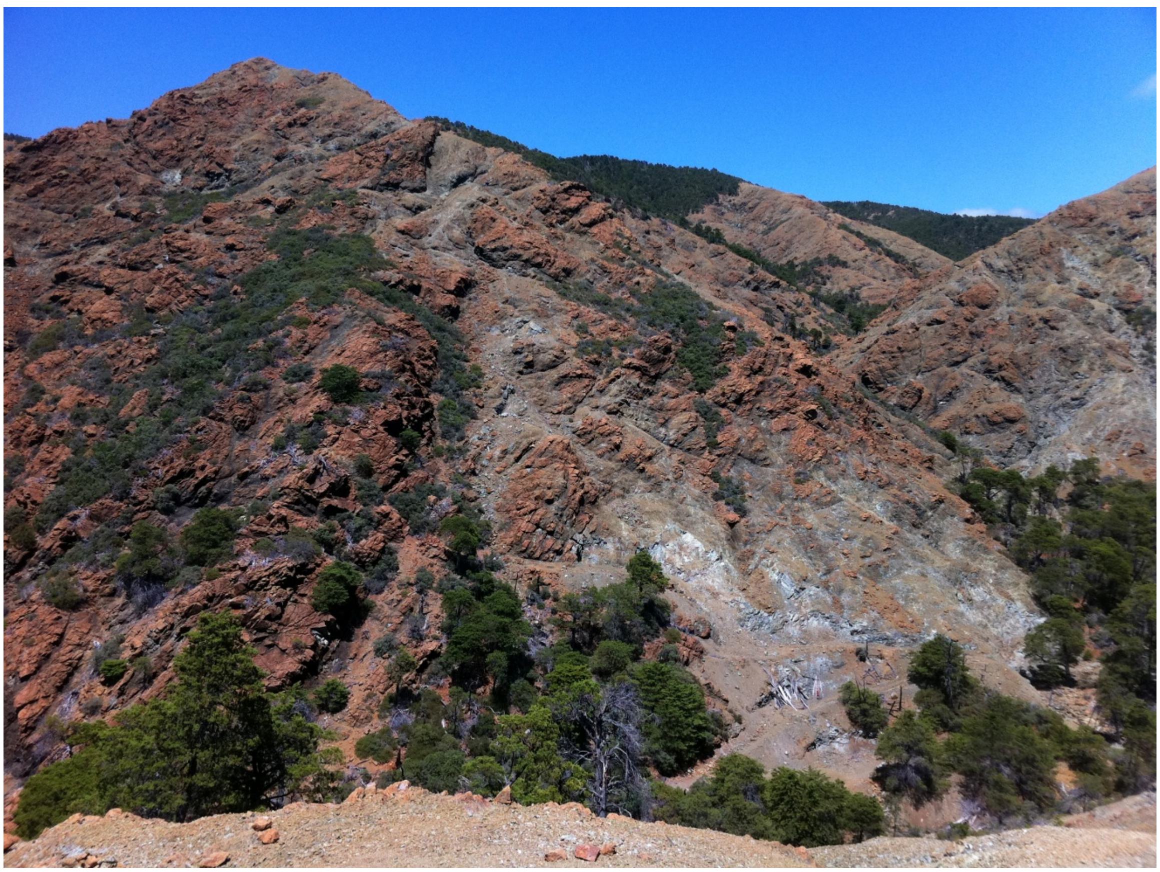
The Cedars Ultramafic Mass, Sonoma County, California

By M. Clark Blake, Jr., Edgar H. Bailey, and Carl M. Wentworth



Open-File Report 2012–1164
Version 1.2, April 2016

U.S. Department of the Interior
U.S. Geological Survey

U.S. Department of the Interior
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U.S. Geological Survey
Marcia K. McNutt, Director

U.S. Geological Survey, Reston, Virginia: 2012
First release: 2012
Revised: August 2012 (ver.1.1)
Revised: April 2016 (ver. 1.2)

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Suggested citation:
Blake, M.C., Jr., Bailey, E.H., and Wentworth, C.M., 2016, The Cedars untramafic mass, Sonoma County, California (ver. 1.2, April 2016): U.S. Geological Survey Open-File Report, 2012–1164, 13 p., 1 plate. (Available at *http://pubs.usgs.gov/of/2012/1164/*.)

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Abstract

The Cedars ultramafic mass is a mantle fragment that consists of partially serpentinized spinel harzburgite and dunite. Compositional layering and a chromite lineation define a penetrative metamorphic foliation that almost certainly formed in the upper mantle. Although detailed petrofabric and mineral chemistry are presently lacking, it seems reasonable that the Cedars peridotite represents a slice of mantle tectonite that once formed the base of the Coast Range ophiolite, and not an abyssal peridotite tectonically emplaced within the Franciscan accretionary prism.

Introduction

In 1955, Edgar Bailey, a geologist with the U.S. Geological Survey (USGS) in Menlo Park, California, flew over the Cedars area of western Sonoma County and, from its color and distinctive vegetation, recognized that it was underlain by a mass of ultramafic rock (fig. 1). Bailey had worked for many years in Franciscan and associated rocks in the Coast Ranges studying mercury deposits, including the New Almaden area in Santa Clara County (Bailey and Everhart, 1964). He later visited the Cedars area and decided to map the geology of the enclosing Skaggs Springs 15' quadrangle (fig. 2), to determine how the ultramafic body formed and got to its present position. As part of the justification for this work, he undoubtedly mentioned that both chromite and magnesite deposits occur in these ultramafic rocks, particularly at the Layton Mine and Red Slide claims, respectively (Dow and Thayer, 1946; Bradley, 1925), although it does not appear that any further research was done on either of these commodities in the Cedars mass.

We describe some of the history of that early work and later regional studies that helped to define the geologic setting of the Cedars ultramafic mass, present previously unpublished structural data for the mass, and include some other relevant observations and data. We do not, however, present a full modern analysis of the mass and its petrologic and structural history, which would be a much larger undertaking.

Bailey’s proposed project, Coast Range Ultramafics, was approved by the USGS in 1956, and in August of that year, Clark Blake was hired as his assistant. Field mapping was started soon after and Blake continued in that role until 1960, when he left to begin graduate studies, although he continued to work on the project on a part-time basis. Bailey hired several other field assistants during the project, including Carl Wentworth in 1961.

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* Although Edgar Bailey died in 1983, we include him as an author here because of his leading role in the original mapping and study of the Cedars ultramafic mass and its geologic context.

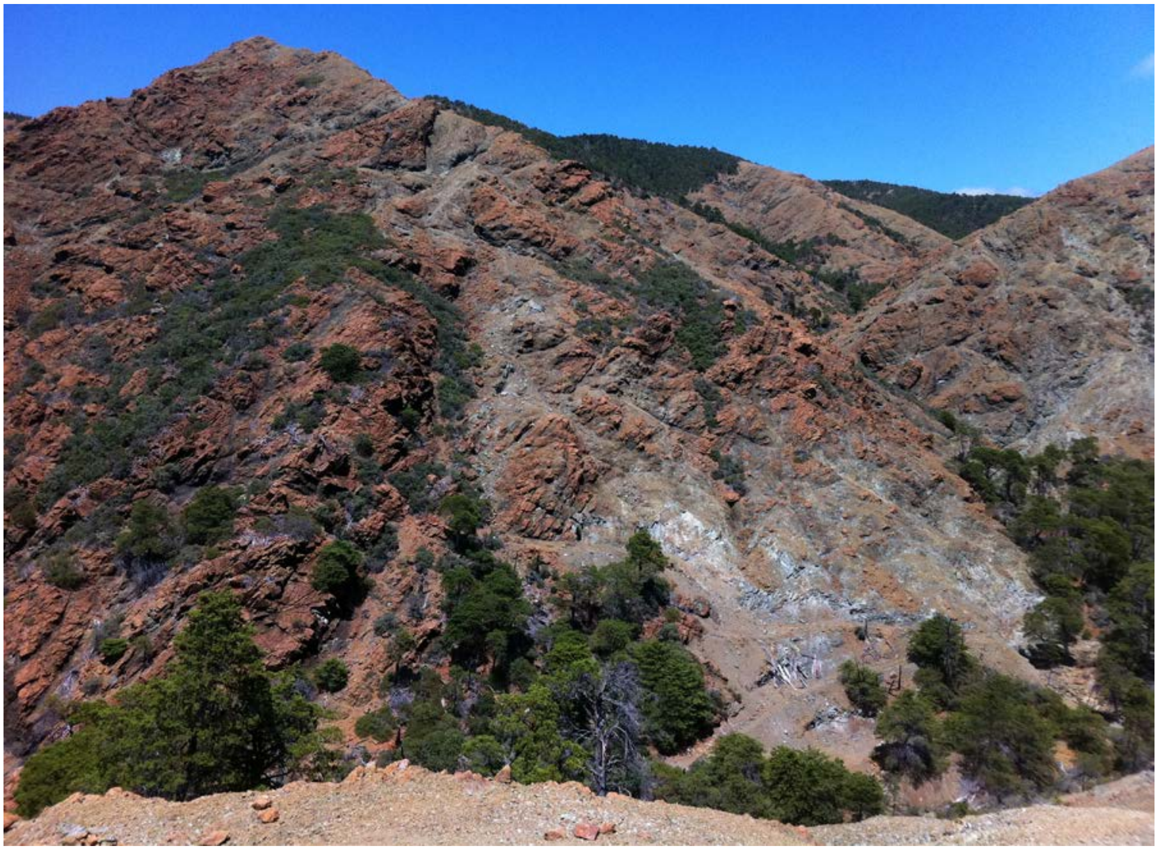

Figure 1. Photograph of the interior of the Cedars mass in the upper Austin Creek drainage. Note typical rusty color of weathered peridotite and sparse vegetation. Trees are Sargent Cypress (*Hesperocyparis sargentii*), endemic to harzburgite and dunite. Glossy gray-green rock low on the near slope is serpentinite on fractures exposed at an old chromite mine. Photo by J.W. Shervais, 2011.

As part of the field investigation, the Cedars ultramafic mass (listed as the Cazadero ultramafic mass in some earlier reports) was mapped in considerable detail and numerous samples were collected for petrographic, geochemical, and paleomagnetic studies (Blake, 1963). These studies determined that the Cedars mass was in fault contact with surrounding rocks of the Franciscan Complex, a eugeosynclinal assemblage of greywacke-type sandstone, greenstone (altered basalt), radiolarian chert, and minor foraminiferal limestone (fig. 2). Previously, such Coast Range ultramafic masses were thought to be igneous intrusions (see, for example, Tallioferro, 1943, p. 202–206).

As the work proceeded, Bailey led a number of informal geologic field trips to the area that stimulated interest by other geologists and led to several specialized projects. These included a study by Coleman and Lee (1962, 1963) of the glaucophane-bearing Franciscan metamorphic rocks

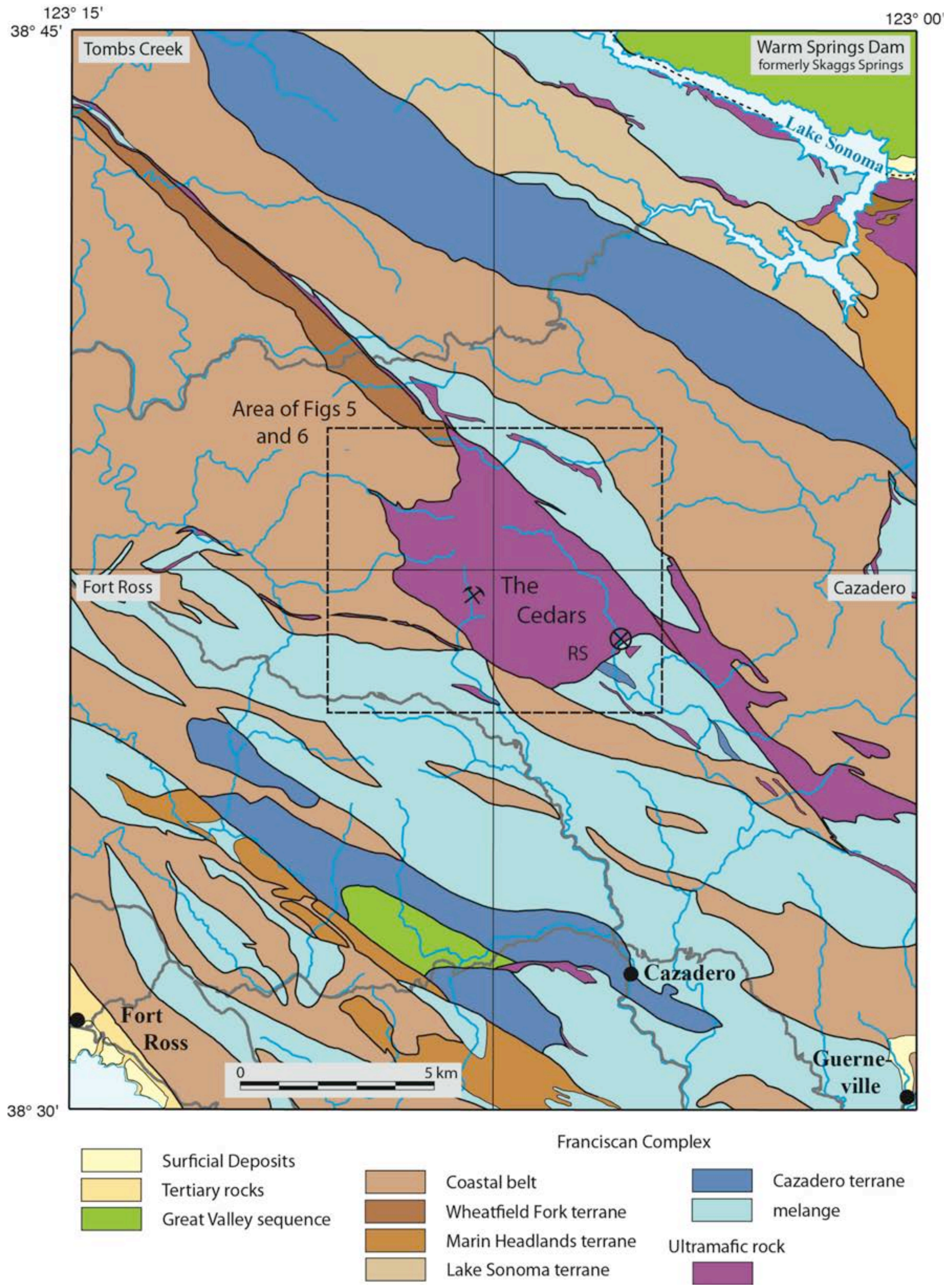

Figure 2. Index map showing the Cedars ultramafic mass and its geologic context. Area is the Skaggs 15-minute quadrangle, with its four 7.5-minute quadrangles labeled. Principal roads are gray, streams blue; principal towns shown by black dots. Mine symbol, Layton chromite mine; RS, Red Slide claims; location of sample 63-75 shown by circled X.

that crop out near Cazadero. Their discovery here of metamorphic aragonite clearly demonstrated that glaucophane-bearing metamorphic rocks (blueschists) formed under very high pressures and relatively low temperatures, conditions that are now recognized to be restricted to subduction zones.

Also important were a geochemical investigation of the serpentine springs within the Cedars mass (Barnes and O'Neal, 1966), which indicated that serpentinization of the ultramafic rocks was ongoing under surface conditions, and a gravity study of the ultramafic mass that was made in the early 1960s but published later (Thompson and Robinson, 1975). More recently, the high-pH springs within the Cedars mass described by Barnes and O'Neal (1966) have been found to contain microbial colonies that, together with their serpentine host, may provide a model for the development of early life (R.G. Coleman, written commun., 2012; Sleep and others, 2004, 2011).

In 1964, Bailey and coauthors published an extensive report dealing with the Franciscan rocks throughout California and their relation to coeval sedimentary rocks along the west side of the Great Valley (Bailey, Irwin, and Jones, 1964). That report included a cross section that ran westward from the Great Valley through the Cazadero area to the ocean. In that cross section, the deformed and metamorphosed Franciscan rocks were shown to be overlain, along a folded thrust fault, by little-deformed, late-Mesozoic rocks of the Great Valley sequence (Irwin, 1964). Critically, a sheet of serpentinized ultramafic rock was shown to be emplaced along that thrust fault.

In 1969, Bailey and others proposed that some of the ultramafic and mafic rocks within the Coast Ranges were part of the oceanic basement to the late Mesozoic Great Valley sequence, which they called the Coast Range ophiolite, rather than being part of the Franciscan Complex, as previously thought. These newly assigned rocks included some in the northeast corner of the map area near Healdsburg and another small patch near Cazadero (Bailey and others, 1970). The Cedars ultramafic mass, together with several other ultramafic bodies in the Coast Ranges, were not then assigned to the Coast Range ophiolite because they did not occur in association with other ophiolitic lithologies (gabbro and basalt). In fact, some studies elsewhere in the Coast Ranges led to the proposal that ultramafic masses like the Cedars represent fragments of abyssal peridotite derived from oceanic fracture zones and tectonically emplaced into the Franciscan accretionary prism during subduction (Loney and others, 1971; Coleman, 2000).

Also in 1969, a new geologic mapping project by the USGS was begun in the north San Francisco Bay area that included the Cedars area. This new work incorporated the original mapping of Bailey and others, modified it to better fit with plate tectonics and several other important concepts that had recently been developed, and enlarged upon it to cover all of Sonoma County and parts of adjacent counties (Blake and others, 1971).

In a volume of collected papers dedicated to E.H. Bailey that was issued soon after his death in 1983, the older geologic mapping was further modified by combining a number of fault-bounded units having similar stratigraphy, age, and metamorphic and structural history (Blake and others, 1984; Murchey and Jones, 1984; Wahrhaftig, 1984). Thus, most of the Franciscan Complex was shown to consist of tectonostratigraphic terranes characterized by basal basalt (greenstone), depositionally overlain by radiolarian chert or foraminiferal limestone that in turn was overlain by greywacke. Based on geochemical and biostratigraphic studies, it was proposed that the basalt had formed at a mid-ocean ridge and was then carried across the ocean by sea-floor spreading, during which time it was covered by radiolarian or calcareous ooze. The rocks finally arrived at a tectonic trench where the oceanic rocks were covered by continent-derived, clastic sedimentary rocks (turbidites) and then subducted to different depths, as indicated by their metamorphic mineral assemblages.

In 2002, Blake and others (2002) further refined these ideas for the western Sonoma County region and included a structural cross section that runs through the Cedars ultramafic mass. This shows the ultramafic mass to be thrust over the Coastal belt Franciscan along its western margin, but at its eastern margin the thrust fault is cut by a high-angle fault that places mélange against the ultramafic mass (see fig. 2).

Regional Geologic Framework

Figure 2 shows the Cedars ultramafic mass and the surrounding terranes and mélange of the Franciscan Complex. Also shown is the outline of the original Skaggs Springs 15' quadrangle and the four 7.5' quadrangles that compose it. The Cedars mass consists of relatively intact, partially serpentinized peridotite with a sheared serpentinite margin (fig. 3). The surrounding Franciscan terranes range in age from Middle Eocene (Wheatfield Fork) to Jurassic (Cazadero) and consist primarily of greywacke that has been subjected to a wide range of metamorphic conditions that extends from zeolite to blueschist facies.

Figure 3. Photograph of typical sheared serpentinite, Cazadero area. Rock hammer for scale. Photo by C.M. Wentworth, 1961.

As mentioned earlier, the Cedars ultramafic mass is in fault contact on its northern and western sides with sedimentary rocks of the Coastal belt Franciscan, now locally differentiated into the Wheatfield Fork terrane (McLaughlin and others, 2009). Unlike the interior of the mass, which is largely intact and only partly serpentinized, the margins have been extensively sheared and altered to serpentine minerals. Locally, the greywacke adjacent to the serpentinite margin on the north and west contains a thin alteration zone up to a meter or so wide where the greywacke is

Figure 4. Photograph of prominent mineral foliation weathered out on a joint surface in hartzburgite in the Cedars ultramafic mass. M.C. Blake for scale. Photo by E.H. Bailey, 1963.

largely replaced by whitish prehnite — another example of the rodingites described by Coleman (1967). The conditions under which this prehnite formed are probably limited by those for Coastal belt metamorphism described by Ernst and McLaughlin — less than 5–8 km and a temperature of 200–300° C — but the actual physical conditions involved were probably much lower. The contact has not been greatly modified since the prehnite zone formed. The gravity study mentioned earlier showed that the ultramafic mass does not extend to great depth, and modeled it as a thin, dish-shaped body lying on the Franciscan Complex (Thompson and Robinson, 1975, fig. 9). Similarly, recent magnetic modeling indicates that the mass is quite thin, with a thickness perhaps little more than the present topographic relief (R.J. Jachens, oral commun., 2012).

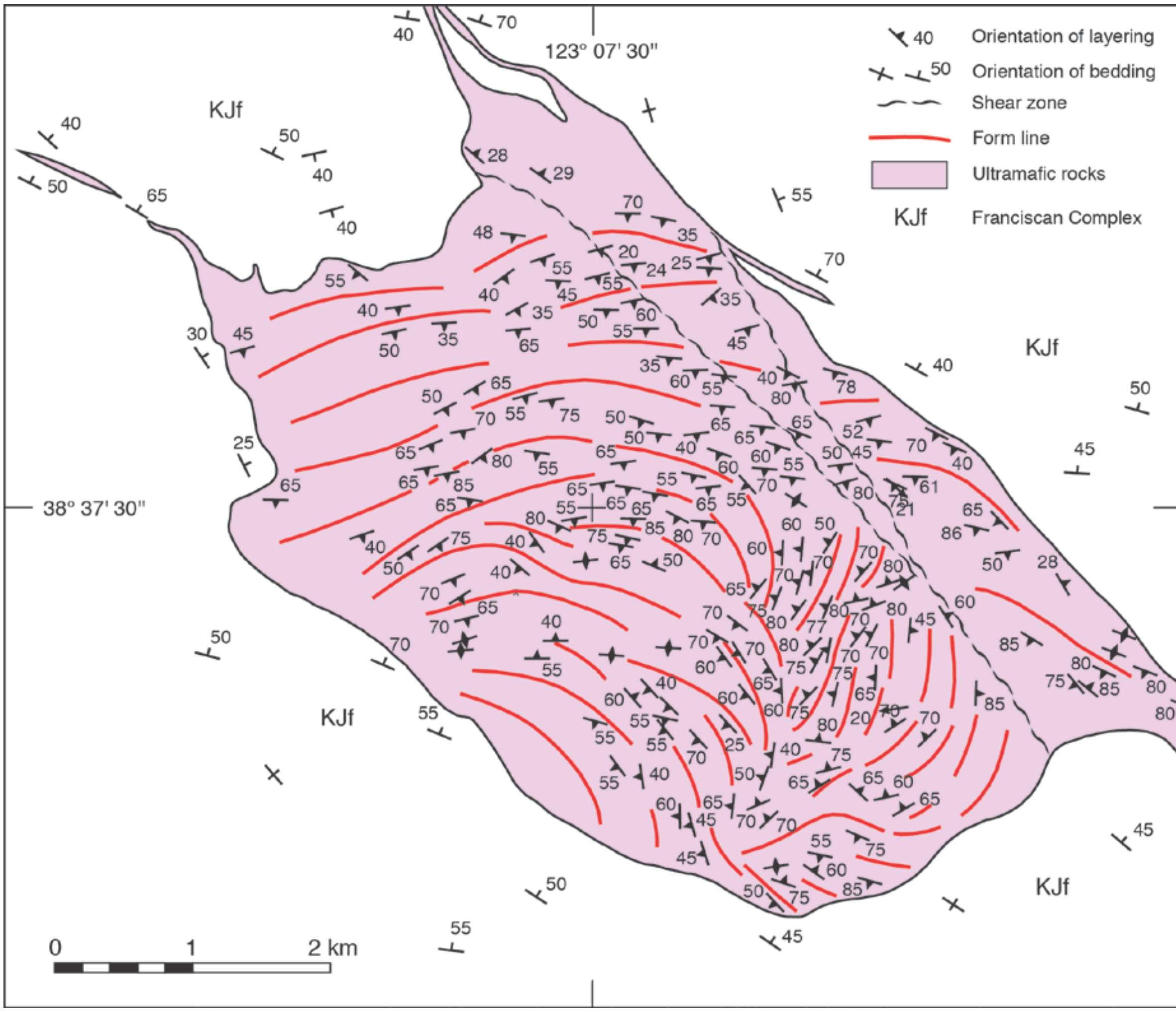

Figure 5. Map showing folded foliation within the Cedars ultramafic mass, form lines drawn to generalize the mapped strikes, and bedding attitudes in the surrounding Franciscan Complex greywackes. See figure 7 for original compilation of foliation attitudes.

On its south side, the serpentinized peridotite is faulted against mélange consisting of highly sheared greywacke and shale with many blocks and slabs of greenstone, chert, metamorphic rocks and serpentine. Mélange is also found along the eastern side of the ultramafic mass. The contact there is marked by a northwest-trending, high-angle fault that appears to have offset the ultramafic rocks laterally to the southeast (fig. 2). The aeromagnetic anomaly associated with the ultramafic rocks extends directly eastward beyond that fault, however, indicating that these magnetic rocks continue eastward beneath the mélange. This relation complicates the idea of simple transcurrent faulting (R.J. Jachens, oral commun., 2012).

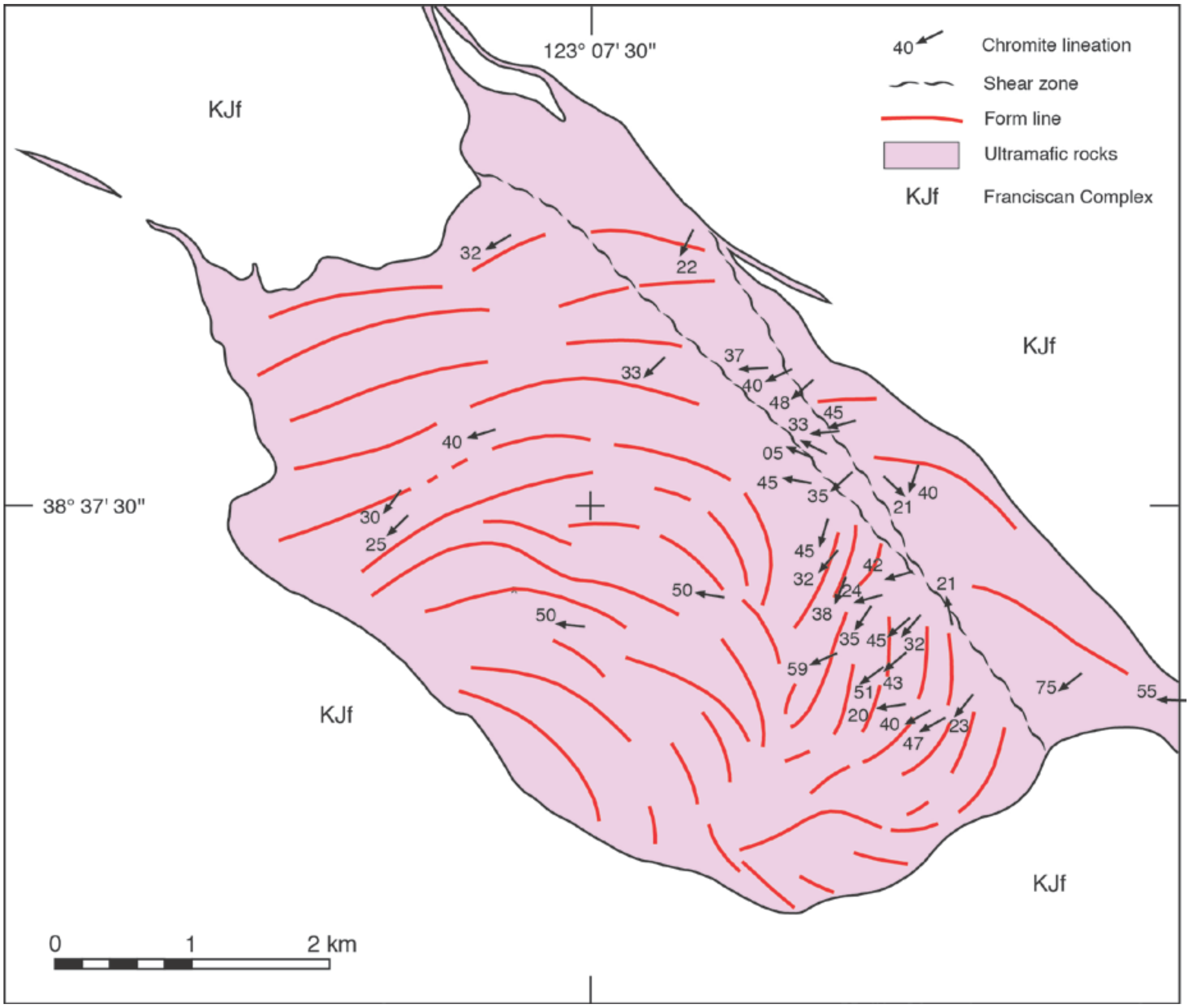

Figure 6. Map showing mineral lineations within the Cedars ultramafic mass and form lines from fig. 2. See figure 7 for original compilation of lineations.

Description of the Peridotite

The rock term "peridotite" includes both harzburgite and dunite. Most of the peridotite in the Cedars mass, prior to serpentinization, was spinel harzburgite with subordinate dunite. The harzburgite is an olivine-rich orthopyroxene (enstatite)-bearing rock with accessory chromium spinel (chromite) and minor clinopyroxene. The dunite is almost entirely olivine with accessory chromium spinel. Although relatively unaltered rock is present within the mass, and the margins are largely serpentinite, much of the interior is also serpentinized. This is clearly indicated by a negative gravity anomaly (Thompson and Robinson, 1975) over a mass that has yielded a measured density of 3.24 on a fresh hand sample collected by R.G. Coleman (R.C. Jachens, oral commun., 2012). Even the standard rock sample PCC-1 (see below) contains 4.71 percent water, which implies that this very fresh-appearing rock contains at least 30 percent serpentine (Loney and others, 1971). Thus, in referring to harzburgite and dunite, we include their undeformed serpentinized equivalents as well.

Like many other peridotites, the Cedars mass contains a prominent compositional layering defined by variations in the amount of olivine and orthopyroxene (fig. 4). We measured the orientation of these layers in the field and the results are shown in fig. 5 (and see fig. 7). We found no evidence in the field or in limited thin-section study that the layering is due to crystal settling, as is commonly seen in the cumulate layers of stratiform peridotites and ophiolite sequences. Instead, it appears to be a metamorphic fabric. Much more detailed studies of mineral fabrics and mineral geochemistry in identical harzburgites and dunites in California and Oregon have demonstrated that such layering is related to deformation and plastic flow in the upper mantle at temperatures of 1,000–1,200˚ C (Loney and others, 1971; Loney and Himmelberg, 1976). In addition, we noted in our field studies that there was a subtle mineral lineation, defined by aggregates of chromium spinel (figs. 6, 7). Similar lineations elsewhere have been interpreted to represent the trace of flow lines during deformation of what are now referred to as mantle tectonites (Nicholas and Boudier, 1975).

In order to enhance the mapped structures shown on figure 5, Bailey drew a number of form lines to help define the shape of the folded surfaces within the peridotite mass. The layering defines a large, moderately south-southwest plunging synformal fold with which the chromite lineations appear to be parallel or subparallel. The most important point that can be made about this structure is that it is strongly discordant to bedding attitudes in the surrounding Franciscan sedimentary rocks and thus formed prior to accretion and deformation of the surrounding Franciscan Complex.

Peridotite Chemistry

On May 25, 1963, Bailey and Blake collected a large sample (about 325 pounds) consisting of 12–14 boulders of relatively fresh harzburgite from the upper part of East Austin Creek (field number 63-75; see figs 2 and 7 for location). These boulders were given to the Analytical Labs of the U. S. Geological Survey in Menlo Park. The boulders were crushed and split into smaller samples that were distributed to numerous other analytical labs throughout the world. They became one of the USGS Standard Rock Samples, PCC-1 (splits of which are no longer available - Govindaraju, 1994). The average chemical composition of PCC-1 determined in the 1960’s is listed (PCC-1-a table 1, in weight percent) as determined by 26 different labs using a variety of techniques, including x-ray florescence (XRF), instrumental neutron activation analysis (INAA), and atomic absorption (AA) (Flanagan, 1969). Also listed for comparison are a more recent analytic compilation for PCC-1 (PCC-1-b: Govindaraju, 1994) and an analysis of a well-studied harzburgite from the Burro Mountain peridotite in the southern Coast Ranges (4-BU-66: Loney and others, 1971). The Cedars and Burro Mountain rocks are nearly identical.

It is important to point out that the unusual chemistry of the Cedars peridotite (and its sparse soil) — particularly the extremely low values for calcium, potassium, and phosphorus together with extremely high values of magnesium, chromium, and nickel — is responsible for the unusual plant communities that are found on this and similar serpentinite bodies (Kruckeberg, 1984: McCarten, 1993). In fact, the unusual plant communities of the Cedars mass have led to its designation as The Cedars Natural Area (Raiche, 2004).

Table 1. Chemical analyses of hartzburgite from the Cedars peridotite (PCC-1a, b) and from the Burro Mountain peridotite of the Southern California Coast Ranges (4BU-66).

	PCC-1-a	PCC-1-b	4BU-66
SiO_2	41.87	41.71	41.92
Al_2O_3	0.85	0.675	0.75
Fe_2O_3	2.84	2.72	1.83
FeO	4.94	5.06	6.03
MgO	43.56	43.43	44.48
CaO	0.53	0.52	0.5
Na_2O	0.05	0.03	0.02
K_2O	0.01	0.007	0
H_2O+	4.71	4.71	3.52
H_2O-	0.47	0.44	0.16
TiO_2	0.02	0.01	0.01
P_2O_5	0.01	0.002	0
MnO	0.12	0.12	0.12
CO_2	0.12	0.15	0.09
Cl	0.02	--	0
F	0	0	0
S	0.01	0	0.09
Cr_2O_3	0.39	0.40	0.43
NiO	0.31	0.30	0.31
Sum	100.83	100.28	100.26

Plate Tectonic Setting

In addition to structural analysis, detailed mineral chemistry has been conducted in other peridotite masses to determine where they formed. Recent studies (for example, Choi and others, 2008) concluded that the mantle tectonites in all but one Coast Range ophiolite occurrence probably represent a supra-subduction zone setting. These authors also studied the Burro Mountain peridotite mass in the southern Coast Ranges and found that it too had a mineral chemistry indicating a supra-subduction zone origin, rather than having formed at a mid-ocean ridge. Until comparable studies are completed on the Cedars ultramafic mass, it is not possible to say what its ultimate origin was. Toward this end, John Shervais (written comm., 2011) has told us that he is studying a number of samples recently collected from the Cedars peridotite mass. Based on the nearly identical whole-rock mineralogy and chemistry of the Cedars and Burro Mountain masses, however, we would predict that the Cedars will also prove to have a supra-subduction zone origin.

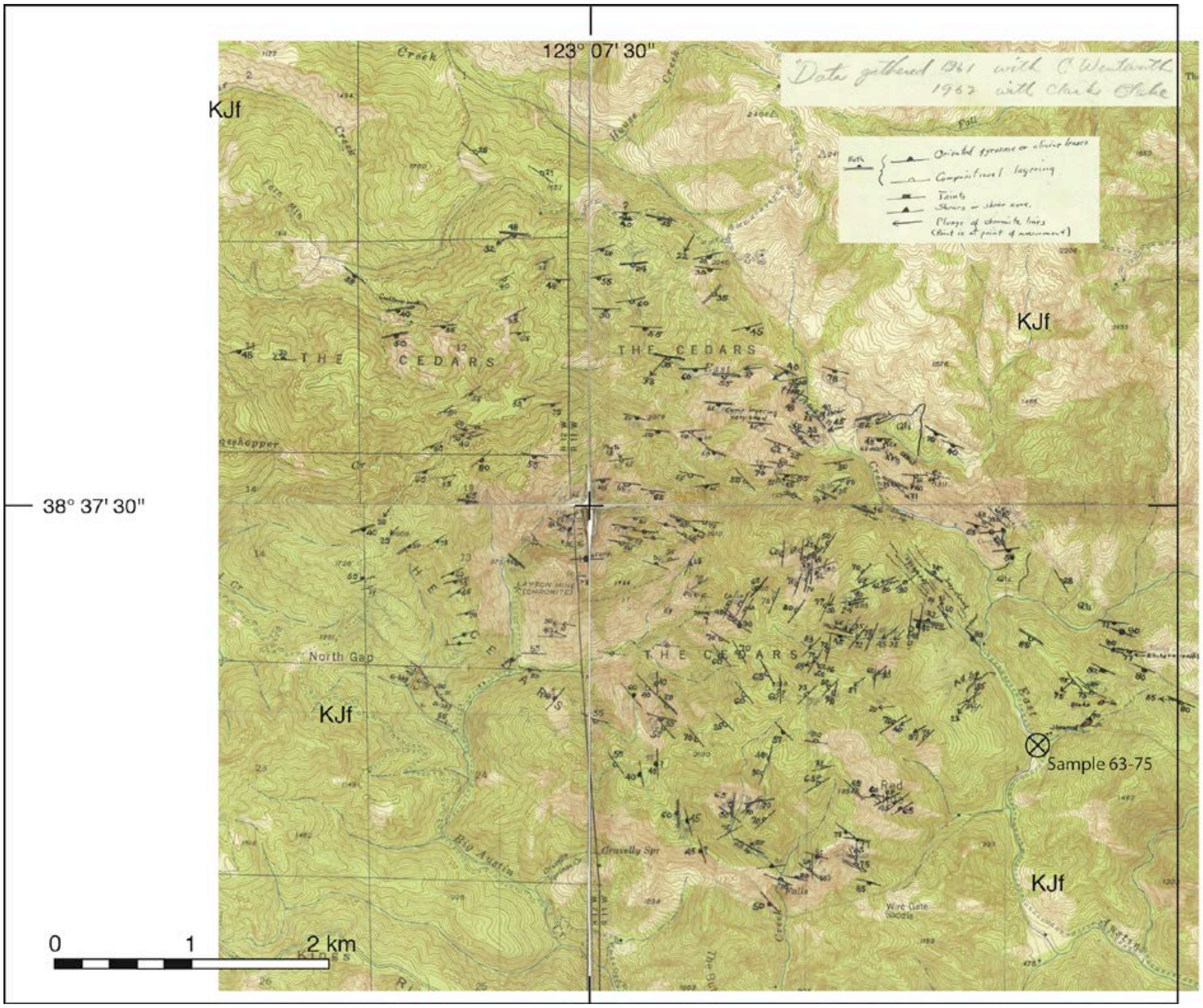

Figure 7. Original compilation of attitudes and lineations by E.H. Bailey on 7.5-minute topographic maps spliced at their common inner corner (see fig. 2 for quadrangle names). Outline box and latitude-longitude tics show relation of this map to those of figures 5 and 6. Insets at upper right, in Bailey's hand, copied from back of map. Location of sample 63-75 shown by circled X. A full-scale copy of this map compilation is separately included with this report as of2012-1164_plate.pdf (at *http://pubs.usgs.gov/of/2012/1164/*)

Conclusions

The Cedars peridotite mass consists largely of partially serpentinized spinel harzburgite and subordinate dunite. A pronounced compositional layering is defined by variations in the amount of olivine and orthopyroxene in the harzburgite. Also present is a mineral lineation defined by aggregates of chromite grains. Both of these features are considered to be the result of high-temperature ductile flow in the upper mantle. Based on water content, even the most massive harzburgite is partially serpentinized. Sheared serpentinite, however, is largely confined to the borders and within a few shear zones that transect the mass. None of the upper levels of an ophiolite sequence are present (gabbro, basalt), but they could have been removed by faulting. Although much more detailed study is needed, we tentatively conclude that the Cedars ultramafic mass is a fragment of mantle tectonite that once underlay the Coast Range ophiolite.

Acknowledgments

We thank our colleagues R.C. Jachens, R.J. McLaughlin, and R.W. Graymer for helpful discussion and comments, and Jachens for his help with geophysical constraints on the thickness of the Cedars mass and offset on the adjacent northwest-trending fault. R.C. Evarts and R.G. Coleman provided timely and very helpful reviews of the manuscript, and J.W. Shervais shared his photograph of the interior of the Cedars mass (our fig. 1). We also want to acknowledge our debt to Edgar Bailey, who introduced us to the Franciscan and led us by example in the fine arts of field geology and scientific inquiry. And of course, he admonished, “Always get it right along the roads”.

References Cited

Bailey, E.H., Blake, M.C., Jr., and Jones, D.L., 1970, On-Land Mesozoic oceanic crust in California Coast Ranges: U.S. Geological Survey Professional Paper 700-C, p. C70–C81.

Bailey, E.H., and Everhart, D.L., 1964, Geology and quicksilver deposits of the New Almaden district, Santa Clara County, California: U.S. Geological Survey Professional Paper 360, 206 p.

Bailey, E.H., Irwin, W.P. and Jones, D.L., 1964, Franciscan and related rocks and their significance in the geology of western California: California Division of Mines and Geology Bulletin 183, 177 p.

Barnes, I., and O’Neal, J.R., 1966, The relationship between fluids in some fresh Alpine-type ultramafics and possible modern serpentinization, western United States: Bulletin Geological Society of America, v. 80, p. 1947–1960.

Blake, M.C., Jr., 1963, Petrology and magnetic properties of the Cazadero Ultramafic Mass, Northern Coast Ranges, California: Geological Society of America Cordilleran Section Meeting, April 8–10, 1963, Berkeley, California, p. 23.

Blake, M.C., Jr., Graymer, R.W., and Stamski, R.E., 2002, Geologic map and map database of western Sonoma, northernmost Marin, and southernmost Mendocino Counties, California: U.S. Geological Survey Miscellaneous Field Studies Map MF-2402, version 1.0, scale 1:62,500.

Blake, M.C., Jr., Howell, D.G., and Jayko, A.S., 1984, Tectonostratigraphic terranes of the San Francisco Bay region, *in* Blake, M.C., Jr., Franciscan geology of northern California: Pacific Section S.E.P.M., v. 43, p. 5–22.

Blake, M.C., Jr., Smith, J.T., Wentworth, C.M., and Wright, R.H., 1971, Preliminary geologic map of western Sonoma County and northernmost Marin County, California: U.S. Geological Survey Open-File Map, scale 1:62,500.

Bradley, W.W., 1925, Magnesite in California: California Division of Mines Bulletin 79, p. 92-96.

Choi, S.H., Shervais, J.W., and Mukasa, S.B., 2008, Supra-subduction and abyssal mantle peridotites of the Coast Range ophiolite, California: Contributions to Mineralogy and Petrology, v. 156, p. 551–576.

Coleman, R.G., 1967, Low-temperature reaction zones and alpine ultramafic rocks of California, Oregon, and Washington: U.S. Geological Survey Bulletin 1247, 49 p.

Coleman, R.G., 2000, Prospecting for amphibolites along the continental California margin, *in* Dilek, Y., Moores, E., Elthon, D., and Nicholas, A., eds., Ophiolites and oceanic crust: Geological Society of America Special Paper, v. 349, p. 351–364.

Coleman, R.G., and Lee, D.E., 1962, Metamorphic aragonite in the glaucophane schists of Cazadero, California: American Journal of Science, v. 260, p. 577–595.

Coleman, R.G., and Lee, D.E., 1963, Glaucophane-bearing metamorphic rock types of the Cazadero area, California: Journal of Petrology, v. 4, p. 260–301.

Dow, D.H., and Thayer, T.P., 1946, Chromite deposits of the northern Coast Ranges of California: California Division of Mines Bulletin 134, p. 26–27, 36.

Ernst, W.G., and McLaughlin, R.J., 2012, Mineral parageneses, regional architecture, and tectonic evolution of Franciscan metagraywackes, Cape Mendocino-Garberville-Covelo 30′ X 60′ quadrangles, northwest California: Tectonics, v. 31, 29 p., TC1001, doi:*10.1029/2011TC002987*.

Flanagan, F.J., 1969, U.S. Geological Survey standards — II. First compilation of data for the new USGS. rocks: Geochimica et Cosmochimica Acta, v. 33, p. 81–120.

Irwin, W.P., 1964, Late Mesozoic orogenies in the ultramafic belts of northwestern California and southwestern Oregon: U.S. Geological Survey Professional Paper 501C, p. C1-C9.

Kruckeberg, A.R., 1984, California serpentines: flora, vegetation, geology, soils, and management problems: Berkeley, California, University of California Press, 180 p.

Loney, R.A., and Himmelberg, G.R., 1976, Structure of the Vulcan Peak alpine-type peridotite, southwestern Oregon: Geological Society of America Bulletin, v. 87, p. 259–274.

Loney, R.A., Himmelberg, G.R., and Coleman, R.G., 1971, Structure and petrology of the Alpine-type peridotite at Burro Mountain, California: Jour. of Petrology, v. 12, p. 245–309.

McCarten, N.F., 1993, Serpentines of the San Francisco Bay Region; vegetation, floristics, distribution and soils: Sacramento, California, California Department of Fish and Game, Nongame-Heritage Division, Endangered Plant Program, (Revised from 1986 version.)

McLaughlin, R.J., Blake, M.C., Jr., Sliter, W.V., Wentworth, C.M., and Graymer, R.W., 2009, The Wheatfield Fork terrane; a remnant of Siletzia (?) in Franciscan Complex Coastal belt of northern California: Geological Society of America Abstracts with Programs, v. 41, no. 7, p. 519.

Murchey, B.L., and Jones, D.L., 1984, Age and significance of chert in the Franciscan complex in the San Francisco Bay region, *in* Blake, M.C., Jr., ed., Franciscan geology of northern California: Pacific Section S.E.P.M., v. 43, p. 25–30.

Nicholas, A., and Boudier, F., 1975, Kinematic interpretation of folds in Alpine-type peridotites: Tectonophysics, v. 25, p. 233–260.

Raiche, Roger, 2004, The Cedars; Sonoma County's hidden treasure: Fremontia, v. 37, no. 2, p. 3–15.

Sleep, N.H., Bird, D.K., and Pope, E.C., 2011, Serpentine and the dawn of life: Philosophical Transactions of the Royal Society, v. 366, p. 2857–2869.

Sleep, N.H., Meibom, A., Fridriksson, T., Coleman, R.G., and Bird, D.K., 2004, H2-rich fluids from serpentinization; geochemical and biotic implications: Proceedings of the National Academy of Sciences, v. 101, p. 2828–12823.

Talliaferro, N.L., 1943, Franciscan-Knoxville problem: American Association of Petroleum Geologists, v. 27, no. 2, p. 109–219.

Thompson, G.A., and Robinson, R., 1975, Gravity and magnetic investigation of the Twin Sisters dunite, northern Washington: Geological Society of America Bulletin, v. 86, p. 1413–1422.

Wahrhaftig, Clyde, 1984, Structure of the Marin Headlands block, California; a progress report, *in* Blake, M. C., Jr., ed., Franciscan geology of northern California: Society of Economic Paleontologists and Mineralogists, Pacific Section, v. 43, p. 31–50.