Serpentinite and Serpentine in California

Wildflowers on serpentinite in Garden Valley area, El Dorado County. Serpentinite is well-known among botanists for its support of unique and rare plant species. Photo: Chris Higgins, CGS.

Serpentinite… a rock admired for its attractive appearance and of concern because of its potential to contain asbestos, a known carcinogen. Besides these properties, it has many other unusual characteristics.

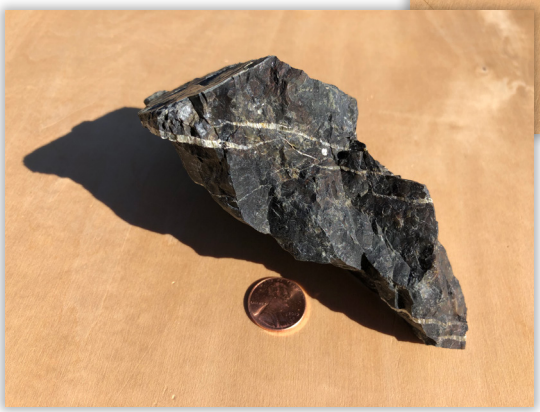
"Serpentine" is the official State Rock of California.

"Serpentinite" or "serpentine?" In 1965, the California State Legislature and Governor designated "serpentine" as the official State Rock. Geologists today, however, classify "serpentine" as a group of minerals and "serpentinite" as a metamorphic rock. The former comprises most or all of the latter. The words "serpentinite" and "serpentine" are derived from the Latin word "serpentinus" ("resembling a serpent") because of the rock's mottled color and scaly texture.

Physical and Chemical Properties of Serpentinite and Serpentine

The color of fresh serpentinite is most commonly shades of green but can also be yellow, black, blue-green, and gray, among others. When strongly weathered, the soils generated from serpentinite are commonly shades of red. The rock forms structureless masses that exhibit waxy or greasy luster, or silky luster when fibrous in texture. The density of serpentinite ranges from about 2.4 to 2.6 grams per cubic centimeter. Because it often contains the iron-bearing mineral magnetite, serpentinite can have magnetic properties that affect compass readings. This property also is useful for recognition of serpentinite in the subsurface by geophysical instruments. Chromium, nickel, and cobalt are also present, inherited from the parent rock of the serpentinite.

Right: Serpentinite with typical mottled grayish-green color and greasy luster. The luster results from intense shearing of the rock. Penny for scale. Photo: Chris Higgins, CGS.



Left: Veinlets of chrysotile asbestos in partially serpentinized ultramafic rock. When properly oriented in sunlight, the veinlets exhibit silky luster and cross-fiber texture. Penny for scale. Photo: Chris Higgins, CGS.

Serpentine actually is the name for a group of many distinct minerals.

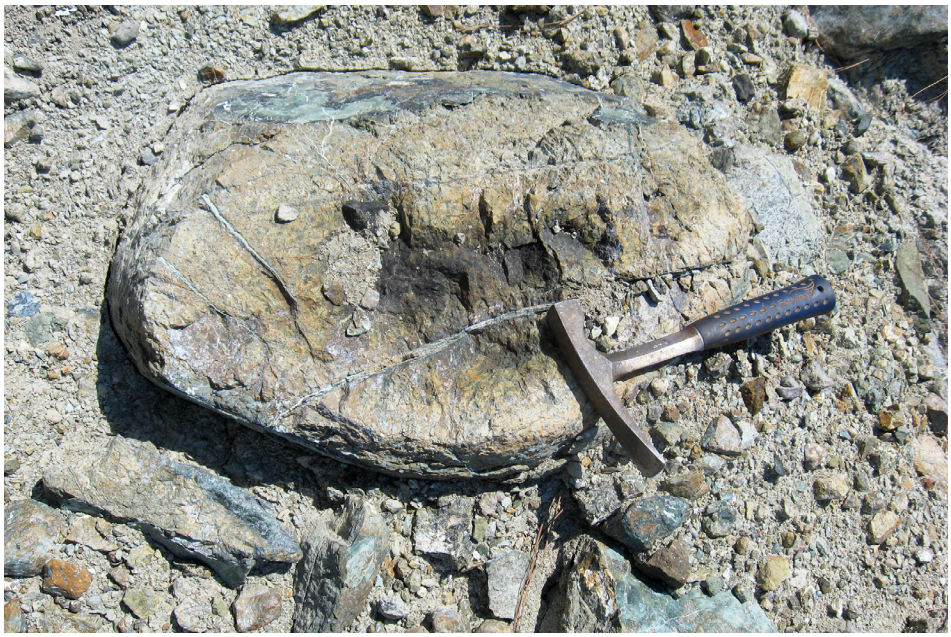
Serpentine actually is the name for a group of many distinct minerals, the most common of which are lizardite, antigorite, and chrysotile. Of these three, lizardite is believed to be the most abundant in nature and chrysotile the least abundant. The general chemical formula for these three is $Mg_3Si_2O_5(OH)_4$. Lizardite and antigorite are platy in structure, although fibrous antigorite is reported in some places. Chrysotile forms as fibers and is a member of the asbestos group, which is a commercial term for six regulated fibrous minerals. Depending on variation in their chemical compositions, the hardness of serpentine minerals ranges from about 3 to 6 on the Mohs scale.

Serpentinite may actually reduce the likelihood of large earthquakes along some faults. Because of the weak sheet-like crystal structure of its most common component minerals, serpentinite, along with talc and certain types of clays, may lessen friction between rocks, thus enabling "creep." Creep is the slow, continuous slippage of rocks along a fault.

Genesis and Distribution of Serpentinite in California

Geologists believe most serpentinite forms chemically by alteration, or "serpentinization," of rocks that originated in the Earth's mantle. These "ultramafic" rocks are composed dominantly of the minerals olivine and pyroxene, which are rich in magnesium and iron, thus the rocks are very dense. During serpentinization, hot water from various sources can react with the olivine and pyroxene to produce serpentine minerals. A simplified example of the chemical reaction that produces the mineral serpentine from one form of olivine is:

$3Mg_2SiO_4$	+	SiO_2	+	$4H_2O$	→	$2Mg_3Si_2O_5(OH)_4$
Olivine		**Silica**		**Water**		**Serpentine**



Boulder of partially serpentinized ultramafic rock in serpentinite-matrix mélange along State Highway 20, Colusa County. Note the roundness of the boulder and other fragments of serpentinite. Veinlets of asbestos are above the head of the hammer. Rock hammer is about one foot long. Photo: Chris Higgins, CGS.

This conversion increases the volume of the rock and also reduces its density, such that it can rise buoyantly through the Earth's crust, particularly along faults. The rock's typically highly-fractured character also aids this upward movement. Serpentine minerals can also form in non-ultramafic rocks. One example is when metamorphosed dolomite (a magnesium-bearing carbonate rock) is altered by hot silica-bearing waters. There is evidence that serpentinization is still active in some on-land ultramafic rocks around the world including the Coast Ranges of California.

The hardness of serpentine minerals ranges from 3 to 6 on the Mohs scale.

Serpentinite forms and is emplaced in many different types of geologic settings. Many bodies of serpentinite have a long and complex history, which, when combined with missing evidence in the rock record due to erosion, often makes it difficult for geologists to determine how these bodies formed and how they were deposited in the places we see them today. These settings range from spreading ridges in the deep ocean ("abyssal" type) to those where forces in the Earth cause tectonic plates to collide causing one plate to descend beneath the other ("subduction-zone" type). The abyssal type results from hot seawater reacting with ultramafic rock of the upper mantle in the Earth's lithosphere. In some subduction-zone settings, fluids rising from the descending plate serpentinize the ultramafic rock in that part of the overriding plate termed the "mantle wedge." Because of its lower density, some of this serpentinite can rise buoyantly along faults in the overriding plate to erupt on the ocean floor as serpentinite "mud volcanoes." Such volcanoes are currently erupting above the Mariana subduction zone in the western Pacific Ocean. In some subduction-zone environments, heavy serpentinite-bearing oceanic rocks have actually overridden, rather than descended beneath, the rocks of

the opposing plate in a process called “obduction.” Where these oceanic rocks are exposed on land today, they are called “ophiolites.” Several large masses exposed in California are of this type.

Serpentinite is commonly associated with a type of rock known as “mélange.” A mélange is a chaotically mixed mass of rock that contains blocks and fragments of rock of all sizes embedded in a fragmental matrix of finer-grained material. A mélange can form by sedimentary or tectonic processes, sometimes both if the mélange has undergone a long history of development. Some mélange has a matrix composed entirely of fragments of serpentinite that encloses blocks of serpentinite and other types of rock.

Serpentinite and partially-serpentinized ultramafic rock are distributed widely in California, dominantly in the Klamath Mountains, Coast Ranges, and lower elevations of the Sierra Nevada (see map on next page). Small areas of serpentine skarns are also present in the southeastern part of the state. Serpentinite is commonly found along fault zones, emplaced by “protrusion” of solid masses of the rock, rather than as hot igneous intrusions. In places where such serpentinite is exposed on top of hills, geologists have interpreted that some of the serpentinite later flowed downslope, not as landslides but like debris flows or lava flows. Serpentinite also occurs as isolated blocks and slabs within tectonic and sedimentary mélange, and as the matrix of some mélange. Geologists believe that some of these serpentinite-matrix mélanges were deposited rapidly as sediments on the ocean floor by submarine landslides or turbidity currents or by the eruption of serpentinite mud volcanoes. They may be a more common type than is currently recognized.

Serpentinite is commonly associated with a type of rock known as “mélange.”

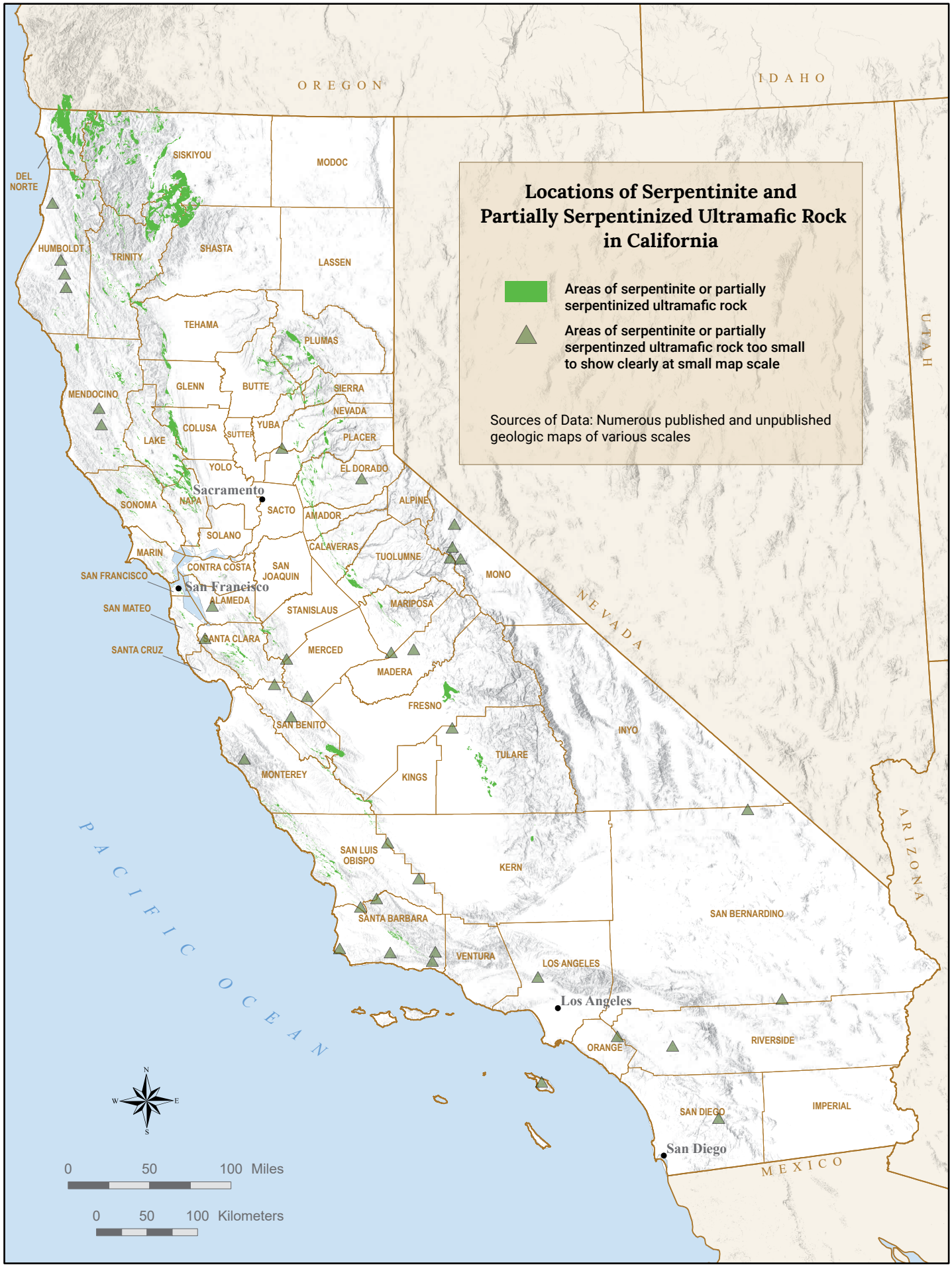
Alteration of Serpentinite

Serpentinite can be altered to other types of rock, some of which can contain valuable mineral deposits. One example is silica-carbonate rock, which forms when serpentinite is invaded by hot water that contains dissolved silica and carbon dioxide (CO_2). Such rock is a common host of mercury deposits in the Coast Ranges of California. A similar alteration product is mariposite rock, which is found in the Mother Lode belt of the Sierra Nevada foothills. It has been used as decorative rock and also contains gold in places. Alteration of serpentinite has also produced deposits of magnesite ($MgCO_3$) and talc (soapstone) through the following chemical reaction:

$$\underset{\text{Serpentine}}{2Mg_3Si_2O_5(OH)_4} + \underset{\text{Carbon Dioxide}}{3CO_2} \rightarrow \underset{\text{Magnesite}}{3MgCO_3} + \underset{\text{Talc}}{Mg_3Si_4O_{10}(OH)_2} + \underset{\text{Water}}{3H_2O}$$

Serpentinite and the Origin of Life on Earth

Many scientists who have studied how life first formed on Earth have proposed that serpentinization contributed to this beginning. They suggest that the serpentinization we see today at and below the ocean floor is similar to what may have provided some of the essential chemicals and conditions to form


Locations of Serpentinite and Partially Serpentinized Ultramafic Rock in California
Areas of serpentinite or partially serpentinized ultramafic rock
Areas of serpentinite or partially serpentinzed ultramafic rock too small to show clearly at small map scale
Sources of Data: Numerous published and unpublished geologic maps of various scales
OREGON
IDAHO
NEVADA
UTAH
ARIZONA
MEXICO
PACIFIC OCEAN
DEL NORTE
SISKIYOU
MODOC
HUMBOLDT
TRINITY
SHASTA
LASSEN
TEHAMA
PLUMAS
MENDOCINO
GLENN
BUTTE
SIERRA
NEVADA
COLUSA
SUTTER
YUBA
PLACER
LAKE
YOLO
EL DORADO
Sacramento
SONOMA
NAPA
SACTO
AMADOR
ALPINE
SOLANO
CALAVERAS
MARIN
CONTRA COSTA
SAN JOAQUIN
TUOLUMNE
MONO
SAN FRANCISCO
San Francisco
ALAMEDA
MARIPOSA
SAN MATEO
STANISLAUS
SANTA CLARA
MERCED
SANTA CRUZ
MADERA
FRESNO
SAN BENITO
INYO
TULARE
MONTEREY
KINGS
SAN LUIS OBISPO
KERN
SAN BERNARDINO
SANTA BARBARA
VENTURA
LOS ANGELES
Los Angeles
ORANGE
RIVERSIDE
SAN DIEGO
IMPERIAL
San Diego
N
W
E
S
0 50 100 Miles
0 50 100 Kilometers

the first organisms billions of years ago. Today, extension of the Earth's crust at the spreading centers along mid-ocean ridges allows seawater to circulate downward into the crust along faults, become heated, and react with ultramafic rock to produce serpentinite. These hydrothermal fluids in places carry hydrogen and methane from the serpentinization process and rise to erupt from vents on the seafloor as "white smokers." These lower-temperature alkaline fluids have deposited unusual towers of calcium carbonate that support various organisms including primitive microbes. The organisms use the hydrogen and methane to create organic matter in a process called "chemosynthesis." The active Lost City Hydrothermal Field adjacent to the Mid-Atlantic Ridge in the Atlantic Ocean is an example of a white-smoker environment.

Vegetation on Serpentinite

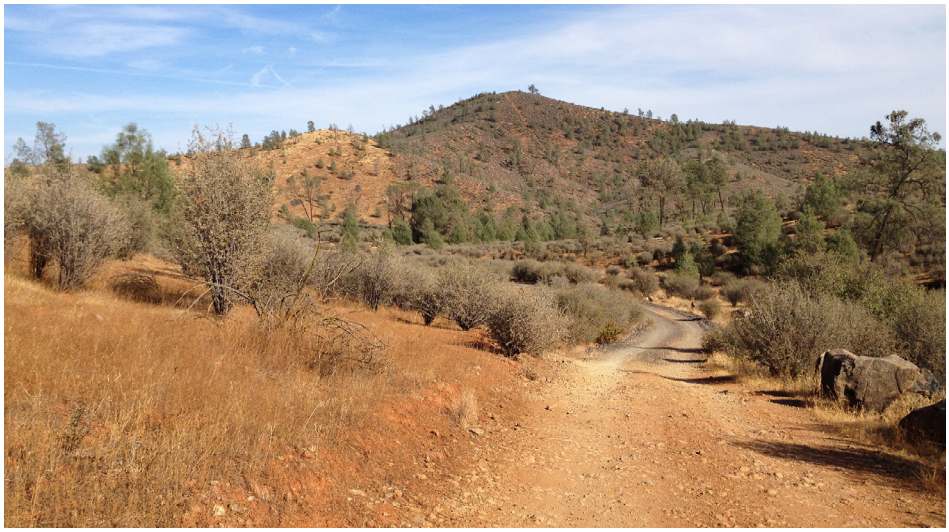
Distinctive types of vegetation populate areas of serpentinite and are often useful in distinguishing this rock from surrounding non-serpentinite terrain. Commonly, vegetation is sparse and stunted, which creates a "barrens" type of landscape. Although local climate has some effect, these characteristics are mainly a result of the properties of the soils derived from the serpentinite. The soils are typically poorly developed, contain high magnesium and other metals that can be toxic to many plants, and are deficient in calcium, nitrogen, and phosphorus. Many plant species are unique to serpentinite and some are endemic to California. Several preserves and natural areas for research have been established in the state to protect and study this unique vegetation.

Many plant species are unique to serpentinite.

Uses of Serpentinite

Serpentinite in California has been the source of several mineral commodities. By far, the most important has been chrysotile asbestos. Although this commodity is no longer mined in the state, California was the largest producer of asbestos in the United States. Other commodities produced include chromite (an ore of chromium); gold, magnesite, mercury, and talc (soapstone) in altered serpentinite; and various rock products. The latter have been used as aggregate, decorative rock/ornamental stone, and more rarely as gemstones and carvings. When used in construction of nuclear power plants, serpentinite functions as a neutron-radiation shield because of its high water content. Although not yet produced in California, nickel and cobalt are enriched in strongly weathered areas of serpentinite and partially serpentinized ultramafic rock in places. Serpentinite and ultramafic rock are important sources of the platinum-group elements; in California, however, these elements have been produced only from placer deposits derived from such rocks.

Agricultural activity on serpentinite terrain is generally very limited mainly because of the poor soil for growth of crops and forage for livestock. Consequently, many of these terrains have remained as public lands administered by the federal government. Attempts have been made to enhance the soil properties to make them more productive, but these generally are not effective or economical. Some wineries in California have planted vineyards on serpentinite soils.



Red Hills, Tuolumne County, which are designated as an Area of Critical Environmental Concern mainly because of rare plant species supported by the serpentinite soils. The sparse vegetation and reddish color are typical of terrain underlain by serpentinite. Photo: Chris Higgins, CGS.

Because many areas of serpentinite are public lands, they are used for recreation such as camping, hiking, hunting, mineral collecting, and off-highway vehicle activities. The Clear Creek Management Area, managed by the U.S. Bureau of Land Management, in the central Coast Ranges is an example.

Researchers have been investigating serpentinite as a potential underground repository for sequestration of waste CO_2 from the burning of fossil fuels. Similar to the chemical process that forms magnesite described earlier, CO_2-bearing fluid is injected into fractured serpentinite where it reacts with the rock to form carbon-bearing minerals. This process has not been applied on a commercial scale in the U.S., although government agencies and academic groups have been investigating possible pilot studies in California.

Potential Issues in Serpentinite Areas

There are several potential issues related to public health and safety concerning serpentinite. Most prominent are slope stability and the natural presence of asbestos and several potentially toxic elements in the rock.

Because of its sheared and fractured character and its ability to retain water, serpentinite is highly susceptible to landslides, particularly along roads. Mountainous areas with high precipitation are most vulnerable. Although irregularly distributed in serpentinite, asbestos, dominantly in the form of chrysotile, is a known carcinogen in humans. Tremolite asbestos and actinolite asbestos are also known in some bodies of serpentinite. If undisturbed, these minerals are generally not harmful, but if continually disturbed by dust-generating conditions and activities, such as windstorms, excavation, or by vehicles traveling over serpentinite-covered roads, prolonged exposure may produce disease in some people. Finally, the presence of elevated amounts of several metals in serpentinite can be detrimental to human health. These metals include chromium, nickel, cobalt, and, in some bodies of altered serpentinite, mercury.

Asbestos, a known carcinogen in humans, is irregularly distributed in serpentinite.

Serpentinite along State Highway 128 near Lake Hennessey, Napa County. The mottled green and gray coloring is typical of serpentinite in California. The abundant fracturing and shearing in serpentinite commonly lead to rockfalls. Rock hammer is about one foot long. Photo: Chris Higgins, CGS.

To download this Note with Authorship Documentation attached, visit conservation.ca.gov/cgs/publications/cgs-notes

Additional Reading

1. Faust, G.T. and Fahey, J.J., 1962, The Serpentine-Group Minerals: U.S. Geological Survey Professional Paper 384-A, 92 p.
2. Krevor, S.C., Graves,C.R., Van Gosen, B.S., and McCafferty, A.E., 2009, Mapping the mineral resource base for mineral carbon-dioxide sequestration in the conterminous United States: U.S. Geological Survey Data Series 414, 14 p.
3. Kruckeberg, A.R., 1984, California Serpentines: Flora, Vegetation, Geology, Soils, and Management Problems: University of California Publications in Botany, v. 78, 180 p.
4. O'Hanley, D.S., 1996, Serpentinites: Records of Tectonic and Petrological History: Oxford University Press, 296 p.
5. Trumbo, S., 2014, From geology to biology: A serpentine story of early life: Small Things Considered Blog (access at https://schaechter.asmblog.org/schaechter/2014/03/from-geology-to-biology-a-serpentine-story-of-early-life.html).
6. Van Gosen, B.S. and Clinkenbeard, J.P., 2011, Reported historic asbestos mines, historic asbestos prospects, and other natural occurrences of asbestos in California: California Geological Survey Map Sheet 59, 22 p., one plate.
7. Wakabayashi, J. 2017, Serpentinites and serpentinites: Variety of origins and emplacement mechanisms of serpentinite bodies in the California Cordillera: Island Arc, v. 26, no. 5, 14 p. (access at https://onlinelibrary.wiley.com/doi/pdf/10.1111/iar.12205)

Visit us on on the world wide web and social media:

www.conservation.ca.gov/cgs twitter: @cageosurvey instagram: @cageosurvey

cgs-note-57-serpentinite-and-serpentine-v1 04-07-23 16:19 rwurgler

AUTHORSHIP DOCUMENTATION AND PRODUCT LIMITATIONS

PUBLICATION TITLE: CGS NOTE 57 Serpentinite and Serpentine in California

LIMITATIONS: The California Department of Conservation makes no warranties as to the suitability of this product for any given purpose. This note should not be considered as an authoritative or comprehensive source for serpentinite and serpentine data.
For more information on serpentinite and serpentine, please visit the California Geological Survey Mineral Hazards web page at:
https://www.conservation.ca.gov/cgs/minerals/mineral-hazards

Author – Chris T. Higgins PG 3694 (CGS retired)

Brenda L. Callen
Brenda L. Callen

Date: 31 August 2022

This authorship document accompanies CGS Note 57 with the following citation:

Higgins, C.T., 2022, CGS NOTE 57 Serpentinite and Serpentine in California, California Geological Survey.