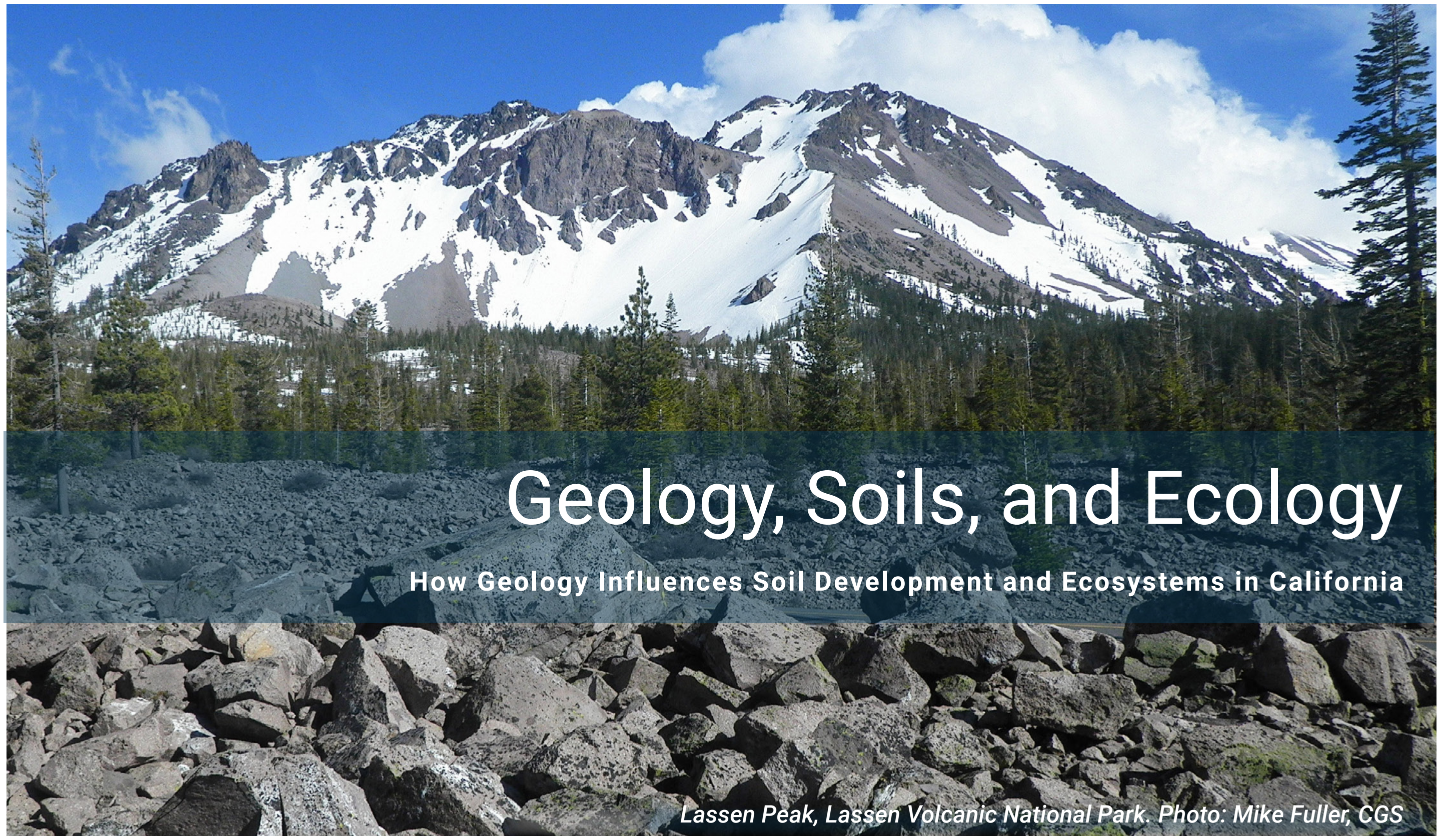


Geology, Soils, and Ecology

How Geology Influences Soil Development and Ecosystems in California

Lassen Peak, Lassen Volcanic National Park. Photo: Mike Fuller, CGS

Habitats and ecosystems rely on soil to support diverse plants and wildlife. Plant communities respond to both extrinsic factors such as elevation, rainfall, and surface hydrology, as well as intrinsic factors such as soil texture, mineralogy, and pedogenic development (soil horizonation). The diverse geology of California influences these factors in various ways. The intent of this note is to highlight the relationship between geology, soil, and ecology by providing selected examples from California's landscape.

California is one of the most geologically and ecologically diverse regions in the world

Of the 48 contiguous United States, California's landscape contains both the highest and lowest elevations: Mt. Whitney at 14,500 feet above sea level (Benti, 2012), and Badwater (Death Valley) at 282 feet below sea level (USGS, 1986). This wide range of elevations and landscape features is a result of the active continental margin of the West Coast, where the North American, Pacific, and Juan De Fuca tectonic plates are slowly moving in relation to one another. As the edges of these tectonic plates collide, high levels of physical stress and strain cause breaks, or faults, in the earth.

For more than 1.8 billion years, tectonic processes have layered and altered geologic terrains to shape the present landscapes of California (Sylvester, 2016). As movement occurs along faults, compressional, extensional, and translational forces create mountains, valleys, and displaced features seen throughout California today.

Over time as stresses decrease or transfer to different regions, faults can become inactive and no longer facilitate movement, while others can continue to move at rates of millimeters or centimeters per year. The State recognizes active faults to be those that have had surface displacement within ***Holocene*** time, the last 11,700 years (CGS SP 42). Although the San Andreas Fault Zone is the most famous active fault, there are over 500 faults considered active in California (Jennings and Bryant, 2010)

California Geomorphic Provinces

- Klamath Mountains
- Modoco Plateau
- Basin and Range
- Cascade Range
- Northern Coastal Ranges
- Great Valley
- Sierra Nevada
- Southern Coastal Ranges
- Transverse Ranges
- Mojave Desert
- Peninsular Ranges
- Colorado Desert

Tectonics and Landscapes

Throughout California's history, various stages of tectonic processes have resulted in the accumulation and development of sedimentary, igneous, and metamorphic geologic units (see geologic map of California on page 4). The topographic, geologic, and physical character of California's diverse terrain are grouped into 12 geomorphic provinces based on landforms as well as their structural and erosional history. These 12 provinces consist of the Klamath Mountains, Cascade Range, Modoc Plateau, Sierra Nevada, Coastal Ranges, Great Valley, Traverse Ranges, Peninsular Ranges, Basin and Range, Mojave Desert, and the Colorado Desert (CGS Note 36).

The physical characteristics of these provinces influence the state's regional climate and environments that help support the various habitats and species that reside in California. For example, the Sierra Nevada is home to about fifty percent of California's plant species and sixty percent of its animal species (CWWR, 1996).

Rock Types

Rocks are an assemblage of minerals that are described and mapped based on their composition and the way (genesis) in which they are formed. The geologic map of California on page 4 exhibits the general distribution of rock types throughout the state. Igneous rocks are formed by the cooling of magma. This process includes ***extrusive*** volcanic magma that rapidly cools to form rocks with fine crystals, such as basalt flows or ash, as well as ***intrusive*** magma that cools slowly to form rocks with coarse crystals, such as granite. In both types, the minerals form based on the chemical composition of the source magma and the surrounding country rock – the host rock that magma intrudes into as it rises.

Sedimentary rocks are formed by the ***diagenesis***, or weathering and erosion, of existing rocks and soil in both marine and non-marine environments. Deposits range from limestone, shale, sandstone, and conglomerate. The mineralogy of these sedimentary rocks is dependent on the broken-down (diagenetic) products of their source rocks.

Young surficial sediments that have not ***lithified*** (solidified into rocks), are mapped as Quaternary deposits on the geologic map (page 4). These poorly consolidated surficial deposits include alluvium, ***eolian*** (wind-blown) sands, as well as coastal estuary and beach deposits.

When both sedimentary and igneous rocks are subjected to high temperatures, pressures, and chemical reactions, their composition and structure alter to become what are called ***metamorphic*** rocks (Harden, 2004). Metamorphic rocks can be very complex because they can be ***metamorphosed*** more than once.

It is the underlying distribution of rock and sediment types that frame California's characteristic landscapes and features, such as the igneous granitic rocks of the Sierra Nevada, shown as pink on the geologic map (page 4), volcanic rocks of the Modoc Plateau (red), or the ultramafic igneous and metamorphic serpentinite rocks (California's State Rock; See CGS Note 14) of the Klamath Mountains (purple).

Parent Material and Soil Textures

As rocks weather and erode over time, they break down in place and form ***residual soils***. If residual soils remain on the landscape for thousands of years, additional soil development occurs and results in more mature soils called ***pedogenic soils***. As soil evolves in stages, pedogenic soils develop layers called soil horizons that together make up the soil profile (see "**What Are Soil Horizons**" section for more information). Nutrients available in soils are dependent on the minerals present in the original rock material (***parent material***) and can provide living organisms with supporting environment conditions.

Although climate, topography, exposure age, and biological activity all contribute to the development of soil profiles, the decomposition from chemical and physical weathering of parent rocks give distinct characteristics to the soil horizons (Birkeland, 1999). For example, coarsely crystalline granitic rocks erode to form sandy soils, while fine-grained sedimentary shale deposits erode to form clay-rich soils. With time and landscape stability, surficial and soil weathering processes transition to finer-grained soils with stronger soil horizonation.

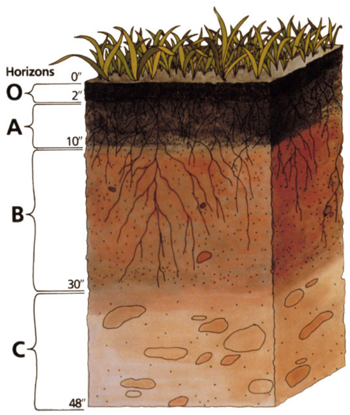
Faults and the Environment

Over millions of years, tectonic activity in California has shifted geologic terrains throughout the state. From river channels to mountains, movement along faults leaves a geologic mark on the landscape. This can be observed along the San Andreas Fault Zone, where geologic units such as the Mesozoic granitic igneous rocks (geologic map, page 4) have been shifted to the northwest about 186-220 miles (300-350 kilometers) over the course of 28-30 million years. That equates to a ***creep rate*** of about 2 inches (5 centimeters) per year. (Rate includes all faults associated with the San Andreas Fault Zone since activation) (USGS, 2017).

Displacement of soils and rock units along faults can redirect or impede groundwater flow, resulting in various local groundwater depths across fault zones. In addition, faults also create planes of weakness in the ground that act as conduits for groundwater travel and water access for root systems. An example of this can be seen in the Colorado Desert at the Thousand Palms

What are Soil Horizons?

Soil profiles are made up of vertically assembled layers called soil horizons. Each layer has distinct characteristics that develop during soil pedogenesis.



O Horizon: This is the upper most layer of the soil profile, called the organic layer. The O horizon includes organic litter, such as decomposing leaves along with other organic material. This layer is often dark in color.

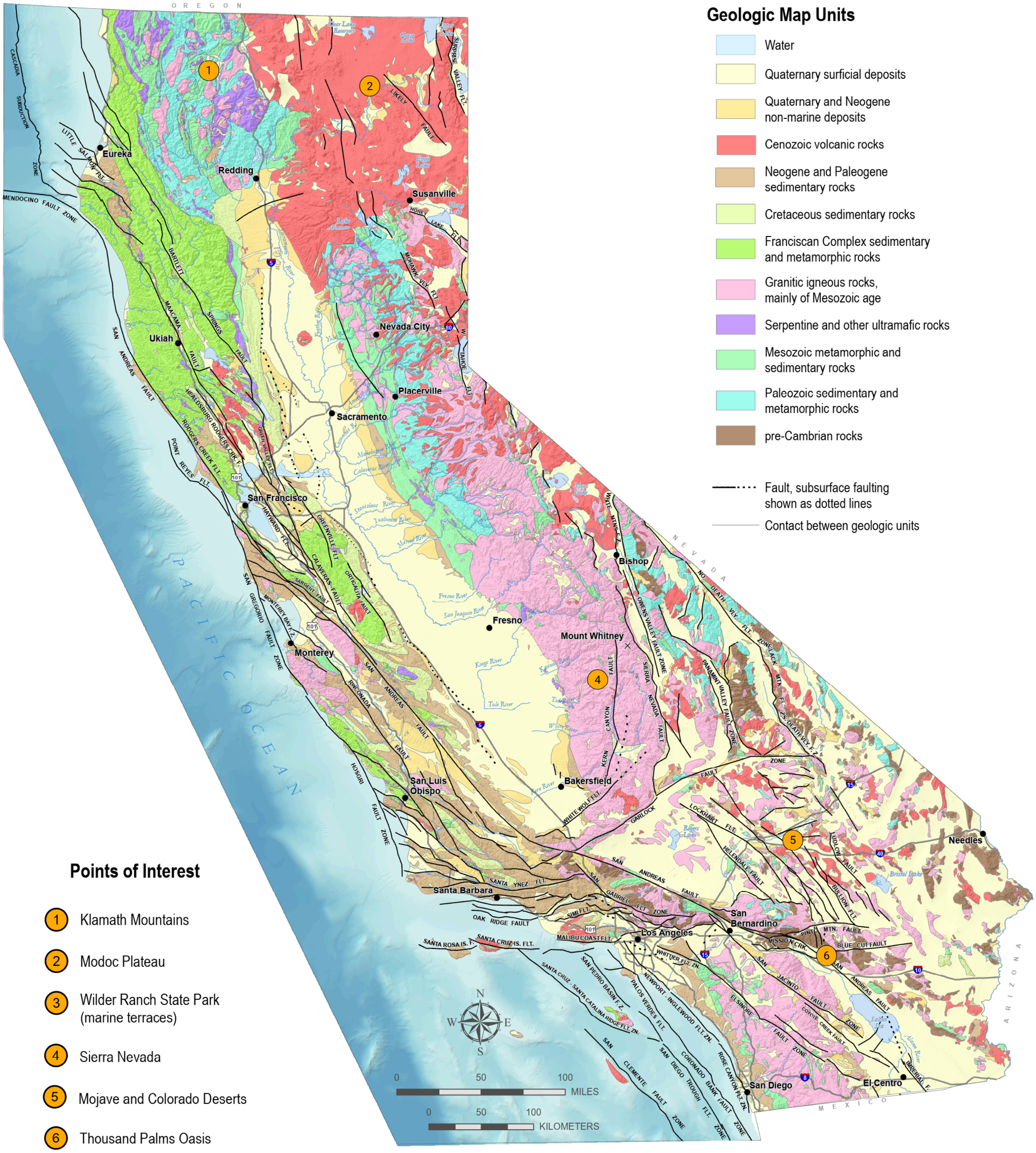
A Horizon: This layer is called the topsoil of the soil profile. It is found below the O horizon, but in environments where little organic material is present, the A horizon can be found at surface level. This layer is darker than the underlying horizons and is considered the most productive layer. This horizon is mineral rich and where most root activity occurs.

B Horizon: The B horizon lies below the A horizon and is referred to as the substratum or subsoil. The B horizon is lighter in color, denser, and contains less organic matter than the A horizon. In this layer, minerals and materials that get leached (washed out) from the A horizon accumulate.

C Horizon: The C horizon is the last horizon in the soil profile and lies above the bedrock. This horizon is comprised mostly of mineral particles and weathered bedrock.

(Adapted from USDA NRCS Soils 101)

Geologic Map of California



Geologic Map Units

- 🟦 Water
- 🟨 Quaternary surficial deposits
- 🟨 Quaternary and Neogene non-marine deposits
- 🟥 Cenozoic volcanic rocks
- 🟫 Neogene and Paleogene sedimentary rocks
- 🟩 Cretaceous sedimentary rocks
- 🟩 Franciscan Complex sedimentary and metamorphic rocks
- 🟪 Granitic igneous rocks, mainly of Mesozoic age
- 🟪 Serpentine and other ultramafic rocks
- 🟩 Mesozoic metamorphic and sedimentary rocks
- 🟦 Paleozoic sedimentary and metamorphic rocks
- 🟫 pre-Cambrian rocks
- —·· Fault, subsurface faulting shown as dotted lines
- — Contact between geologic units

Points of Interest

① Klamath Mountains

② Modoc Plateau

③ Wilder Ranch State Park (marine terraces)

④ Sierra Nevada

⑤ Mojave and Colorado Deserts

⑥ Thousand Palms Oasis

This geologic map of California shows the distribution, relationship, and composition of earth materials including rocks and surficial deposits–such as sediments and landslides–on the earth's surface. Each color on the map represents a different type or age of rock. Thick black lines represent the locations of faults. (CGS Map Sheet 57)

Oasis Preserve (CNLM, 2021), where you can find the only native species of palm trees in California, known as the California fan palm (*Washingtonia filifera*). This palm tree utilizes access to shallow groundwater and springs that are present due to faulting in the area, allowing it to flourish and provide shelter to the western yellow bat (*Lasurus xanthinus*), a California species of special concern (Ortiz and Barrows, 2014). The accessibility of the groundwater in this desert region is a direct result of the influence faults can have on groundwater flow.

In Northern California, active faults have uplifted marine terraces, resulting in what is referred to as an ***ecological staircase***. With each step-up in elevation of the terrace platforms, differing soil characteristics and nutrients reflect distinct periods of weathering and soil development that correspond with the tectonic uplift of the region (Schulz, 2018). Similarly, in desert regions where alluvial surfaces and sand dunes are actively forming, soil horizons are absent, and the soils present are typically made up of well-drained sands. However, over time, horizons will still develop and allow for moisture retention that is critical for supporting habitats in these moisture limited environments.

The Thousand Palms Oasis in the Coachella Valley Preserve is located within the San Andreas fault zone. The linear alignment of vegetation that extends beyond the Thousand Palms Canyon Road indicates the surface trace of the fault that has allowed groundwater to be redirected to the surface, providing palm trees with an adequate water supply and ample space for root growth. Photo: USDA 2018 NAIP Imagery

At Wilder Ranch State Park, near Santa Cruz, marine terraces formed by wave-cut platforms and sea cliffs represent ancient shorelines that have been uplifted due to slow-moving tectonic activity. In the background, another, even older terrace is visible along the horizon. These terraces may vanish over time as sea level rises, unless they are thrust upward by a powerful earthquake. For more information see CGS GeoGem Note 18. Photo: Mike Fuller, CGS

Parent Material, Soil and Ecology

The erosion rate of different parent rocks also plays a role in soil features. ***Lithology*** (rock type), age, and depositional environments have been shown to control soil texture, hydrology, vegetation morphology, root structure density, and plant community characteristics (Hamerlynck, 2002).

Texture and grain size contribute to the soil ***permeability***, or the ability of water to move through the soil to underlying layers or bedrock. Fine-grained soils typically have low permeability and retain water, whereas coarse-grained permeable soils tend to drain rapidly. These texture differences can affect the water transport and retention in root systems which can directly affect plant growth.

Studies have also shown that soils of different ages, deposit types, and with different horizon characteristics, affect the sizes, distributions, and ecophysiological responses of plants (Hamerlynck and others, 2002; Miller and others, 2009). Soil development progresses faster where there is geomorphic stability and on geologic units that are more easily weathered. As weathering occurs, the resulting soils are enriched with minerals from their parent rocks, forming a foundation for vegetation growth.

Darlingtonia californica has adapted to serpentine soils by trapping and decomposing insects to obtain nutrients. Photo: © Barry Rice, sarracenia.com

It's all about Chemistry: The Relationship Between Minerals and Soils

About 99.9% of the Earth's crust is comprised of only 10 chemical elements which are found in the minerals that make up various rock types around the globe. In California, there are over 600 minerals throughout the state, 50 of which that aren't found anywhere else in the world (Harden, 2004). Plants depend on the nutrients found in soils by the breakdown of minerals, however, not all minerals provide nourishing conditions.

Plants require large amounts of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), and potassium (K); moderate amounts of sodium (Na), zinc (Zn), and calcium (Ca); and very small amounts of molybdenum (Mo), cobalt (Co), and nickel (Ni) to thrive and grow (Marschner, 1995 *as cited in* Medeiros and others, 2015). The breakdown of minerals and their chemical components influence the available nutrients present in soil for plant development.

Ultramafic intrusive igneous and metamorphic rocks can weather into soils rich in magnesium (Mg), nickel (Ni), chromium (Cr), along with other heavy metals, and are typically low in nitrogen. Minerals rich in these elements are known as serpentine minerals, and unique metamorphic rocks rich in these minerals are called ***serpentinite***. In the Klamath Mountains of Northern California, soils containing these characteristics are called ***serpentine soils*** and are a staple for the region (purple on the geologic map on page 4). The chemical composition of serpentine soils can alter cell membranes and reduce root growth resulting in ***pygmy***, or stunted, plants. This can be observed in Jeffrey pine trees (*Pinus jeffreyi*) that inhabit serpentine soils.

Other plants have adaptive qualities which allow them to thrive in the nitrogen-poor serpentine soils, such as the rare carnivorous California pitcher plant (*Darlingtonia californica*). Found in serpentine wetland communities, the California pitcher catches and decomposes insects to obtain its needed nitrogen. The distribution of these soils also plays a role in the plant speciation process. Since not all plants can grow or thrive on serpentine soils, these characteristics facilitate geographic isolation causing the inhabitants to be reproductively isolated (U.S. Forest Service, 2020).

Soils, Habitats, and Species . . . Oh My!

On landscapes where igneous rocks are resistant to erosion, soils can be poorly developed. Igneous rocks of California are predominantly concentrated in the northeast corner of the State in the Modoc Plateau and Cascade Range provinces but are also seen in the Sierra Nevada and portions of the Mojave Desert (red and pink on the geologic map of California). Despite being nearly absent of soil, young basaltic rocks found in Northern California can still host vegetation, like the Modoc cypress (*Hesperocyparis bakeri*). In the eastern Sierra Nevada, the Whitebark pine (*Pinus albicaulis*) also flourishes on poorly developed and well drained soils derived from granitic or basaltic bedrock (Tilley and others, 2011). As one of its main sources of food, the Clark's nutcracker (*Nucifraga columbiana*) depends on the Whitebark pine; while in turn, the Whitebark pine relies on the nutcracker's strong beak to extract the seeds found inside its very hard pinecones. The nutcracker stores the seeds in food stashes across the region with the intent of revisiting their supply later. However, if the nutcracker leaves the seeds behind, the Whitebark pine can ***germinate*** (begin to grow) and establish itself in the rough landscape (Tilley and others, 2011).

In the Sierra Nevada, the California Black Oak (*Quercus kelloggii*) can inhabit steep slopes with thinner soil development (UCANR, 2015). On the western slope of the Sierra Nevada in central California, the ***endemic*** (native) giant sequoia trees, *Sequoiadendron giganteum*, are found in the moisture and temperature gradients that occur at elevations between 4,600 and 7,100 feet above sea-level (Weatherspoon, 1990). Here, the optimum soil moisture is provided by the sandy soil textures from glacial outwash, residual, and alluvial soils comprised primarily of granitic sources. (Habeck, 1992).

Sequoiadendron giganteum are the largest trees in the world. Photo: National Park Service

The Mojave and Colorado deserts, in the southeast portion of California, are home to the endemic Joshua trees (*Yucca brevifolia*) and Mojave yuccas (*Yucca schidigera*) which are found concentrated in the Joshua Tree National Park. Across these desert regions, significant differences exist between the size and density of the Creosote bush (*Larrea tridentata*) on varying sedimentary deposits. When inhabiting older soils with distinct horizonation, the finer-textured and deeper soils horizons limit root growth of the Creosote bush to shallow depths resulting in bush heights of less than 3 feet tall (<1 meter). However, when occupying well-drained sands on geologically young deposits with little or no soil horizons, the Creosote bush thrives and can grow up to 9 feet (3 meters) high (Miller and others, 2009). The extensive distribution of Creosote bush across the Mojave Desert provides habitats for other living organisms. Lizards, tortoises, and kangaroo rats often seek refuge below this bush, but for the desert woodrat the Creosote bush is a dominant source of its diet (Marshall, 1995).

An active wind-blown sand sheet encroaches upon the creosote bush at left, Chuckwalla Valley, Mojave Desert. Photo: Jeremy Lancaster, CGS

Soil Processes and Change

As tectonic, erosional, and depositional processes continue in the future throughout California, the landscape and habitats we know today will change. Although the geologic processes move slowly relative to human life, impacts made by humans are resulting in drastic and visible changes in the state. As the number and size of wildfires increase, soil erosion and deposition will have profound effects on watershed ecology. As sea level rises, erosion of the iconic California Coast and changes in the base level, will disrupt our coastal and inland watersheds. Existing coastal estuaries, soils, and plant communities will be consumed by sea water, causing estuaries to migrate inland and create significant adjustments to erosion and deposition in river systems. However, just as in the past, California's unique ecology will again adapt to the dynamic geologic processes and underlying geologic framework.

Addenda

Visit conservation.ca.gov/cgs/publications/cgs-notes for the following addenda:

- References used in the development of CGS Note 56
- Authorship Documentation for CGS Note 56

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AUTHORSHIP DOCUMENTATION

PUBLICATION TITLE: Geology, Soils, and Ecology: How Geology Influences Soil Development and Ecosystems in California
CGS Note 56

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This authorship document accompanies CGS Note 56 with the following citation:

Valencia, F.N., Lancaster, J.T., 2022, Geology, Soils and Ecology: How Geology Influences Soil Development and Ecosystems in California, CGS Note 56. Department of Conservation, California Geological Survey, 8 pp.