GEOLOGY OF SERPENTINE AND RELATED ULTRAMAFIC ROCKS

Serpentinite is California's state rock!

LITHOLOGY AND MINERALOGY

Ultramafic rocks like serpentinite, dunite, and peridotite have in common some form of ferromagnesian silicate mineral. Such rocks occur on every major landmass of our planet, in local outcrops or as extensive regional displays. In western North America, the three Pacific coast states and the Canadian province of British Columbia have both local and massive occurrences of ultramafics—California with 1100 sq. mi. (2860 km^2), Oregon with 450 sq. mi.(1170 km^2), and Washington with 200 sq. mi. (520 km^2). The chief constituent, some mineralogical variant of iron–magnesium silicate, gives ultramafic rocks their chemical and physical character and is very likely the major cause of the consequent biological properties of the outcrop.

In the Coast Ranges the ultramafics are largely serpentinite (see fig. 1), derived from ophiolites[1] of Mesozoic Age and companion to the vast and complex Franciscan sedimentary rocks. In the Sierran foothills, serpentinite is usually associated with sedimentary and volcanic rocks (ophiolites) older than the granitics of the Nevadan orogeny—the great series of intrusions that made the granitic Sierra Nevada. Though much disputed earlier in this century, there is now substantial agreement as to how the serpentinite invaded the sedimentary rocks. For Franciscan-associated serpentinites, Norris and Webb (1976, p. 253) state:

> All these Franciscan rocks have been intruded by ultrabasic igneous rocks, now serpentinized peridotite (serpentinite). Sometimes the serpentinites have been injected as normal molten intrusives, but in other instances they occur in sill-like sheets that lack the thermal alteration of enclosing rocks expected in most sills. In still other cases, these plastic serpentinites have squeezed up through the overlying rocks as plugs or diapirs [injections by a mobile core of a brittle overlying rock]. The prevailing view is that these serpentinized peridotites are altered masses derived from the upper mantle and transferred tectonically to the earth's surface.

R.G. Coleman, an authority on ultramafic geology, takes exception (personal communication) to portions of Norris and Webb's explanation. Rather than intrusion, Coleman uses the term "tectonic emplacement" to account for the appearance of ultramafics in Franciscan rocks. He also modifies Norris and Webb's last sentence above on mode of emplacement, to:

1 *Ophiolite*: An assemblage of mafic to ultramafic rocks of the oceanic crust and upper mantle (Coleman, 1977).

Kruckeberg, A.R. 1984. California Serpentines. UC Press

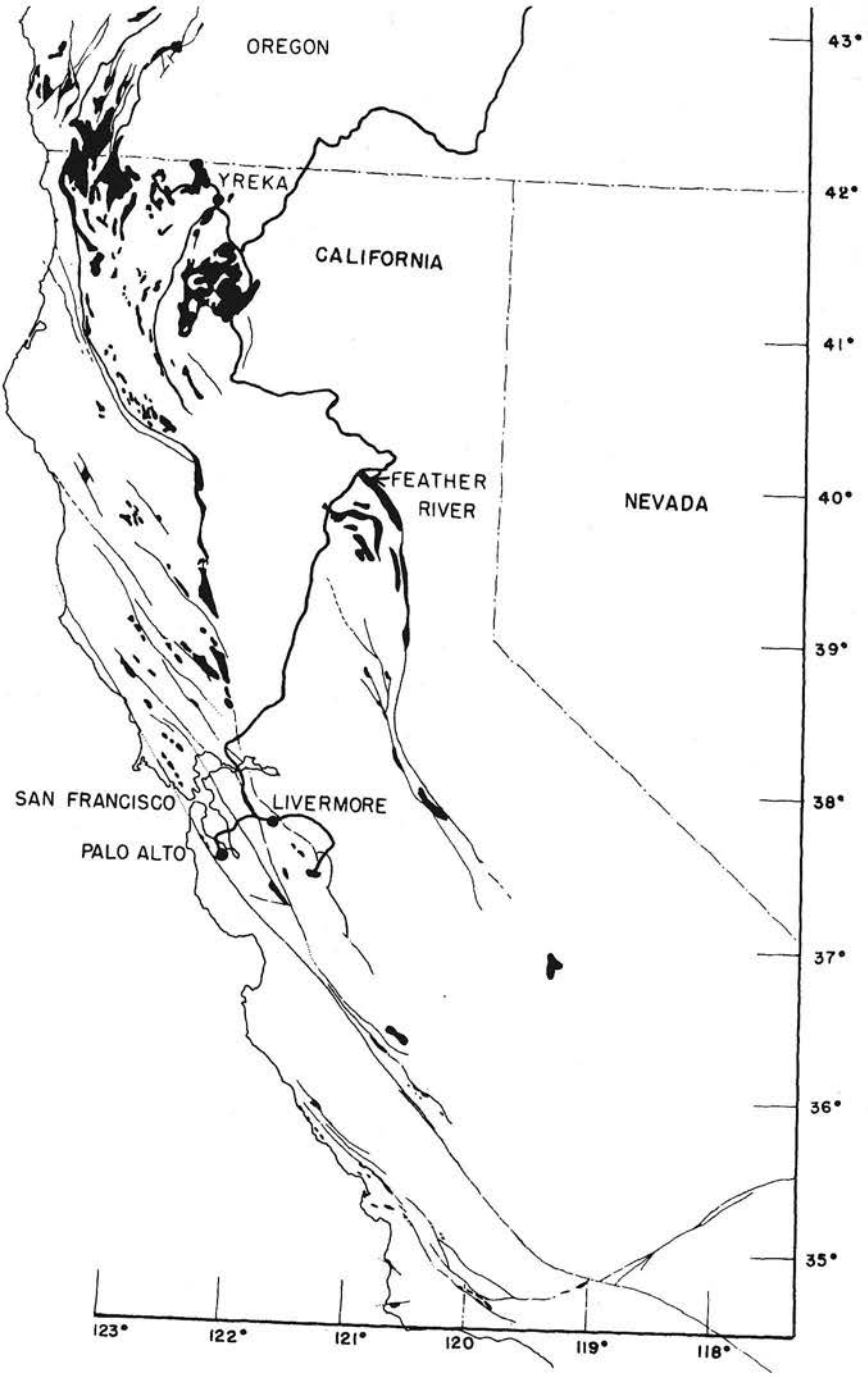


FIG. 1. Map of serpentine occurrences in California and Oregon. 1 cm = 55 km. (Courtesy of R. Coleman.)

Kruckeberg, A.R. 1984. California Serpentines. UC Press

" . . . serpentinized peridotites are altered ophiolites derived from the oceanic lithosphere and transferred tectonically to the continental margin."

Serpentinite and other ultramafic rocks tend to be associated with extensive southeast-to-northwest-trending fault zones (fig. 1) in both the cismontane Sierra Nevada foothills and the Coast Ranges. It now seems quite certain that both the faulting patterns and ultramafic intrusion are structurally associated with crustal movements (plate tectonics), as the ultramafic mantle of the oceanic crust moves under the continental crust. Ultramafics thus emerge at the margins of oceanic and continental plates.

Less common than the metamorphic rock serpentinite are the outcrops and intrusions that remained unaltered (igneous). Dunite, hartzburgite, and especially peridotite, three common igneous ultramafic rocks, are more abundant in the Klamath–Siskiyou region— the Mt. Eddy massif (Siskiyou County) and the adjacent mountainous terrain are largely peridotite.

The main mineral constituent of igneous ultramafic rocks is olivine: $(Mg,Fe)_2SiO_4$. But several other mineral types, such as chromite and pyroxene can occur in igneous ultramafics (Wyllie, 1967). The ultramafic rock serpentinite contains members of the serpentine-group minerals (Faust and Fahey, 1962) that are formed anew during metamorphosis: chrysotile (or asbestos), lizardite, and antigorite are the most prevalent of these minerals. No new elements absent in the parent igneous ultramafics are added; however, there may be some gain or loss of silica, magnesium, calcium, iron, or carbon dioxide. At the contact zones between igneous and metamorphic ultramafics, reaction-zone mineralization can take place. Coleman (1967) refers to the occurrence of rodingite at such contact zones; though recorded here in California, the phenomenon may be worldwide in occurrence (rodingite derives its name from its type locality in New Zealand). That rodingite is rich in calcium silicate minerals is significant in tracking the path of serpentine-tolerant plants across such a contact.

It is well to emphasize the rather wide range of variation in kind and amount of elemental and mineralogical constituents of ultramafic rocks, as well as the frequent occurrence of "contaminants" along contact zones. The consequences of this variation become apparent when ultramafics weather; the soils will invariably contain more than iron and magnesium silicates. Besides iron, magnesium, and silica, both soils and rocks of the ultramafic clan can contain elements such as calcium, aluminum, nickel, chromium, and magnesium, either in trace amounts or at more substantial concentrations (Faust and Fahey, 1962; Robinson, Edgington, and Byers, 1935).

Of great importance to the botanist is the geological timespan during which ultramafic deposits have been at the surface, available to plant colonization. Authors on California serpentinites differ on this matter. Coleman (1967, p. 5) states that "The presence of detrital serpentine debris within Mesozoic and Tertiary sedimentary rocks of California attests to the long exposure of ultramafic rocks at the surface." This implies their continued availability to plant life through the Tertiary. But Raven and Axelrod (1978) give a more recent time frame: they suggest that continuous exposure began in the Miocene for some localities, and for other areas in California came as late as the Pleistocene. Naturally such different time periods for exposure have to be considered when postulating the biological event of colonization on serpentine.

DISTRIBUTION OF ULTRAMAFIC OUTCROPS IN CALIFORNIA

Serpentinites and other ultramafic rocks occur in many places in California, from Santa

Kruckeberg, A.R. 1984. California Serpentines. UC Press

Barbara County to the Oregon border in the Coast Ranges and intermittently along the western foothills of the Sierra Nevada from Tulare to Plumas counties (fig. 2). I know of only one isolated outcrop south of Santa Barbara County, in the Santa Ana Mountains of Orange County (Vogl, 1973).

The following summary of serpentinite distribution in California (and southwestern Oregon) is taken from separate area sheets of the Geologic Map of California (California Div. of Mines and Geology, 1958–1967). The Fresno and Santa Rosa sheets illustrate well the elongate, south-to-north pattern of the outcrops noted above. (A more detailed account of the geography of serpentinite localities is given in Appendix A.)

South Coast Ranges

Going from south to north, the first substantial serpentine outcrops are encountered in the Figueroa Mountain area of the San Rafael Mountains in Santa Barbara County. The next areas of significance are in San Luis Obispo County, near the coast and inland at the eastern end of the Carrizo Plain. From here northward in the south Coast Ranges to the San Francisco Bay Region, serpentinite outcrops with great frequency. The most impressive of these outcrops are in the inner south Coast Ranges of San Benito County, notably in the New Idria barrens and San Benito Peak (1597 m altitude). (See figs. 3 and 4 for historic views of the area.)

San Francisco Bay Region

Serpentines are rather common in the Bay Region. They include the Crystal Springs area of San Mateo County, the Presidio within the city of San Francisco, and areas in the Oakland–Berkeley hills. Many of these outcrops are obscured by human development.

North Bay Counties (Marin, Sonoma, and Napa counties)

Here serpentines begin at sea level (Angel Island, Tiburon Peninsula) and can reach nearly to the summit of such peaks as Mt. Tamalpais and Mt. St. Helena. Although both local and extensive ultramafics are found in the southern sector of the region, the most spectacular and botanically rich outcrops are farther north, in northern Sonoma and Napa counties (figs. 5 and 6).

North Coast Ranges (Lake and Mendocino counties north to Josephine and Curry counties of southwestern Oregon)

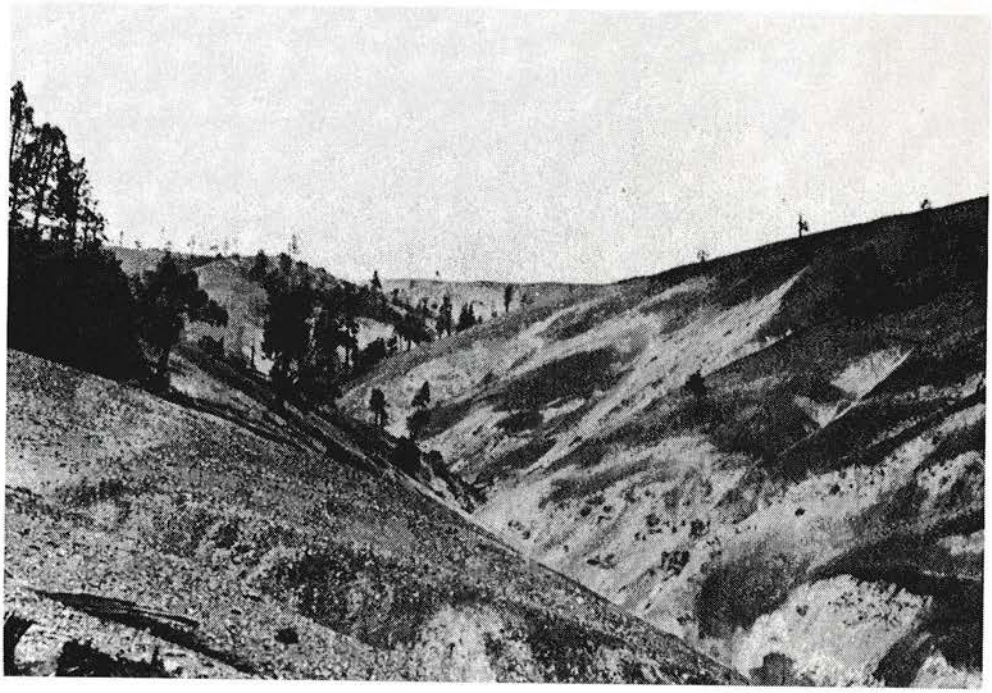
From the arid foothills bordering the western edge of the Sacramento Valley to the fog belt of the coastal redwood region, serpentines outcrop with great frequency (figs. 7 and 8). The Klamath–Siskiyou mountains to the north have the largest ultramafic outcrops in the state, indeed in North America. From arid to mesic, from low elevation (Gasquet, Del Norte County) to the summits of the highest peaks (Mt. Eddy, 9038 ft. (2755 m), Dubakella Mountain, 5891 ft. (1796 m), and Preston Peak, 7310 ft. (2229 m), there is an ultramafic outcrop (either igneous or metamorphic) for nearly every kind of terrain and exposure in northwestern California.

Kruckeberg, A.R. 1984. California Serpentines. UC Press



FIG. 2. Distribution of serpentine outcrops in California by county. 1 cm = 71 km. (With permission, California Division of Mines and Geology.)

Kruckeberg, A.R. 1984. California Serpentines. UC Press





FIGS. 3 and 4. Views of the stark, barren serpentine outcrops of the New Idria area, San Benito County. (Photos by A.E. Wieslander on May 7, 1932, courtesy of Pacific Southwest Forest and Range Experiment Station, U.S. Forest Service). Comparison with the view of the same area taken many years later (see upper photo of frontispiece), reveals little change in the barren scene.

Kruckeberg, A.R. 1984. California Serpentines. UC Press

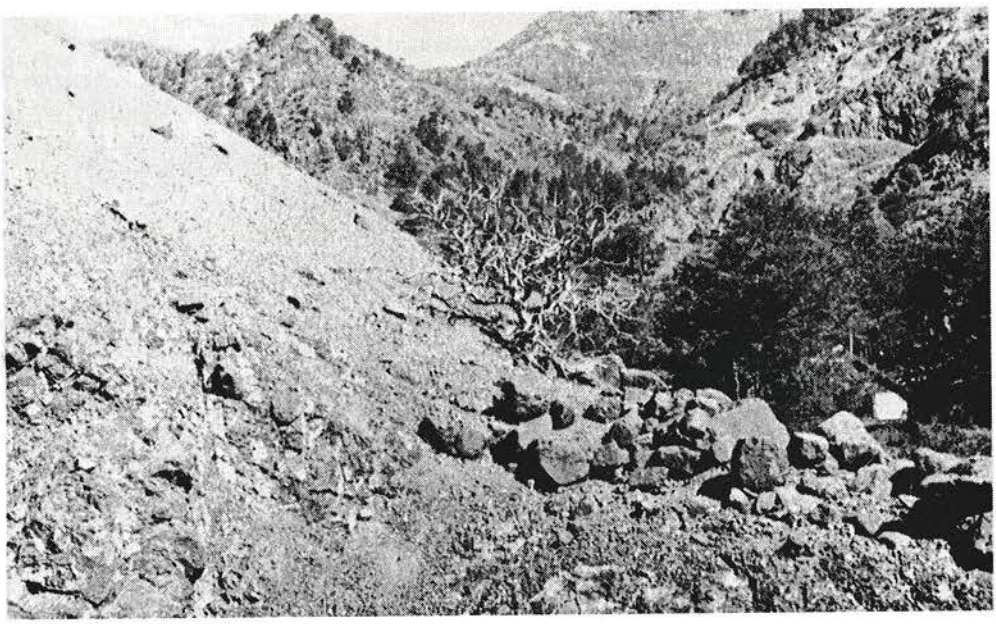


FIG. 5. Massive serpentine outcrop in the vicinity of the Layton Mine, upper east Austin Creek, Sonoma County.

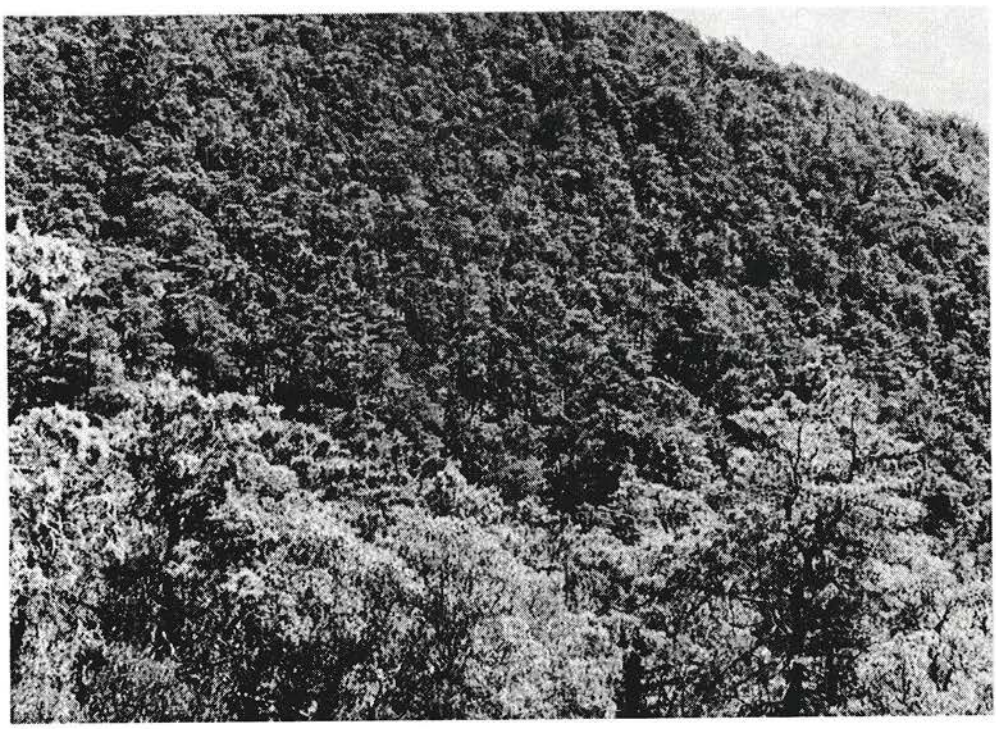
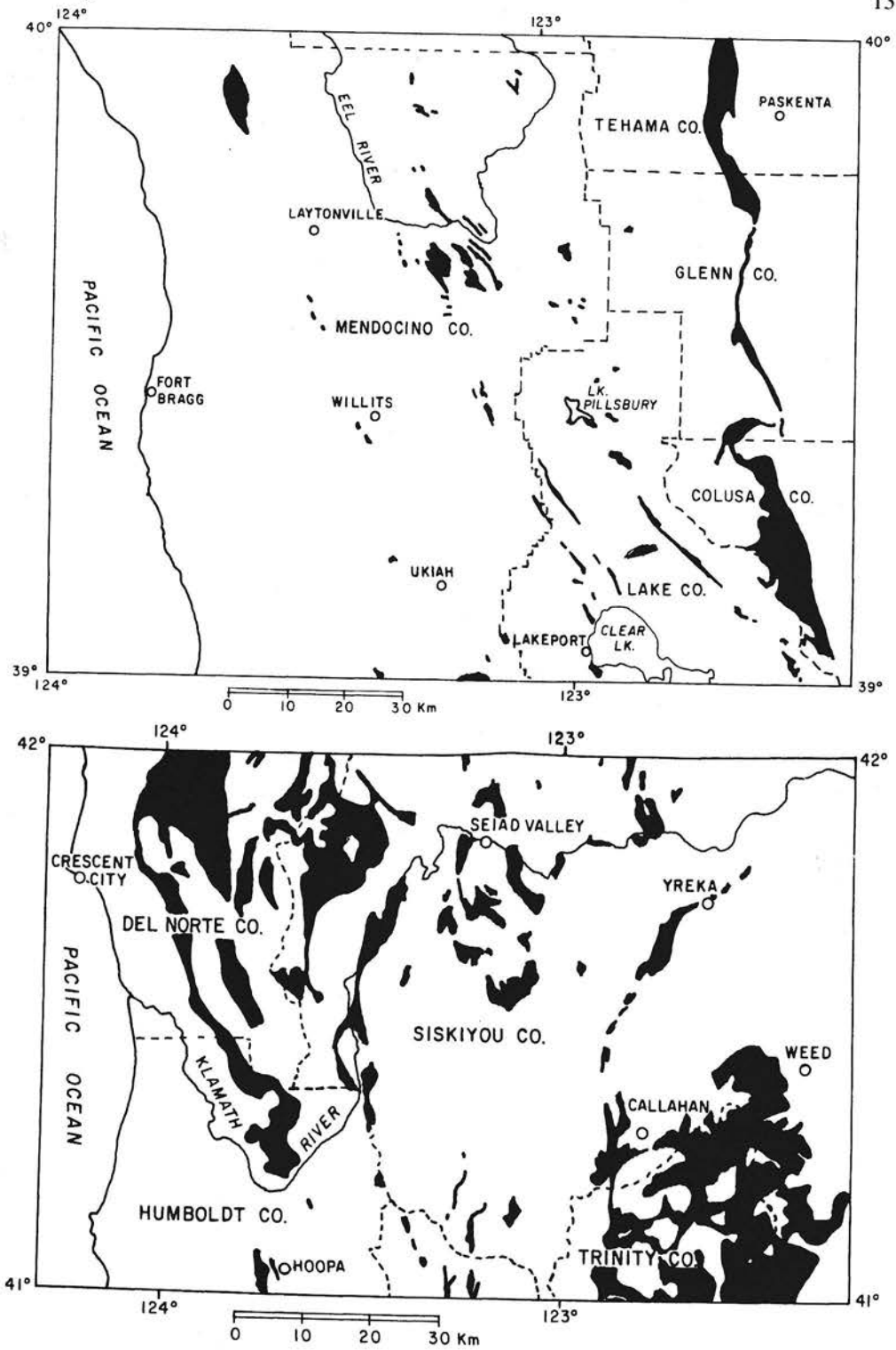


FIG. 6. Pure stand of *Cupressus sargentii* on ultramafics, locally known as "The Cedars," in the upper east fork of Austin Creek area, Sonoma County.

Kruckeberg, A.R. 1984. California Serpentines. UC Press



FIGS. 7 and 8. The Ukiah and Weed sheets, redrawn from Geologic Map of California (California Div. of Mines and Geology, 1958–1967) by Floyd Bardsley, showing major ultramafic outcrops (darkest areas) in the north Coast Ranges. 1 cm = 12 km.

Kruckeberg, A.R. 1984. California Serpentines. UC Press

Sierra Nevada

Ultramafics are discontinuous along a narrow belt from the southernmost Sierra to near the northern terminus of the range at Lake Almanor (figs. 9 and 10). All outcrops are cismontane and mostly at low elevations, more so in the south and increasing slightly in elevation northward.

Apart from the mafic (gabbro) outcrop in the Piute Mountains of Kern County, Tulare County contains the first substantial serpentinites. From there northward, every foothill county of the Sierras, from Tulare and Fresno to Plumas, contains serpentine (see fig. 11). Some of the most notable large outcrops are in the Coulterville–Bagby area of Mariposa County and on either side of the Feather River Canyon in Butte and Plumas counties.

All the area sheets of the Geologic Map of California are now in print. Those covering the Coast Ranges and the Sierra Nevada should be consulted for specific localities, pattern of outcrop, etc. Serpentinite is easily spotted by its map color—shocking purple; its map symbol is "ub." (I have provided a more extended account of the distribution of ultramafics in Appendix A.)

HISTORY OF THE GEOLOGIST'S INTEREST IN THE ULTRAMAFICS OF CALIFORNIA

Early geologists in California were aware of serpentinites, even if botanists were not. Perhaps the first recognition of serpentine is on a geological map of the San Francisco Bay area published in 1826 (figured in Norris and Webb, 1976, p. 275). This map, made by Edward Belcher, surveyor, and Alex Collie, surgeon, of H.M.S. Blossom, designated serpentine on the Tiburon peninsula and Angel Island. In the pioneer work on the geology of California (Whitney, 1865), the term "serpentine" was used several times in connection with outcrops visited by the Survey party. Yet in their visit to New Idria, the most spectacular serpentine barren in the West, the Survey writers seem not to have connected that vast tract of barren land with the serpentine substrate.

Only much later, in the early 20th century, did the connection between serpentine and vegetation appear in print. Two reports on quicksilver resources of California (Aubery, 1908; Bradley, 1918) make numerous references to serpentine, as it is so commonly associated with quicksilver ore deposits. The link between serpentine and plant life is finally made explicit in Bradley's 1918 quicksilver report; in describing the ore deposits and mines of the Mayacamas Mountains region of Lake County (p. 31), Bradley states: "Even where not bare, the serpentine can be detected at a distance by a sparse vegetation." In the same report, a photograph of the New Idria landscape (p. 94) is captioned "Serpentine surface near New Idria, San Benito County, showing characteristic sparseness of timber and brush growth." So at least field geologists had begun to notice the striking coincidences of serpentine rocks and the barrenness of the vegetation.

The paucity of early recorded observations from both botanists and geologists on serpentine and its link to the flora seems strange, especially in light of the fact that the serpentine phenomenon had long been known in Europe. Geological use of the term "serpentine" goes back before the l6th century (Challinor, 1967; Faust and Fahey, 1962); the allusion to "serpent" was to suggest the likeness between the mottled pattern of a serpent's skin and that of the rock.

Kruckeberg, A.R. 1984. California Serpentines. UC Press

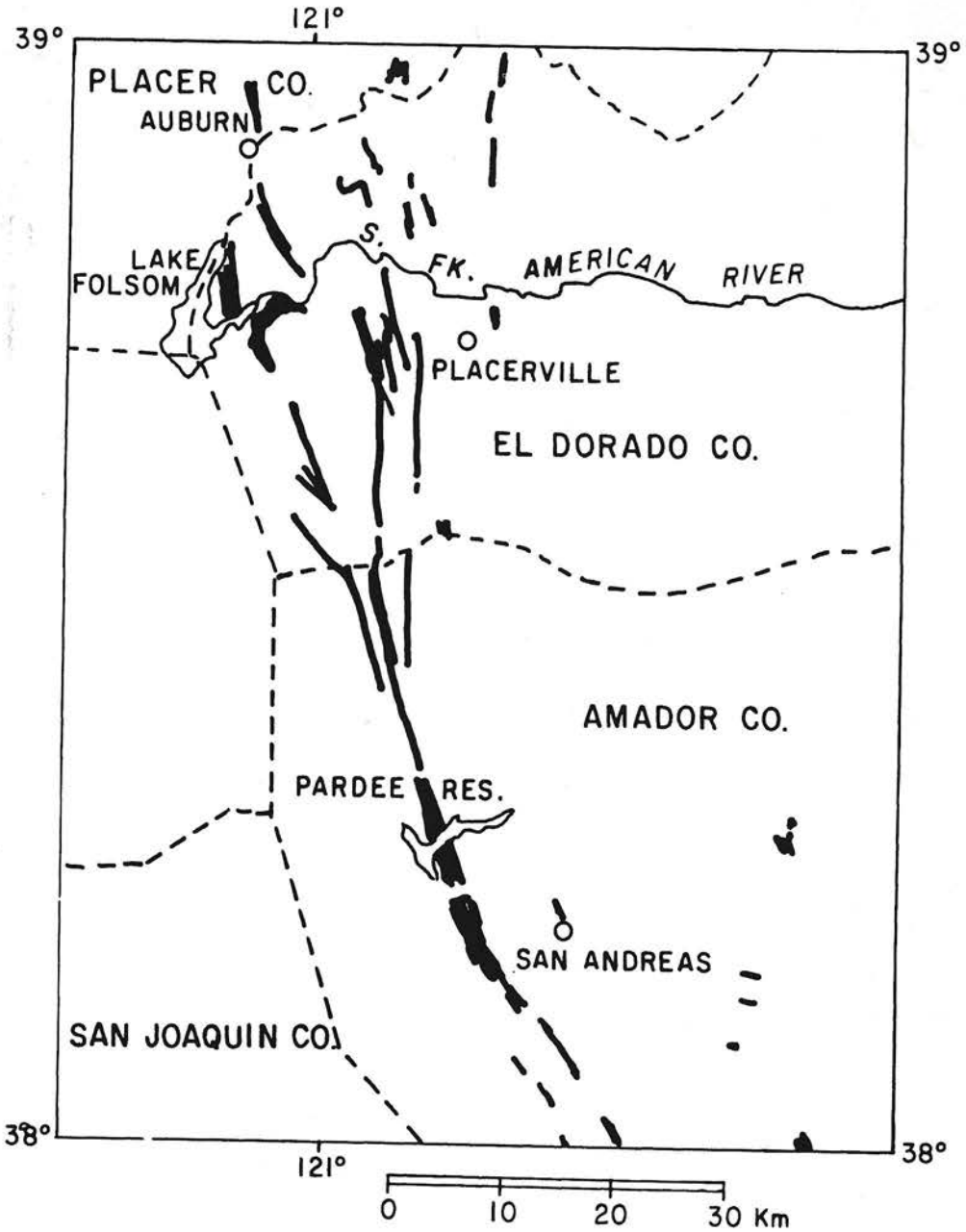


FIG 9. The Sacramento sheet, redrawn from Geologic Map of California (California Div. of Mines and Geology, 1958–1967) by Floyd Bardsley, showing representative ultramafic outcrops (dark areas) in the Sierra Nevada foothills from Amador to Placer counties. 1 cm = 7 km.

Kruckeberg, A.R. 1984. California Serpentines. UC Press

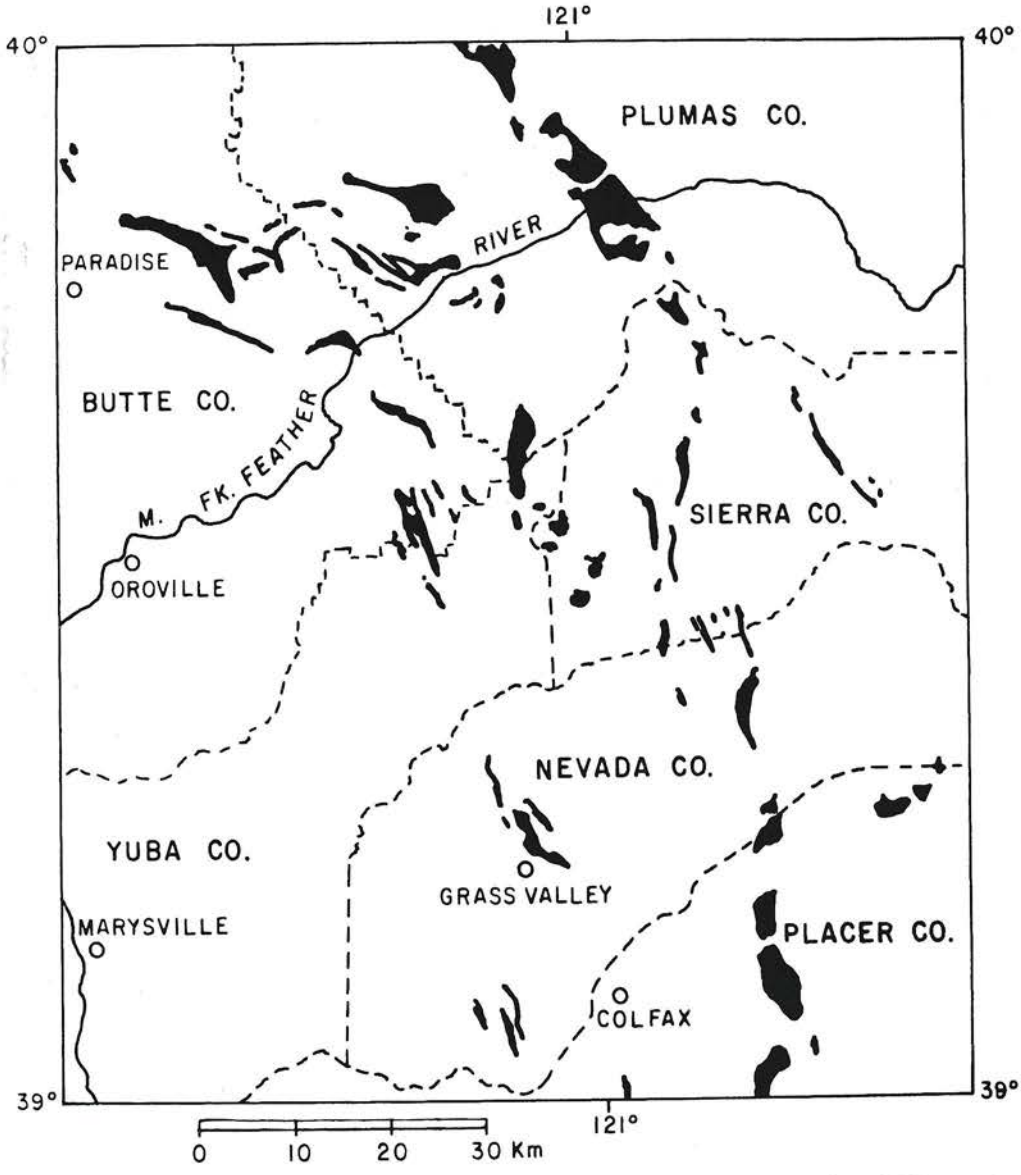


FIG 10. The Chico sheet, redrawn from Geologic Map of California (California Div. of Mines and Geology, 1958–1967) by Floyd Bardsley, showing representative ultramafic outcrops (dark areas) in the Sierra Nevada foothills from Placer to Plumas counties. 1 cm = 7 km.

An intriguing account of the history of western civilization's association with rocks and minerals of the serpentine group is given in Faust and Fahey's review (1962). The term *serpentine* was latinized from the Greek *lithos ophitidis*;Agricola in 1546 used the name "serpentinaria," a borrowing from the Greek of Dioscorides and Pliny. The Greek root *ophitidis* is often used both in geology and botany for attributes of ultramafic origin, and the term *ophiolite* has gained prominence in recent times as a collective term to embrace "a distinc-

Kruckeberg, A.R. 1984. California Serpentines. UC Press

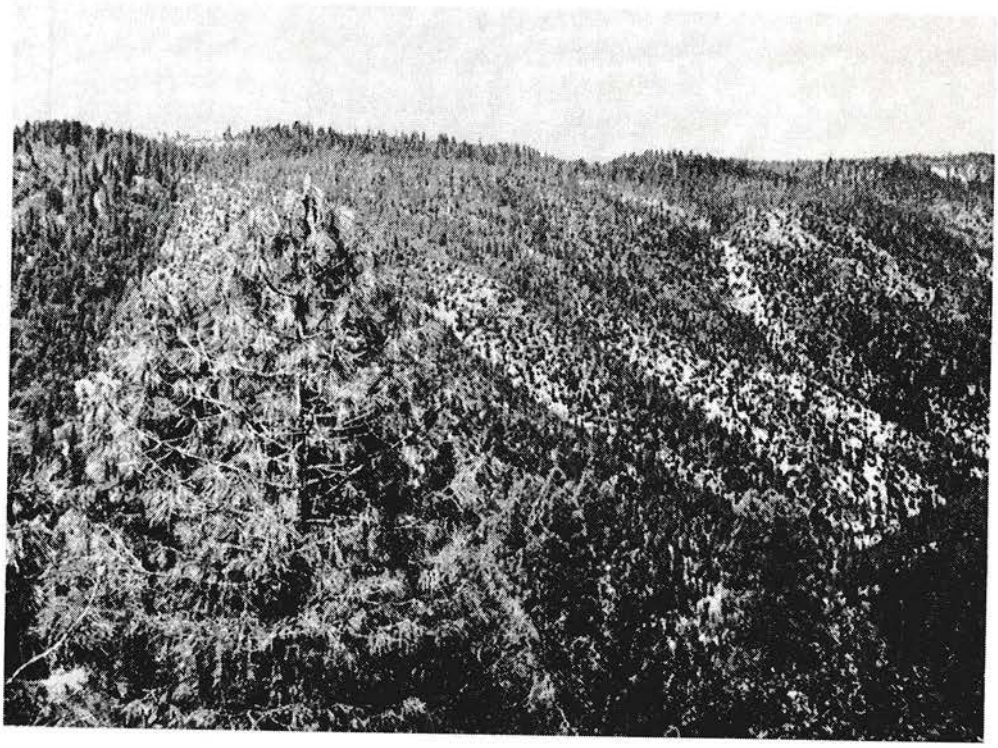


FIG. 11. Digger pine (*Pinus sabiniana*) in association with mixed conifer forest on serpentine, Washington Ridge, Nevada County. (Photo by J. Griffin.)

tive assemblage of mafic to ultramafic rocks'' (Coleman, 1977, p. 6). In this sense it is neither a specific rock name nor a mapped lithological unit. This contemporary usage is usually framed in the context of plate tectonics.

The present term *serpentine* is found in variant form in many European languages. And its meanings are many: it has been used to refer to rock, soil, vegetation, and even in architecture and sculpture where ultramafic rock is used. At present geologists prefer the term *serpentinite* for rocks containing serpentine-group minerals. Though stricter usage may be preferred, I suspect we will continue to use the word ''serpentine'' to refer to the physical and biological attributes of ultramafic lithologies.

Botanists in Europe were writing about the plant response to serpentine in the mid-19th century. Amidei (1841) and Pancic (1859) are the earliest writers on the subject known to me; other 19th and early 20th century papers are cited in the reviews by Whittaker et al. (1954), Krause (1958), and Proctor and Woodell (1975). Given the precedence of European knowledge on plant life of serpentines, it is surprising that early scientific interest in the phenomenon of serpentine flora and vegetation in California did not surface in print in those early days of botanical activity in the state.