CHLORITE VEINS IN SERPENTINE NEAR KINGS RIVER, CALIFORNIA

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Introduction

In the vicinity of the Kings River, in the western foothills of the Sierra Nevada, California, there are several localities showing narrow veins of chlorite cutting serpentine. There are two such localities in the northwestern part of the Dinuba quadrangle. One locality is about 1¼ miles N 20° E of the top of Wildcat Mountain, in the eastern half of section 11, T. 12 S., R. 23 E. The other, which is better exposed and more easily accessible, is described in the present paper. It is exposed in road-cuts along the highway which follows the north side of the Kings River, about ⅜ mile southwest of the northern end of the bridge at Piedra.

Clinochlore zones in serpentine, which appear to be similar in nature to those described here, have also been recorded from Bernstein, Austria.[1]

General Geology

The crystalline "Bedrock Complex" of the Sierra Nevada is made up in this region of a series of metamorphosed sedimentary and volcanic rocks which have been intruded by the granitic rocks of the Sierra Nevada batholithic complex. At some time previous to the Nevadan (Late Jurassic) orogeny and batholithic invasions, there were intruded into the sedimentary and volcanic rocks sills of serpentine, some of them of very large size. These serpentine bodies have undergone the same degree of folding and metamorphism (both dynamothermal and contact) as the enclosing rocks.

Petrography

Serpentine: The serpentine in which the chlorite veins are found is a hard, brittle rock of dark to pale grayish-green color. Under the microscope it is seen to consist of tiny, irregular grains of olivine and a few scattered prisms of pale green actinolitic hornblende, set in a groundweb of reticulate plates of antigorite. A few crystals of magnetite and apatite are present. Scattered flakes and streaks of talc are common, and short, discontinuous veinlets of a carbonate, probably magnesite, occur. Net structure, such as is commonly observed in unmetamorphosed serpentines, is completely lacking.

[1] Smith, W. C., On a compact chlorite from Bernstein, Austria: *Mineral. Mag.*, **20,** 241–244 (1924).

Within 5 to 30 mm. from the chlorite veins the serpentine becomes enriched in amphibole and clinochlore, and passes into an actinolite-clinochlore rock containing a small amount of talc. This zone terminates with great suddenness, and usually at a slickensided surface, against the chlorite veins. A few tiny veinlets of chlorite are found within this zone, but they are invariably composed entirely of clinochlore.

Megascopic features of the chlorite veins: The chlorite veins are found at intervals of from one to several feet, cutting the serpentine in nearly vertical and parallel planes. They are locally bent as though folded, and they are almost invariably slickensided along one or both walls.

In thickness the veins range from less than an inch to six or even eight inches, but they reach this latter dimension only in local swellings. These swellings are lenticular, pod-shaped enlargements along continuous veins. Most of the veins are between one and two inches in thickness. Where they are of this order of magnitude, they are composed of large, hexagonal plates of clinochlore from one to four millimeters in diameter and from one to two millimeters in thickness, with finer grained chlorite between them. The greater part of these narrow veins is clinochlore. The fine grained interstial material consists of positive and negative penninite and an unnamed chlorite.

In some places plates of clinochlore are concentrated along the edges of the veins, with the basal planes nearly normal to the walls, but in all azimuths. Locally, in the central parts of the veins, the plates of clinochlore do not touch each other, and they then show a quite complete development of crystal faces.

In the larger swellings the chlorites are often arranged in the same manner, but a more perfect banding is frequently exhibited. In the latter case the clinochlore is concentrated at the edges of the veins, which consist of nearly pure clinochlore for a thickness of from 5 to 25 mm. The central parts of the veins are here composed of finer grained aggregates of the other chlorites, in some instances with a few large idiomorphic plates of clinochlore.

Microscopic features of the chlorite veins: Under the microscope four varieties of chlorite are easily distinguished. Exact properties are, however, difficult to determine for the finer grained material. The indices of refraction were determined in oils, and are subject to a possible error of $\pm .002$.

The clinochlore shows abundant lamellar twinning parallel to $\{001\}$, repeated many times on each crystal. Its optical properties are as follows:

(+) $2V = 5°–20°$ (average 15°)
(−) elongation
dispersion $r < v$, weak

X and Y=pale green
Z=colorless to very pale green
$\alpha=1.581$
$\beta=1.583$
$\gamma=1.588$
$\gamma-\alpha=0.007$

These properties fall within the range determined by Durrell[2] for clinochlore from the Rocky Hill district, about 40 miles to the south. A specimen of the latter has the composition shown below.

SiO_2	31.04%
Al_2O_3	18.77
Fe_2O_3	0.47
FeO	3.56
MgO	34.24
CaO	nil
H_2O (+)	10.40
H_2O (−)	1.10
Total	99.58

W. H. Herdsman, *analyst.*

The greater part of the fine grained aggregates of chlorite consists of penninite. Of the penninite, a variety which is optically negative and shows ultra-blue colors under crossed nicols is most abundant. A variety which is optically positive and shows ultra-brown colors is far less abundant, and occurs only as cores in crystals whose borders consist of the negative variety. The optical properties of these two varieties of penninite are as follows:

Positive Penninite	Negative Penninite
(+) 2V=30°–40°	(−) 2V=0°
dispersion $r<v$, strong	
X and Y=very pale green	X=colorless
Z=colorless	Y and Z=very pale green
$\alpha=1.578$	$\alpha=1.574-$
$\gamma=1.580$	β and $\gamma=1.576+$
$\gamma-\alpha=0.002$	$\gamma-\alpha=0.002-0.004$
Characteristically shows strong ultra-brown interference color.	Characteristically shows strong ultra-blue interference color.

In addition to its occurrence in the fine grained aggregates, negative penninite is frequently found as rims on the large plates of clinochlore. The passage from clinochlore to penninite appears to be gradational.

[2] Durrell, C., Metamorphism in the southwestern Sierra Nevada northeast of Visalia, Calif.: *Univ. Calif. Publ., Bull. Dept. Geol. Sci.*, in press.

A chlorite, the properties of which do not correspond to those of any described variety, is also abundantly represented in the veins. It occurs in the fine grained aggregates, either with positive and negative penninite, or as the sole constituent. It is also found interlaminated with clinochlore, the plates reaching a diameter equal to that of the large clinochlore crystals. Its properties are as follows:

(−) $2V=0°$
X = colorless
Y and Z = green, variable; usually pale, but in small areas very dark green
$\alpha=1.545$
β and $\gamma=1.565$
$\gamma-\alpha=0.020-0.022$

The indices of refraction of this mineral are low for chlorites, and the double refraction unusually high. However, chlorites with still higher double refraction have been described. Its properties are close to those of bowlingite, beidellite, and griffithite. All of these are hydrous and aluminous, and it seems very probable that the mineral here described is also aluminous.

Magnetite occurs throughout the veins in small, irregular crystals, and a few irregular grains of apatite are also present.

Chemical Constitution of the Veins

The essential feature to be noted is the alumina content of the vein materials. The alumina content of penninite is stated by Orcel[3] to range from 11.6 to 13.8 per cent, while that of the clinochlore is close to 18 per cent. The unnamed chlorite is almost certainly aluminous, although without additional information it is not possible to make any reliable estimate of its Al_2O_3 content. Even where this unnamed chlorite is present in considerable abundance, however, it seems safe to assume an Al_2O_3 content for the veins of at least 12 per cent, and in many of the veins, where this mineral is not found, alumina must reach about 16 per cent. The remaining principal oxides present, in their probable order of abundance, are SiO_2, MgO, FeO, H_2O, and Fe_2O_3.

Whereas the alumina content of the chlorite veins ranges from about 12 to 16 per cent, the surrounding serpentine is practically devoid of Al_2O_3. Although actual analyses are lacking, calculations from the observed modal composition of the serpentine indicate that its alumina content probably does not anywhere much exceed 1 per cent. On the other hand, the clinochlore-actinolite selvages bordering the veins con-

[3] Orcel, M. J., Recherches sur la composition chimique des chlorites: *Bull. Soc. franç. minéral.*, **50**, 424–425 (1927).

tain up to about 6 per cent Al_2O_3 (corresponding to one-third clinochlore).

Origin of the Veins

It seems certain that the source of most of the alumina in the veins and selvages must be sought outside of the serpentine. Not only is alumina practically lacking in the serpentine itself, but there appears to be no evidence of the introduction of alumina into contact aureoles about serpentines, either here or elsewhere.

The veins are located near bodies of hornblende diorite and hornblende-biotite quartz diorite which are later than the serpentine. The alumina is believed to have been introduced along fracture planes in the serpentine from these or similar plutonic intrusions. The introduction of alumina by igneous emanations is indicated in this district also by the occurrence of andalusite and corundum in a pegmatite dike cutting the metamorphic rocks.[4] It is probable that CaO was also introduced in the actinolite-rich selvages along the veins, although the lime content of the veins themselves is very low.

The introduction of the alumina appears to have been antecedent to the cessation of the orogeny, since the veins are slickensided, and possibly folded. It may, indeed, have preceded the rise of the batholith to its final level, since in the Rocky Hill district clinochlore can be shown to have developed in the serpentine surrounding quartz diorite stocks before the formation of contact metamorphic olivine and enstatite.[5]

[4] Macdonald, G. A., and Merriam, R., Andalusite in pegmatite from Fresno County, Calif.: *Am. Mineral.*, **23**, 588–594 (1938).

[5] Durrell, C., *op. cit.*