead to catastrophic floods Damage or destruction to roadways, utility systems, and other infrastructure Damage to or loss of natural or cultural resource sites or features Human injury or casualty	**Known Hazard (susceptible to landslides and avalanches; DOI SHIRA)**	Austin (2012, 2013) Brown and Schaible (2008) Capps et al. (2024) Costa and Schuster (1991) DOI SHIRA Risk Mapper Report GSRI GIS hazard layers or hazard-related deposits (e.g., “talus and colluvium” and “landslide deposits”)
Permafrost	Thawing can lead to enhanced erosion, destabilized building or road foundations, and surface collapse Increased mass wasting susceptibility Thermokarst development	**Known Hazard (sporadic 10–50% permafrost coverage; DOI SHIRA)**	DOI SHIRA Risk Mapper Report Gonzalez (2017)
Cave/karst	Caves can contain dangerous passageways with sudden drop-offs or narrow corridors Flooding Sinkholes Slope failure Surface or ceiling collapse Roadway damage or collapse Human injury or casualty	**Potential Hazard (very low)**	DOI SHIRA Risk Mapper Report

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Sources of Geohazard Information
Shrink/swell soils	Damage of infrastructure "Heaving" of ground beneath roads, trails, or structures Increased susceptibility to mass wasting events	**Known Hazard (low to moderate; USDA Web Soil Survey)**	Capps et al. (2024) US Department of Agriculture (USDA) Web Soil Survey Wahrhaftig (1965, 1984)
Coastal storm surge/ sea or lake level change/shoreline erosion	Not applicable	Not applicable	Not applicable
Tsunami	Not applicable	Not applicable	Not applicable
Riverine Flood	Flooding (driven by prolonged rainfall or snowmelt, hurricanes, tropical storms, atmospheric rivers, etc.) compounded with debris flows Destruction of infrastructure Stream channel migration Stream bank erosion Destruction of cultural or paleontological sites Human injury or casualty	**Known Hazard (extreme; DOI SHIRA)**	Austin (2012, 2013) DOI SHIRA Risk Mapper Report Federal Emergency Management Agency (FEMA) Map Service Center
Flash Flood	Sudden rising water (i.e., dry wash or tributary valley) Flooding compounded with debris flows Destruction of infrastructure Increased sedimentation along major tributary mouths Destruction of cultural or paleontological sites Human injury or casualty	**Known Hazard**	Austin (2012, 2013) DOI SHIRA Risk Mapper Report
Volcanic eruption	Not applicable	Not applicable	Not applicable
Hydrothermal activity	Not applicable	Not applicable	Not applicable
Radon	Health hazard	**Potential Hazard (moderate – zone 2; US EPA)**	DOI SHIRA Risk Mapper Report US Environmental Protection Agency (EPA) Map of Radon Zones: Fresno and Tulare Counties, California

Hazard	Examples of Risk or Secondary Hazard	Best Professional Judgment	Sources of Geohazard Information
Toxicological soil (arsenic[1,4], asbestos or erionite[2,4], *Bacillus anthracis* [causes anthrax][2,4], cadmium[2,5], lead[2,4], selenium[2,6], and Valley Fever fungus[3,7]	Health hazard	Kings Canyon National Park **[1]Potential Hazard (moderate)** **[2]Potential Hazard (high)** **[3]Potential Hazard (very low)** Sequoia National Park **[4]Potential Hazard (high)** **[5]Potential Hazard (moderate)** **[6]Potential Hazard (low)** **[7]Potential Hazard (very low)**	DOI SHIRA Risk Mapper Report

Cave and Karst Development

The national parks host an extensive network of cave and karst features that pose potential hazards but also contain sensitive ecological habitats, speleothems (cave formations), fossils, and cultural resources (see "Cave and Karst Resource Protection"). Cave and karst features are generally restricted to narrow bands of marble bedrock that have been dissolved and weathered to form caverns, karst aquifers, sinkholes, springs, and active subterranean streams (Kahn 2008; National Park Service 2013; Sisson and Moore 2013). Cave and karst development is inherently dangerous; when bedrock voids or conduits expand, they increase the susceptibility to physical (e.g., falls, injuries, getting stuck), environmental (e.g., dangerous flora or fauna, flooding), and structural hazards (e.g., surface or ceiling collapse, slope failure). In June 2024, a sinkhole emerged near Stony Creek along the Generals Highway in nearby Sequoia National Forest, causing a portion of the roadway surface to collapse and requiring emergency repairs (Figure 7). According to the SEKI scoping summary (National Park Service 2002), a desired geoscience research project that may help mitigate the risk of cave and karst hazards involves the use of high-resolution elevation data to map the distribution of sinkhole features. This project aligns with some of the current inventory needs of the national parks, including park-wide LiDAR imagery and the development of a high-resolution digital elevation model (see "Inventory Needs").



Figure 7. Sinkhole development along the Generals Highway near Stony Creek. Cave and karst development can lead to subsurface or slope instability that negatively impacts roadways. NPS photograph.

Climate Change

Although climate change planning is beyond the scope of this GSRI summary, a brief section is included because of the potential disruption it may cause to SEKI's geologic features and processes. In the High Sierras, climate change, fire management, and water availability are three major management concerns. As average temperatures continue to rise, the susceptibility to drought and wildfire may increase and will likely be accompanied by receding glaciers, shrinking snowpacks, thawing permafrost, decreased biodiversity, and enhanced fire effects on soils. Enhanced wildfire susceptibility may lead to increased tree mortality (including giant sequoia) and could threaten sensitive cave habitats. Areas that have recently burned (wildfire or controlled burning) may be susceptible to debris flows or rockslides as stabilizing vegetation is consumed and soils become hydrophobic (not attracted to water), resulting in enhanced surface runoff and erosion (see "Mass Wasting"; Capps et al. 2024). These processes promote cave sedimentation and could endanger sensitive cave habitats. Monitoring the effects of climate change on cave systems may want to be considered given how cave species can be vulnerable to habitat loss and thermal alteration (Mammola et al. 2019; Trey Brink, NPS SEKI, written communication April 2025).

The climate at SEKI is already changing; 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 2024a, b). Projected increases in temperature, drought, wildfire, and storm frequency or intensity may negatively impact (1) ecosystems, including giant sequoia groves; (2) the water quality and quantity of major rivers, streams, and alpine lakes; and (3) geohazards such as floods, debris flows, landslides, and rockfalls. Furthermore, projected climate change is likely to influence additional geologic processes (e.g., erosion, sedimentation), ecological processes (e.g., invasive species, phenology), recreational opportunities, visitation, and park management procedures (Climate Change Response Program 2024a, b).

Climate change manifestations that may impact geologic resources or intensify geohazards include the following:

- Increased frequency and intensity of droughts, which will promote additional wildfires
- Increased frequency and intensity of storms, including hurricanes and tropical storms
- Increased frequency and magnitude of flooding, debris flows, and mass wasting events
- Enhanced erosion along major drainage networks of the national parks—including the Kings, Kern, Kaweah, Tule, and San Joaquin Rivers
- Enhanced sedimentation along major tributary mouths
- Decreased water quality and quantity as glaciers recede, snowpacks shrink, and permafrost regions thaw

Disturbed Lands

Disturbed lands are those park lands where natural conditions and processes have been directly impacted by development, including facilities, mining, roads, dams, and campgrounds; agricultural activities such as farming, grazing, timber harvest, and irrigation ditches; overuse; or inappropriate use. Restoration returns a site, watershed, or landscape to some previous condition, commonly some desirable historic baseline. Usually, 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 often 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.

Historic Ranching and Trespass Livestock

Historic grazing practices and modern trespass livestock (e.g., cattle and sheep) have damaged many of SEKI's meadow and wetland regions. Overgrazed areas have been hydrologically and biologically altered as livestock remove montane and alpine vegetation. The disappearance of vegetative cover enhances surface erosion and promotes the spread of invasive species, as well as gullying, incision, and stream modification (Mutch et al. 2008; Austin 2013; National Park Service 2016b).

Two examples of heavily overgrazed areas in Sequoia National Park include Cahoon Meadow and Halstead Meadow. Located along the East Fork drainage of the Kaweah River, Cahoon Meadow is a 25.1 ac (10.1 ha) meadow wetland complex that was heavily damaged by cattle grazing prior to its assimilation into the national park in 1980. Erosion of the bare soil has created an extensive gully network roughly 366 m (1,200 ft) long by 18–27 m (60–90 ft) wide, and at its deepest point has incised up to 5 m (17 ft) below the ground surface (National Park Service 2016b). The gully network has drained more than 5 ac (2 ha) of wetland, creating large areas of dry, exposed soil and dead vegetation; an additional 14.9 ac (6 ha) of wetland are threatened by gully-related drainage (National Park Service 2016a). Currently, Cahoon Meadow is part of a restoration plan to prevent further degradation (Austin 2013; National Park Service 2016a, b).

In the northwestern portion of Sequoia National Park, Halstead Meadow is a 21 ac (8.5 ha) meadow wetland that is bisected by the Generals Highway. A combination of historic overgrazing, road construction and maintenance, and water channelization led to the development of a gully network up to 5.5 m (18 ft) deep by 26 m (85 ft) wide (Austin 2013). Similar to Cahoon Meadow, the creation of gullies enhanced erosion—including a loss of at least 18,350 m^3 (648,000 ft^3) of sediment—but also lowered the local water table, which dried out wetland soils and killed plant communities (Austin 2013). Once considered the most severely damaged meadow in the national park, the wilderness character of Halstead Meadow has been significantly improved through a multi-phase restoration project. As part of the restorative effort, SEKI staff infilled the gullies with replacement sediment, leveled the topography, reintroduced wetland vegetation, and restored the meadow's natural hydrological flow.

Mining

The boom-and-bust mining operations of the late 19th century have left behind a collection of AML relics, including 122 mine features and 16 mining sites (Burghardt et al. 2014). The inherent dangers associated with early mining operations are still present today, as abandoned sites pose a considerable risk to the public, SEKI staff, and the environment. Mining sites can contain unstable shafts and adits, perilous drop-offs, and may emit toxic fumes or other pollutants that contribute to acid mine drainage or heavy metal contamination.

Illegal Marijuana Cultivation

Illegal marijuana growing operations have been detected within the secluded foothill regions of SEKI but are difficult to enforce given the massive size and rugged terrain of the national parks. The illegal cultivation of

marijuana negatively impacts the landscape, taxes the water supply, contaminates water sources, introduces harmful pollutants or trash, and negatively manipulates the ecosystem by displacing native species with marijuana (National Park Service 2016b). In the process of creating these sites, growers often cut down or damage trees and plants, utilize illegal pesticides, herbicides, and rodenticides that kill off endangered species, poach native wildlife, create unauthorized trails, and damage local resources. Additionally, cultivated marijuana plots are often supplied with water from artificial catchments that divert the natural flow of water (Parvini 2014).

Since the early 2000s, the national parks have seen an increasing trend of large-scale cultivation operations that are responsible for the removal of approximately 270,000 plants with an estimated street value of over $900 million (see https://www.nps.gov/seki/learn/news/illegal-marijuana-eradicated-from-sequoia-national-park.htm; accessed September 2024). Illegal marijuana cultivation sites are inventoried during eradication or restoration efforts, and SEKI staff monitor for reoccupation or resource recovery as funding is available (Figure 8; National Park Service 2013).



Figure 8. Photograph of a NPS marijuana tactical team officer inspecting an illegal growing operation. The cultivation of marijuana detrimentally impacts the environment, ecosystems, and resources of the national parks. NPS photograph.

Flooding

Flooding, flash flooding, and debris flows are common occurrences in SEKI that range from minor inconvenience to catastrophic disaster. The national parks share a Mediterranean-style climate that delivers a majority of its rain and snowfall during the months of November through April; however, sustained snowmelt can contribute to flooding events well into the month of June. Situated in the Tulare Lake Basin of central California, the major watersheds of SEKI—including the Kings, Kaweah, Kern, Tule, and San Joaquin rivers—ultimately drain into an interior basin rather than the ocean and are vital sources of water for the Central Valley region (see "Hydrological Resource Protection").

Flooding events in SEKI are known to occur sporadically and are driven by various natural processes, including heavy winter rainstorms, spring snowmelt, remnants of Pacific hurricanes, atmospheric rivers, high-intensity non-tropical storms, monsoonal moisture, and landslide dam failures. Flash floods typically result from heavy rainfall over a short duration of time (usually six hours) and are often associated with thunderstorms or hurricanes. A detailed flood history of the Tulare Lake Basin by Austin (2012, 2013) includes approximately 180 flood events over the last 2,000 years. There are three different types of floods that occur in SEKI: (1) short-duration (about 1–2 days), high-peak floods of comparatively small volume; (2) sustained floods driven by seasonal snowmelt that typically last a month or more; and (3) cyclic mega-floods that occur approximately every 200 years and can result in a series of flood events lasting up to 10 years (Austin 2012).

In the High Sierra Nevada, flooding leads to erosion that is enhanced by some of the steepest watershed gradients in the US combined with soil veneers that are often sparsely vegetated and weakly anchored to bedrock hillslopes or colluvial deposits (Austin 2013). Large storms occasionally result in more than just flooding but are often associated with other geohazards such as debris flows, rockslides, rockfalls, and avalanches (see "Mass Wasting"). Since the establishment of the national parks, flooding has caused major infrastructural damage, including the undermining or loss of roadways and bridges, fallen trees (including giant sequoias), washouts of roads and trails, destroyed culverts, and gullying. Additionally, vital cultural and paleontological resources are susceptible to damage or loss. In extreme cases, storm- and flood-related damages can restrict access to specific areas of SEKI or even lead to park closures.

Mass Wasting

The term "mass wasting" is used to describe downhill movements of rock, soil, or ice, which include events such as rockslides, debris flows, rockfalls, and avalanches. Mass wasting events are driven by many natural processes, including erosion, precipitation, flooding, fluvial incision, thermal expansion/contraction, preferential weathering (the selective breakdown of less competent rocks), dissolution (chemical disintegration), and seismicity (earthquakes), but can also be artificially induced by construction, mining, undercutting, vegetative clearing, and other projects that destabilize the ground. The granitic rocks of the Sierra Nevada batholith are prone to developing fractures or joints that allow water or roots to penetrate and weaken the rock internally through a combination of weathering, frost wedging, and root wedging (Wahrhaftig 1984; Austin 2012). Sometimes, long parallel fractures called sheet joints create large slabs of rock that "peel" or fall away in a process known as exfoliation. Several popular geologic features of SEKI, including Tehipite Dome and Moro Rock, represent premier examples of granitic exfoliation.

Projected climate change scenarios for SEKI include increased temperatures and extreme weather events that will likely exacerbate the occurrence and effects of mass wasting (see "Climate Change"). Although mass wasting can be damaging or destructive, these processes have and will continue to shape the modern landscape and topography of the national parks.

Ice Avalanches

Ice avalanches are rapid downhill movements of ice and snow that can flatten or entrain trees and rock debris, damage or destroy infrastructure, and bury obstacles in their path. Several avalanche-triggering mechanisms include prolonged storms, rain-on-snow events, seismicity, and physical disturbance (e.g., hiking, skiing, snowmobiling, explosive blasting). The history of SEKI includes several examples of avalanches that caused considerable damage, the most notable of which was initiated by the famous 1906 San Francisco earthquake (Table 4). Although the epicenter was located north of San Francisco, the powerful 7.9 magnitude earthquake could be felt throughout the Sierra Nevada. The earthquake triggered a series of avalanches in the Mineral King region, which destroyed several historic buildings, including the Smith Hotel (Brown and Schaible 2008; Austin 2012; see "Historic Mining and Timber Industries"). According to Austin (2012), one of the largest avalanches in SEKI was the Paradise Valley "logalanche," which scoured a large swath of forest along the Middle Paradise Valley below the headwaters of Kidd Creek.

Table 4. A list of avalanche events within SEKI. Information in the table was sourced from Moore (1963), National Park Service (1995), and Austin (2012).

Date	Avalanche event description
1867	A spring avalanche struck the mining camp on the slopes of Kearsarge Peak that destroyed 11 cabins, temporarily buried several people, and killed one person.
1870s	Avalanches repeatedly hit the Mineral King mining district. One particular avalanche in 1878 destroyed the White Chief Mine bunkhouse and endangered the company that owned the mine.
18 April 1906	A 7.9 magnitude earthquake triggered a series of avalanches in the Mineral King area that destroyed several buildings associated with the 1870s silver rush.
1936	Approximately 72 in (6 ft) of snow fell at Giant Forest during the last week of December, which contributed to an avalanche that swept away the 38 m (125 ft)-long Hamilton Gorge Suspension Bridge.
1941	The national parks experience extensive tree failures due to heavy snowfalls and avalanches.
13 January 1952	A huge avalanche west of Donner Pass stalled the westbound (to San Francisco) Southern Pacific Railroad's transcontinental passenger train in the snow. On the train were 226 people.
2011	The Middle Fork of the Kings Trail was closed due to a large avalanche deposit.

Rockslides

Landslides include downhill movements of rock and/or soil that can vary in size and destructive capability. A rockslide or debris slide is a particular type of landslide caused by rock failure where material moves as a collective mass rather than individual blocks (Austin 2013). Across the national parks are several Quaternary landslide deposits (**Qls**) that often form broad, gently dipping alluvial aprons consisting of fragmented rock debris (Sisson and Moore 1984, 1994, 2013; Moore and Sisson 1985; Moore et al. 1994). Some landslides, including the one that deposited Hospital Rock, date back hundreds to possibly thousands of years ago.

In the High Sierras, landslides are a common occurrence and are primarily generated by prolonged storms or snowmelt that oversaturate steep hillslopes. Landslide debris can often include large boulders and trees, which add to their density, volume, and destructive power. Small landslide events are more common than

large ones and are prone to occur in areas underlain by loose colluvial debris and where hillslopes are undercut by roads, trails, and other infrastructure (Figure 9; Austin 2013). For example, the Generals Highway and Colony Mill Road have been subject to numerous landslides and rockfalls that overwhelm the highway drainage systems and result in costly roadway damage. Large-scale landslide events can happen when hillslopes are soaked to great depth and can cause landslide dams (channel blockages), channel diversions, flood conditions, and localized erosion (Austin 2013). The rich history of SEKI includes multiple examples of landslide dams that formed across the major river drainages—some of which were up to 122 m (400 ft) high; large dam failures such as these often resulted in catastrophic downstream flooding (Table 5; Austin 2012). According to Moore and Mack (2008), of all the natural lakes in the SEKI region, the only ones that are not of glacial origin include Oriole Lake and Kern Lake, both of which were previously dammed and formed by landslides.



Figure 9. Slope instability and failure along Highway 180 between Grant Grove and Cedar Grove. Landslides such as this one in 2023 are considerable geohazard events capable of destroying SEKI infrastructure and jeopardizing lives and resources. NPS photograph.

Table 5. A list of landslide events within SEKI. Information in the table was sourced from Costa and Schuster (1991), Austin (2012, 2013), and Capps et al. (2024).

Date	Landslide event description
Unknown	Landslide that deposited Hospital Rock along the Middle Fork of the Kaweah River.
1861–1862	The 1861–1862 flood resulted in significant fluvial drainage reorganizations as major rivers (e.g., Kaweah, Kern, Kings, and Tule rivers) incised new channels. These floods were accompanied by landslides and landslide dams.
20 December 1867	This is the largest recorded landslide dam to have occurred in the national parks and is included in a USGS report (Costa and Schuster 1991) of documented historical landslide dams from around the world. The unstable mass of rock and soil broke loose from Dennison Ridge and swept 4.0 km (2.5 mi) down into the canyon of the South Fork Kaweah River. The landslide had an estimated mass of about 445,000 m^3 (15.7 million ft^3). Two streams were temporarily obstructed by a landslide dam that failed approximately 25 hours later on December 22nd. The collapse of the dam generated a 12 m (40 ft) flood surge down the South Fork Canyon.
28 December 1867	Large landslide and landslide dam occurred within Kern Canyon along the North Fork of Kern River. The dam failed within a matter of hours, resulting in catastrophic downstream flooding. For example, the residents of Bakersfield, California, woke on 1 January 1868, to a 61 m (200 ft)-high flood coming out of Kern Canyon.
November 1924	Major highway damage resulting from a landslide event on the Giant Forest Road above Cedar Creek.
February 1937	Major highway damage resulting from a landslide event along the Generals Highway. The road was closed for nearly a month following a huge landslide just above Deer Creek; the slide took out more than just the road and also disintegrated a large section of the mountainside.
1943	Major highway damage resulting from heavy landslides and washouts.
November 1950	Major highway damage resulting from a landslide event. Roughly 3,800 m^3 (134,000 ft^3) of landslide material had to be removed from sections of the Generals Highway.
December 1955	Major highway damage resulting from a landslide event along the Generals Highway approximately 0.8 km (0.5 mi) above the national park headquarters.
1958 or 1959	Major highway damage resulting from a landslide event. At some point in 1958 or 1959, a short section of the Colony Mill Road slid off the hillside. That section of the road was immediately downhill of the junction with the Admiration Point Trail. Colony Mill Road remained closed until June 1960. To reopen the road, rather than constructing a bypass around the section of failed roadway, construction crews built roughly a mile of new road (the Over-the-Hump Road) on the other side of the ridge.
December 1966	Major highway damage resulting from multiple landslide events; all major mountain roads were either washed out or closed. Highway 180 was closed at Snowline Lodge by a rockslide. The Giant Forest area was isolated for a week by landslides and rockfalls along the Generals Highway between Giant Forest and Ash Mountain.
25 May 1980[?]	Cliff Creek rockslide. According to National Park Service (2013), the rockslide occurred circa 1980 and may have been caused by the 25 May 1980 Mammoth Lakes earthquakes (see “Seismicity”). The rockslide occurred on the cliffs near Cliff Creek and the Timber Gap Trail and generated so much dust that it was originally mistaken for a wildfire.
27 May 1980	Horseshoe Bend rockslide that occurred downstream of Kings Canyon National Park along the South Fork Kings River.
January 1997	Numerous landslides temporarily blocked sections of the Generals Highway below Giant Forest. A large slide occurred on the old Middle Fork Trail, just west of Elk Creek.
November 2002	Small landslide dam occurrence on a stream on the north side of Shepherd’s Saddle. When the dam failed, an immense amount of water overwhelmed the small drainage, washed out Shepherd’s Saddle Road, and deposited large boulders.
19 December 2010	A combination of flooding, debris flows, landslides, and rockfalls forced the national parks to close the inbound lane of the Generals Highway at the Ash Mountain Entrance Station. On 21 December, about 15 small landslides were documented along the Generals Highway for several miles below Hospital Rock.

Date	Landslide event description
December 2022 and January 2023	A series of atmospheric rivers inundated portions of Sequoia National Park and triggered numerous landslides and debris flows along the South Fork Kaweah River. Slope failures blocked road access to South Fork Campground, destroyed campground facilities, and undermined or buried trails in several locations.

Debris Flows

Debris flows are intimately associated with flooding and consist of moving masses of loose soil, rock, debris, and water that travel downslope. In SEKI, debris flows can transport exceptionally large boulders up to several meters in diameter, as well as woody material, including fallen trees. High energy flows are often turbulent, dangerous geohazards capable of destroying buildings, washing out roads, trails, or bridges, sweeping away vehicles, knocking down trees, obstructing streams and roadways, as well as altering drainage patterns (Austin 2012, 2013). Within the national parks, some of the most hazardous and susceptible areas for debris flows include canyon bottoms, areas near canyon outlets, and slopes excavated for buildings or other infrastructure. A list of selected debris flow events within SEKI is included in Table 6.

Several known mechanisms for debris flows in SEKI include intense rainstorms or prolonged snowmelt, saturated soils, landslides, and steep, sparsely vegetated slopes. Additionally, areas that have recently burned (wildfire or controlled burning) may be susceptible to debris flows or landslides as stabilizing vegetation is consumed and soils become hydrophobic, resulting in enhanced surface runoff and erosion (Capps et al. 2024). Soils can become hydrophobic due to the burning of organic material, which produces a waxy substance that penetrates the ground. According to Austin (2013), there are two categories of debris flows in SEKI. The first category consists of relatively small debris flows that routinely occur in the frontcountry and backcountry regions of the national parks. Ironically, although these flows only extend a few hundred meters or less, they often result in the most economic damage because they impact roads and trails constructed on colluvial debris slopes or at the bottom of hillslopes. The second category includes large-scale debris flows that typically originate in the backcountry and can continue several kilometers into the frontcountry. These large-scale flows often scour down to bedrock, uproot old-growth trees, and have the greatest potential for property damage and death.

Table 6. A list of debris flow events within SEKI. Information in the table was sourced from Austin (2012, 2013) and Capps et al. (2024).

Date	Debris flow event description
Unknown date	Grand Sentinel Chute debris flow
February 1963	Debris flows occurred in the drainage above Simpson Meadow.
27 May 1983	Multiple debris flows occurred along the drainage of the South Fork Kings River, including Bubbs Creek, Lewis Creek, and Castle Domes Meadow.
July 1983	A debris flow occurred along Redwood Creek, a tributary of the East Fork of the Kaweah River. The flow destroyed a swath of forest about 30 m (100 ft) wide and deposited rocks of all sizes.
January 1997	Numerous debris flows along the Generals Highway washed out portions of the road at Halstead Meadow.
2000s (possibly 2005?)	Discovered by SEKI staff in 2008, the Cement Table debris flow has an uncertain age but formed sometime after 1999. It is speculated to have formed during floods that occurred in 2005. The debris flow began on the east side of Cloud Canyon and incised two large channels that eroded down to bedrock in many places.
November 2002	Numerous debris flows damaged and closed the Generals Highway and Mineral King Road. The roadways sustained costly damages to the sum of $1.25 million.
12 July 2008	North Fork of Oak Creek debris flow

Date	Debris flow event description
14 July 2008	Multiple debris flows occurred along the drainage of the South Fork Kings River, including Charlotte Lake and the East Fork of Lewis Creek.
13 October 2009	Multiple debris flows occurred along the drainages of the Middle and East Fork Kaweah River, including the Tablelands, Black Rock Pass, and Hamilton Gorge.
19 December 2010	A combination of flooding, debris flows, landslides, and rockfalls force the national parks to close the inbound lane of the Generals Highway at the Ash Mountain Entrance Station.
December 2022 and January 2023	A series of atmospheric rivers inundated portions of Sequoia National Park and triggered numerous landslides and debris flows along the South Fork Kaweah River. Slope failures blocked road access to South Fork Campground, destroyed campground facilities, and undermined or buried trails in several locations.

Rockfalls

Unlike rockslides, rockfalls are individual fragments or blocks of rock that detach and proceed downslope by rolling, sliding, or bouncing. One of the most notable rockfall events to occur within SEKI took place on 13 November 1998 along the Generals Highway at Granite Spring. A massive boulder weighing nearly 110 tons originated from near Hanging Rock and gained enough downhill momentum that it went airborne for over 30 m (100 ft) before landing on the roadway pavement. The sheer force of the impact drove the boulder about 2 m (6 ft) into the roadway surface and melted the pavement several inches outward from the rock (Austin 2012). Numerous rockfalls have occurred within the national parks and range from isolated incidents to somewhat continuous events (Figure 10). An example of a consistent rockfall locality in SEKI is the alpine region surrounding Black Kaweah, which experiences routine freeze-thaw cycles that weaken the metamorphic bedrock (Austin 2013). Several documented rockfalls that have impacted SEKI are included below in Table 7.



Figure 10. A large 2023 rockfall blocks both lanes of Highway 180 between Giant Grove and Cedar Grove. Rockfall events such as this can destroy national park infrastructure (e.g., roadways, trails, buildings, utility systems), limit access, and endanger lives. NPS photograph.

Table 7. A list of selected rockfall events within SEKI. Information in the table was sourced from Austin (2012, 2013).

Date	Rockfall event description
21 February 1995	A rockfall impacted the Generals Highway between Wuksachi and Red Fir.
23 January 1997	A major storm event brought rockfalls and debris flows that damaged the Generals Highway below Giant Forest.
13 November 1998	Rockfall that originated from a point near Hanging Rock on the west slope of Moro Rock. The massive boulder (weighing about 110 tons) gained enough downhill momentum that it went airborne for over 30 m (100 ft) before it landed on the Generals Highway at Granite Spring. The force of the boulder's impact drove the rock about 2 m (6 ft) into the roadway surface and melted the pavement for several inches out from the rock.
19 November 2002	A rockfall impacted the Generals Highway below Big Fern Springs.
28 January 2005	A rockfall impacted the Generals Highway about a 1.6 km (1.0 mi) below Tunnel Rock; the rock was large enough to completely obstruct the roadway.
9 February 2006	A rockfall impacted Oriole Lake Road just above Squirrel Creek.
8 March 2007	Three separate rockfalls impacted the Generals Highway just north of the Red Fir gate.
19 December 2010	A combination of flooding, debris flows, landslides, and rockfalls forced the national parks to close the inbound lane of the Generals Highway at the Ash Mountain Entrance Station. The rate of rockfall and debris accumulation along the highway outpaced the road crews who were tasked to remove them.
March 2011	A rockfall impacted the Generals Highway near the Ash Meadow entrance.

Permafrost

Permafrost is ground that remains frozen throughout the year due to cold climate conditions. Over the last century, permafrost throughout the Arctic regions of Alaska has thawed in response to warming climate, leading to a slew of consequences, including drying or emerging ponds, soil erosion, mass wasting (e.g. slumps, landslides), destabilized building or road foundations, thermokarst (karst resulting from the selective thawing of ground ice), increased sediment loads of streams and lakes, enhanced greenhouse gas emissions, altered soil profiles, and impacted nutrient cycling (Gonzalez 2017). Although no incidents of permafrost thaw have been reported within SEKI, it may be important for park management to remain aware of its effects.

Because permafrost is located in the subsurface, it is often difficult to observe or map without sufficient soil, environmental, and climate data. According to the DOI SHIRA Risk Mapper report, the national parks contain sporadic permafrost probability, meaning that between 10–50% of SEKI's land area is underlain by permafrost. Permafrost data provided to DOI SHIRA were produced by the Central Institute for Meteorology and Geodynamics in Austria based on remotely sensed land surface temperatures, climate reanalysis (numerical simulations of Earth's climate through time), and land cover classification data.

Radon

Radon is a naturally occurring gas created by the radioactive decay of the element radium. Although radon is almost always present in small amounts in the substrate, 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 that can pose a known health risk (Otton 1992). According to the US Environmental Protection Agency (EPA) map of radon zones, Fresno and Tulare counties are identified as a zone of moderate potential (zone 2) for elevated indoor radon levels between 2 and 4 pCi/L (see https://www.epa.gov/radon/epa-maps-radon-zones-and-supporting-documents-state; accessed March 2025). The EPA has guidance for radon mitigation.

Seismicity

The national parks are located in the Sierra Nevada province of eastern California, a seismically active region known for generating frequent and sometimes powerful earthquakes. According to seismic hazard models by Petersen et al. (2023), the national parks occupy a zone of very high to high seismic probability compared to the rest of the country. The Sierra Nevada crest marks the easternmost boundary of the Cascade-Sierra Mountains province and is flanked by front-range normal faults that are responsible for uplifting and tilting the Sierra Nevada toward the west; these faults are still active today. Certain fault zones within SEKI, such as the Kern Canyon fault, act as a conduit for hydrothermal fluid flow that sustains geothermal features such as Kern Hot Spring (see "Hydrological Resource Protection"; Moore and Sisson 1987). Low-magnitude earthquakes are regularly recorded within SEKI, including a recent 1.6 magnitude event that originated in the vicinity of Mount Whitney on 3 September 2024 (https://earthquake.usgs.gov/earthquakes/map/; accessed September 2024). Several seismograph sites surround the national parks, including the Rocky Hill station near Visalia and a suite of 16 stations located around Mammoth Lakes.

Earthquakes have and will continue to influence the landscape of SEKI and are known for triggering other geohazards, including landslides, rockfalls, and debris flows. Some notable seismic events that impacted the national parks include (1) the famous April 1906 San Francisco earthquake and (2) the May 1980 Mammoth Lakes earthquakes. The 1906 quake was a powerful 7.9 magnitude event that originated north of San

Francisco but triggered a series of damaging avalanches throughout the Sierra Nevada, including in Mineral King Valley (Brown and Schaible 2008; Austin 2012). The Mammoth Lakes earthquakes were a prolonged series of seismic events that began on 25 May 1980—nearly one week after the spectacular eruption of Mount St. Helens. An initial 6.0 magnitude earthquake occurred about 10.5 km (6.5 mi) southeast of Mammoth Lakes, California (about 32 km [20 mi] north of Kings Canyon National Park) and was followed by thousands of aftershocks in the next 48 hours, including 72 magnitude 4.0–4.9 events, six magnitude 5.0–5.5 events, and three events of magnitude 6.0–6.3 (McJunkin and Bedrossian 1980; see also https://calconservation.blog/2020/05/22/the-mammoth-lakes-earthquakes-40th-anniversary/; accessed September 2024). These seismic pulses impacted the area of Horseshoe Bend and caused a moderately large rockslide that almost killed a SEKI forestry crew member (National Park Service 2013).

Swelling Clays

Swelling clays, or shrink-swell clays, include minerals such as smectites that are physically altered by the presence of water and tend to swell when wet and shrink when dry. As swelling clays expand or contract, the change in volume can undermine the integrity of the substrate, increase the susceptibility of slope failure, and cause infrastructural problems along roadways or trails. According to the USDA NRCS Web Soil Survey, several soils mapped within the military park are rated “moderate” in linear extensibility (a determination of shrink-swell potential). Linear extensibility ratings are based on the percentage of volume change as soil dries and include four assessment categories: (1) low, <3%; (2) medium, 3-6%; (3) high, 6–9%; and (4) very high, >9%. The ratings for SEKI indicate that swelling clays can cause significant volume change capable of damaging buildings, roads, and other structures. Anthropogenic modifications that redirect the flow of water should take into account the distribution and extent of swelling clay deposits, as these activities can disturb the ground and negatively impact SEKI resources, habitats, and infrastructure.

Investigations by Wahrhaftig (1965, 1984) report that granitic weathering sequences of the Sierra Nevada contain about 1–2% biotite that is altered to montmorillonite and vermiculate (shrink-swell clay minerals). The presence of these minerals allows the bedrock to slightly expand, which facilitates the development of joints that can ultimately weaken and shatter the bedrock (Wahrhaftig 1984).

Toxicological Soil

According to the DOI SHIRA Risk Mapper report, the soils of the national parks 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. 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, selenium, and 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 September 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 September 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 September 2024).

Geologic Resource Protection

The NPS GRD has developed an article series (https://www.nps.gov/articles/series.htm?id=FA0A8F89-CD67-1CCE-5A6608B444E8A7C0; accessed February 2025) 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 human activity.

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 (2006b), 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 assess the impacts of natural processes and human activities on geologic resources; maintain and restore the integrity of existing geologic resources; integrate geologic resources management into NPS operations and planning; and 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 can be found at the following website: https://home.nps.gov/subjects/geology/geoheritage-nps-management-policies.htm (accessed September 2024).

Cave and Karst Resource Protection

The national parks contain approximately 275 caves that are generally restricted to narrow bands of marble in the western area of SEKI. Lilburn Cave is the largest cave in Kings Canyon National Park and the state of California, with over 48 km (30 mi) of mapped passageway (Wortham et al. 2021). Caves in SEKI are sensitive environments that are found at different elevations, feature a range of internal temperatures, and sometimes contain active streams, delicate speleothems, rare minerals, karst aquifers, and endemic species (National Park Service 2013, 2016b). Additionally, caves within the national parks preserve many paleontological and cultural resources that are vital windows to the past (see "Paleontological and Cultural Resource Protection").

Over many years, the cave and karst resources of SEKI have been subjected to several instances of degradation stemming from visitor use, commercialization, litter, and vandalism. For example, numerous reports of vandalism from Overhang Cave, Clough Cave, and Lost Soldier's Cave document the destruction of delicate cave formations (National Park Service 1987; Panek and Despain 2013). At Clough Cave, thousands of stalactites, stalagmites, soda straws, cave pearls, and columns were removed or broken by heavy public use, and the walls have been blackened by the smoke of pine torches (Panek and Despain 2013). To better protect sensitive cave habitats and resources, the national parks initiated an active cave

management program in 1992 that restricts access to specific passages and requires special access permits. According to the SEKI cave management plan (National Park Service 1998), caves are an extension of the surface and are thus susceptible to various human activities that include (1) road, trail, or parking lot construction; (2) the development of water sources, including wells and septic systems; (3) building construction and utility installation; and (4) projects that divert water or pollution.

Hydrological Resource Protection

The hydrological resources of SEKI are a critical source of water with profound ecological, geological, recreational, and societal value and include the headwaters of several major river drainages (including three designated Wild and Scenic Rivers), streams, glaciers, snowpacks, lakes, wetlands, aquifers, and cold-water springs or seeps. Additionally, Sequoia National Park protects several geothermal features, including soda springs (Kaweah River drainage and near the mouth of Golden Trout Creek), Whitney Warm Springs (Kern River drainage), and Kern Hot Springs (upper Kern Canyon) that are sustained through fault-controlled hydrothermal fluid flow (National Park Service 1984; Moore and Sisson 1987; Arndt 2024). The alpine watersheds of the Sierra Nevada are a valuable source of sustenance within the national parks but also provide drinking water, habitat, power generation, and agriculture to the downstream Central Valley of California (National Park Service 2013; 2016b).

The diverse hydrological resources of the national parks are sensitive and susceptible to a wide range of natural and anthropogenic stressors, including climate change, agriculture (pesticides and fertilizers), illegal marijuana cultivation, and increased human consumption. Climate change poses a significant threat to the quality, quantity, and existence of various hydrological systems—especially SEKI's glaciers. Throughout the 20th century, alpine glaciers in SEKI and YOSE have receded in response to a warming climate and are now in poor condition compared to historical references of the early 1900s (Basagic and Panek 2013). According to Basagic and Panek (2013), an intensive study of a subset of 14 glaciers revealed an average 55% loss of original glacial area in YOSE and SEKI over the last century. The loss or disappearance of glaciers and snowpacks will likely have a profound impact on other natural systems, as these resources represent vast frozen aquifers that regulate runoff, nutrients, and seasonal response but also buffer the water quality and temperature of nearby lakes, rivers, or streams (Basagic and Panek 2013; National Park Service 2013).

Although pesticides and fertilizers are not naturally present in SEKI's watersheds, these contaminants can be introduced from heavily farmed, upwind sources and through illegal marijuana cultivation activities. Agricultural pesticides used in the San Joaquin Valley, as well as pesticide-laden soil, can become airborne and deposited downwind in the national parks (National Park Service 2013; Panek and Despain 2013). The illegal cultivation of marijuana introduces not only pesticides and fertilizers but also dangerous toxins that can have a severe impact on SEKI's hydrology and ecology (Panek and Despain 2013; National Park Service 2016b). Additionally, cultivated marijuana plots are often supplied with water from artificial catchments that divert the natural flow of water (see "Disturbed Lands").

The combined effects of climate change and increased human consumption may negatively impact groundwater quality and availability in both SEKI and the Central Valley. As average temperatures are projected to increase, prolonged or exacerbated droughts will likely increase groundwater withdrawals (e.g., agricultural, domestic, or recreational use) and stress aquifer sources such as glaciers or snowpack regions (Basagic and Panek 2013; Climate Change Response Program 2024a, b). Groundwater consumption within

the San Joaquin Valley is already a known issue, as the regional water table has progressively diminished, making it one of the largest subsidence areas in the world (Austin 2012). Since the 1920s, excessive groundwater pumping associated with agriculture and residential development has caused the valley to sink by as much as 8.5 m (28 ft).

Paleontological and Cultural Resource Protection

Paleontological (fossils) and cultural resources are a valuable, protected component of SEKI's identity, as these irreplaceable assets provide insight into the geologic and historical past of the southern Sierra Nevada. Fossils include any evidence of life preserved in a geologic context (Santucci et al. 2009). They may be body fossils (any remains of the actual organism such as bones, teeth, shells, or leaves) or trace fossils (evidence of an organism's activity such as nests, burrows, tracks, or feces). Fossils may occur in rocks or unconsolidated deposits, in museum collections, or in cultural contexts, such as building stone. Fossils preserved at SEKI include park collections and *in situ* specimens found in association with metamorphic roof pendants, including those that host the national park's marble caves (Santucci and Kenworthy 2007). Although fossils are rare in metamorphic rocks of the Sierra Nevada, numerous marine invertebrate species (e.g., ammonites, pelecypods, brachiopods, crinoids) have been reported from various roof pendants within the national parks (Moore et al. 1994; Santucci and Kenworthy 2007; Sisson and Moore 2013). Additionally, a diverse Quaternary fossil assemblage has been found in SEKI's caves that includes vertebrate fauna and fossilized sequoia specimens (Santucci et al. 2001; Santucci and Kenworthy 2007). The distribution of fossil sequoia in numerous caves suggests that tree groves may have formerly existed in areas of SEKI where they are no longer found today. Cultural resources of SEKI record an extensive history of human occupation spanning the last 8,000 years and include campsites, shelters, pictographs (rock paintings), and artifacts (see "Indigenous Connections"; National Park Service 2016b).

Proper management protocols are critical to safeguarding paleontological and cultural resources in SEKI. Additional inventory needs that may enhance these protocols include resource vulnerability assessments that address various geohazards (e.g., climate change, flooding, mass wasting, seismicity), improved digital data records, and increased surveys (see "Inventory Needs"). For example, only 6–8% of SEKI has been surveyed for cultural resources (National Park Service 2016b). As additional caves continue to be discovered within the national parks, it is likely that additional fossil and cultural resources will need to be inventoried, monitored, and protected.

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 26 June 2024).

Giant Sequoia Resource Protection

The health and longevity of giant sequoia groves is a major management concern for SEKI, as these stands of ancient forest are susceptible to climate change and often grow adjacent to barren patches where soil is absent and bedrock is exposed. As the climate within the national parks continues to warm and produce more extreme weather events, the NPS may want to evaluate the role lithology plays within a broader ecological framework that includes precipitation, elevation, biology, and controlled burning (see "Climate Change").

Throughout the Sierra Nevada, bedrock composition helps regulate mountain ecosystems and landscape evolution by providing vital nutrients necessary for soil health and vegetative growth. As a substrate for life,

the extensive Sierra Nevada batholith is comprised of geochemically distinct plutons that supply varying amounts of rock-derived nutrients (e.g., phosphorous, calcium, silicon, iron, magnesium, aluminum) that drive changes in vegetative cover and control relative rates of erosion (Moore et al. 2004; Hahm et al. 2014). Additionally, several other physical and chemical properties unique to individual plutons can regulate the presence or distribution of floral communities by influencing the hydrology and chemistry of the substrate. These properties include (1) toxin concentrations (e.g., arsenic, cadmium, selenium); (2) concentrations of weatherable minerals (e.g., feldspars, clays); (3) concentrations of clay-forming minerals; and (4) fracture density (Moore et al. 2004; Hahm et al. 2014). The degree of geologic control on vegetation is observed across pluton boundaries that coincide with sharp changes between densely forested, soil-mantled slopes and sparsely vegetated, mostly soil-free bedrock (Hahm et al. 2014). According to Hahm et al. (2014), variations in vegetative growth result in differences in landscape evolution, as bedrock surfaces lacking vegetation or soil cover are eroding more than two times slower on average than more densely vegetated, soil-mantled areas.

Although soil type is not considered to be a significant determinant of giant sequoia grove location, other factors such as soil texture, chemistry, and moisture play a role in grove establishment (Harrison 2013). In general, giant sequoia groves tend to prefer sandy soils with low clay content that are typically higher in pH and calcium concentrations compared to neighboring soils associated with conifers (Hartesveldt et al. 1975; Zinke and Crocker 1962; Zinke and Stangenberger 1994; Harrison 2013). Additionally, studied groves have shown significant increases in soil moisture content compared to surrounding forests, which may represent differences in water-holding capacity of soils (Halpin 1995; Harrison 2013). Additional soil and ecological investigations may help SEKI management determine the soil-mantle distribution and subsurface moisture conditions vital to giant sequoia groves (Despain 2013). Recent studies have used seismic techniques to image the subsurface critical zone (permeable layer from the tops of the trees to the bottom of the groundwater table) and better understand the volume of groundwater underlying groves of giant sequoia (Gupta et al. 2025). Initial findings from Gupta et al. (2025) suggest that the giant mass of the trees exerts enhanced pressure that distorts the underlying soil structure and significantly stresses the subsurface critical zone.

Inventory Needs

Moving forward, the GSRI program will fund inventory projects that:

- 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.
- Provide information about features or processes on an individual feature or landscape scale.
- Provide data about 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.

The following table (Table 8) presents several geologic and soil resources inventories needs that were identified during the 2025 follow-up meeting, in NPS planning documents, or through literature review.

Table 8. List of identified geologic and soil resources inventory needs for SEKI.

Subject	Inventory Need(s)	Reference(s)
Cave and karst systems	Updated cave management plan, including improved documentation, mapping, and cave-specific management and restoration strategies.	National Park Service (2016b)
Cave and karst systems	Monitoring visitor use of caves, including the addition of human activity sensors for easy to access caves that contain a large diversity of sensitive features and species. Activity sensors would help verify that the use of these caves by unauthorized visitors is minimal.	Panek and Despain (2013)
Cultural resources	Resource vulnerability assessments that address various geohazards (e.g., climate change, flooding, mass wasting, seismic activity)	National Park Service (2016b)
Cultural resources	Improved cultural resource documentation and surveys. Only 6–8% of SEKI has been archeologically surveyed. Further inventory is needed, especially in developed areas and heavily used backcountry areas.	Wells (1994); National Park Service (2016b)
Cultural resources	Cultural resources digital data and records management plan	National Park Service (2016b)
Climate change	Natural resource stewardship strategy. The resource stewardship strategy is needed as a baseline to continue addressing management challenges related to key issues and stressors on SEKI resources. It would also contribute to the protection of nearly every fundamental resource and value for the national parks.	National Park Service (2016b)
Climate change	Continued evaluation of observed and projected climate change, including climate-related responses (e.g., fire frequency, snowmelt, shifting biomes), resource vulnerability assessments, and models. As new data is introduced, it should be incorporated into park planning, management, and decision making.	National Park Service (2016b)
Disturbed lands	Parkwide disturbed lands assessment and restoration strategy	National Park Service (2016b)
Disturbed lands	Feral animal management plan	National Park Service (2016b)
Geoscience research	A list of desired geoscience research projects include: Updated radiometric dating of geologic units Active glaciers/permanent snowfields Karst hydrology Rock glaciers GPS monitoring of active tectonics Active fault identification How geology impacts rare plants/vegetation How catastrophic fires impact sediment deposition	National Park Service (2002)
Geothermal features	Geothermal feature inventory. Although several soda springs, warm springs (e.g., Whitney Warm Springs), and hot springs (e.g., Kern Hot Springs) are known, a more detailed assessment is needed of SEKI's geothermal resources.	2025 follow-up meeting
Glaciers	Determination of glacial volume change estimates. Volume measurements would quantify changes that area measurements alone miss and could be more directly related to changes in climate. Improved high elevation estimates of precipitation inputs (e.g., timing, amount, and form) would better quantify glacier accretion terms, as the southern Sierra Nevada appear to be a zone where precipitation dominates over temperature to determine high elevation snowpack extent.	Basagic and Panek (2013)

Subject	Inventory Need(s)	Reference(s)
Glaciers	Updated glacier inventory, including an increased number and extent of glacier studies. Increasing the number of study glaciers and interval between observations would improve statistical analyses of climate and topographic factors. The continuation of repeat photography and GPS mapping of glacier terminus is an important and cost-effective method of documenting change. Monitoring should be conducted at a minimum of every 5 years.	Basagic and Panek (2013)
Groundwater	SEKI needs more groundwater data as climate change is affecting surface water availability and the domestic water supply. More exploration is needed to find new groundwater capture sites for future water well installation.	2025 follow-up meeting
Mapping	Park-wide LiDAR imagery	National Park Service (2016b)
Mapping	Detailed mapping of glacial deposits, especially along the South Fork and Middle Fork of King's Canyon	National Park Service (2002)
Mapping	High-resolution digital elevation model. The parks currently use a digital elevation model that was derived from 1970s era USGS topographic quadrangles. Today's methodologies are higher resolution, more accurate, and capture characteristics of vegetation and built objects on the landscape. High-resolution data of the parks will assist with the analysis of microclimates, hydrology, moisture regimes, fire and fuels management, and lead to a better understanding of the role landforms play in the parks. Additionally, high-resolution elevation data can help with the mapping and identification of geologic features (e.g., karst, landslides)	National Park Service (2002, 2016b)
Mapping	Additional floodplain mapping. The only floodplain mapping in SEKI is a published 2018 dataset of the Kern River and the S. Fork of the Kings River.	National Park Service (1984), Paul Hardwick (NPS, SEKI, written communication April 2025)
Mass wasting	Geohazard assessment and documentation system. Currently, little documentation has been done in SEKI for mass wasting events (e.g., landslides, rockfalls) and small-scale debris flows. Therefore, when such events occur, they are not routinely documented, nor do they make it into the parks' records management system. Instead, they are managed as individual incidents rather than as part of a hazard management program. Detailed assessments and documentation will better allow park management to predict, evaluate, and know when or how often mass wasting events occur.	Austin (2013); 2025 follow-up meeting
Mass wasting	Development of a mass wasting spatial model. Identifying high risk areas would require the assemblage and analysis of the following spatial layers: slope, watershed boundaries, vegetation, land use, and rainfall isohyets; all of which currently exist for the park.	Austin (2013)
Paleontological resources	Resource vulnerability assessments that address various geohazards (e.g., climate change, flooding, mass wasting, seismic activity)	National Park Service (2016b)
Soils	A detailed soil inventory (e.g., cryptobiotic crusts, bryophytes, cyanobacteria) to better understand how substrate and microorganisms impact the health of giant sequoia groves. High quality data would be helpful in modeling efforts in terms of grove management.	2025 follow-up meeting

Subject	Inventory Need(s)	Reference(s)
Soils	Pesticide impact study on soils in SEKI. There has been insufficient monitoring to accurately assess the impact of wind-blown pesticides, specifically in the national parks. Studies conducted elsewhere indicate that the levels of certain pesticides measured in SEKI can have significant negative effects. Pesticides that have been detected in the national parks include DDT, endosulfan, aldrin (or related dieldrin), Simazine, and Dacthal.	National Park Service (2013)
Stratotypes	Resource vulnerability assessments that address various geohazards (e.g., climate change, flooding, mass wasting, seismic activity)	National Park Service (2016b)
Visitor use	Scenic resource inventory	National Park Service (2016b)
Visitor use	Climbing management plan	National Park Service (2016b)
Visitor use	Visitor use monitoring and impacts study (e.g., for public tours of Crystal Cave)	Panek and Despain (2013); National Park Service (2016b)

Prior NRSS-Supported Work

Geologic or Soil Research Permits

Table 9 is a compilation of completed research projects related to the geology or soils of SEKI. These items are located on the NPS Research Permit and Reporting System of IRMA (see https://irma.nps.gov/RPRS/Search; accessed May 2024) but may require government access or assistance. Since 2000, there have been numerous (>100) geoscience research permits issued that include various geoscience investigations (e.g., geochronology, geophysics, glacial, hydrology, karst, mapping, paleontology, petrology, soil, structural geology) and resource monitoring (e.g., karst).

Table 9. Completed or ongoing geology or soil-related research investigations within SEKI.

Year(s)	Title	Author(s)
2006	Cave passage locating and documentation in Sequoia and Kings Canyon National Parks, California	Mark Scott
2006	Weathering in glacial tills as a function of climate and time	Georg Grathoff
2006	Sierra Nevada EarthScope Project: lithospheric foundering beneath the Sierra Nevada	Craig Jones
2006, 2009	Geologic map of the Mineral King 15' Quadrangle	Thomas Sisson
2007	Predicting karst development in an alpine location: Mineral King, Sequoia National Park, California	Patrick Kahn
2007	Kinematic and timing relations of the solid-state deformation associated with the Lamarck pluton and wall rock in the Long Lake-Dusy Basin area, John Muir intrusive suite, King Canyon National Park and John Muir Wilderness, California	Kristopher Clemons
2007	Assembly of the incrementally emplaced McDoogle pluton, central Sierra Nevada, California	Michael Stearns
2008, 2009	A non-destructive and restorative approach to using speleothems from Sequoia National Park for climate and hydrologic reconstructions	Ashish Sinha
2008	Fluid flow through fault zones in granite exhumed from seismogenic depths	Susan Lawther
2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021, 2022	Cartography of caves in Redwood Canyon	Jed Mosenfelder
2009	Internal anatomy and growth of granitic plutons	John Bartley
2006, 2007, 2009, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020, 2021	Intrusive architecture of the northern Paradise and Whitney plutons, eastern Sierra Nevada, California	William Hirt
2009, 2010, 2011, 2012, 2015, 2016, 2017, 2018	Structural geology of the Redwood Mountain pendant, Sequoia and Kings Canyon National Parks, California	Marek Cichanski
2009	Testing correlation of the Golden Bear dike and Coso dikes and 65 km of dextral offset across the eastern Sierra since 83 Ma	Christopher Pluhar
2010, 2011, 2012, 2013	Assessing the paleoclimate potential of speleothems from Sierra Nevada mountains: a preliminary study	Kathleen Johnson
2010	Pluton-wallrock interactions in the Sequoia region: evaluating crustal contamination in the early Sierran arc	Jade Star Lackey
2011	Cartography of caves in Mineral King, Sequoia and Kings Canyon National Parks	Elaine Garvey

Year(s)	Title	Author(s)
2011, 2012	Shapes of Sierra plutons	Robert Hildebrand
2011, 2012, 2013	Understanding cave environments: monitoring of modern caves along an elevation transect in Sequoia/Kings Canyon National Park	Jessica Oster
2011, 2012, 2013, 2014, 2015, 2016, 2017, 2019, 2020, 2021, 2022, 2023	Magma-wallrock interactions in the Sierran arc	Jade Star Lackey
2011, 2012, 2013	Mechanisms of comb layering formation in shallow level calc-alkaline plutonic rocks	Anders McMarthy
2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020	Soil survey of Sequoia-Kings Canyon National Park	Catherine Scott
2013	The role of rock mass strength and lithology in glacial valley formation	Kaai Jensen
2014, 2015	Testing environmental controls on speleothems and cave drip water geochemistry in Crystal Cave, Sequoia and Kings Canyon National Parks	Kathleen Johnson
2014	Quantifying spatial and temporal patterns of cave temperature in the Kaweah River Basin, Sequoia and Kings Canyon National Parks	Benjamin Tobin
2015, 2016	Documenting woodrat middens in Sequoia-Kings Canyon National Park	Jessica Blois
2015	Structural geology and geochronology of the White Fork pluton, Mount Pinchot quadrangle, southern Sierra Nevada	Scott Johnston
2016	Paradise Ridge karst inventory	Kathryn Biacindo
2017	The geomorphic history and spatial extent of Ursa Minor cave, Sequoia National Park, California	Joel Despain
2020	Influence of soil processes on giant sequoia survival with drought	Courtney Creamer
2021	Inventory and mapping of Hurricane Crawl Cave	Joel Despain
2021	Operate a remote geophysical station in Cedar Grove	Margaret Hellweg
2021, 2022	Are warming soils leading to phosphorus enrichment in remote mountain lakes?	Gordon Gianniny
2021, 2022, 2023	Soil Climate Study of Sequoia and Kings Canyon National Parks	Catherine Scott
2021, 2022	Impact of autogenic waterfall formation on landscape evolution	Sophie Rothman
2022	Soil and microbial response to prescribed fire and site hydrology in giant sequoia groves	Courtney Creamer

Previous or Ongoing Technical Assistance Requests

The following table (Table 10) provides previous or ongoing technical assistance requests submitted to the GRD related to the geology or soils of the national parks. These items are located on the NPS Solution for Technical Assistance Requests (STAR) of IRMA (see https://irma.nps.gov/STAR/; accessed September 2024) but may require government access or assistance.

Table 10. Previous or ongoing technical assistance requests related to the geology and soils of SEKI.

Year(s)	Title	Program Area
2020	Cave resources management scoping meeting	Caves, Paleontology, and other Geologic Features
2022	Assess impacts of recent extreme wildfire on sensitive cave resources in SEKI	Caves, Paleontology, and other Geologic Features

Year(s)	Title	Program Area
2022	Assess post-fire rockfall hazards in heavily burned Marble Fork of Kaweah River above trail to Crystal Cave	Active Geologic Processes and Hazards (Rockfall, Landslides, and Terrestrial Geomorphology)
2024	Geomorphic site assessment of South Fork campground for debris flow damage and on-going hazard assessment	Active Geologic Processes and Hazards (Rockfall, Landslides, and Terrestrial Geomorphology)
2024	South Fork Road and campground slope stability and geologic hazards analysis	Active Geologic Processes and Hazards (Rockfall, Landslides, and Terrestrial Geomorphology)

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