THE GARNETS IN THE GLAUCOPHANE SCHISTS OF CALIFORNIA

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ABSTRACT

It is shown that the garnets of the glaucophane schists of California are nearly uniform in composition. The dominant constituent is almandite. Grossularite, pyrope and andradite are also present. These garnets lie within the group called "eclogite-garnets" by Eskola. One new garnet analysis is reported.

INTRODUCTION

Among the characteristic minerals of the glaucophane schists in the California coast ranges are the garnets. The glaucophane schists appear in many small detached areas and the outcrops often consist only of isolated boulders so that it is extremely difficult to ascertain their relation to other rocks. The schists are most variable in appearance and composition and garnets occur in them only sporadically in patches or in zones paralleling the schistosity. Still, garnets were found in at least a few spots in each of the areas of glaucophane schist visited. Though the garnets are most typically associated with glaucophane they occur in a few places in rocks consisting largely of actinolite or of omphacite. It was doubtless this fact that led several early writers[1] to refer to some of these rocks as eclogites or glaucophane-eclogites.

So far there has been available only one partial analysis of one of the garnets in these rocks[2] and no information whatever as to their physical properties. The basis for the statement by Professor Eakle[3] that the garnet in the schist of the Tiburon Peninsula is andradite is not known to the writer. The composition of these garnets is shown in Table II.

Garnetiferous glaucophane schists are known in a number of other regions, but the available data on their garnets is most scanty. They are usually described only as being red and occurring in do-

[1] Holway, R. S., Eclogites of California: *Journ. Geol.*, vol. **XII**, pp. 344–358, 1904; Murgoci, G., II.—On some glaucophane schists, syenites, etc. *Univ. Calif. Publ. Bull., Dept. Geol. Sci.*, vol. **IV**, pp. 359–396, 1906; Smith, J. P., The paragenesis of the minerals in the glaucophane-bearing rocks of California; *Proc. Am. Phil. Soc.*, vol. **XLV**, pp. 183–242, 1907.

[2] Smith, J. P., *op. cit.*, p. 202.

[3] Eakle, A. S., Minerals of California: *Bull.* **91**, *Calif. State Mining Bureau*, p. 173, **1923**.

decahedrons. Luedecke[4] in describing the garnets in the glaucophane schists of Syra mentions only that they give a bead test for iron and have a hardness of 7.5. Later descriptions of these rocks give no information at all.

On the Isle de Groix there are also garnet-bearing glaucophane rocks. The only mention of their character known to the writer is a remark by Mlle. Y. Briere[5] that "almandite" occurs on Groix in a glaucophane—epidote rock. Other descriptions of similar rocks lack any specific references to garnets. An analysis of a garnet from an undescribed glaucophane schist from New Caledonia is quoted in Table I.

Eskola, in his paper on the facies classification of rocks,[6] proposes a subfacies of his "eclogite facies" of metamorphic rocks which comprises the rocks here considered. He says in part:

> Another facies closely related to that of eclogite is one characterized by eclogite-garnet, glaucophane, lawsonite and paragonite (?). It might be designed [sic] as the hydrated eclogite facies and probably belongs to a region of somewhat lower temperature. These remarkable rocks are associated with eclogites and jadeitites on the island Syra, in the Alps and in California.

In describing the eclogite facies Eskola says:[7]

> The eclogite-garnets present an isomorphic series of almandite and pyrope in all proportions uptil 75 mol. per cent pyrope, and with small amounts of grossularite.

He does not give any evidence for the statement that the garnets of glaucophané rocks are "eclogite-garnets."

The analyses given in Table I are not entirely comparable because the same constituents have not been determined in each case. In the main the analyses are very similar. The ratio of the oxides has not been calculated for analysis II as it shows a great excess of ferrous iron. This is doubtless due to the nondetermination of the ferric iron and in using this analysis for Table II an arbitrary adjustment has been made by recalculating a part of the ferrous iron to ferric iron. The marked departure of the ratio, $RO:R_2O_3:SiO_2$, for analysis I from the theoretical value, 3:1:3, need not alarm one.

[4] Luedecke, O., Der Glaukophan und die Glaukophan führenden Gesteine der Insel Syra: *Zeit. d. deut. geol. Ges.*, vol. **28**, pp. 270 and 274, 1876.

[5] Briere, Mlle. Y., Les Eclogites francaises—leur composition mineralogique et chimique: leur origine. Thesis, Faculte Sci., *Paris*, p. 84, **1920**.

[6] Eskola, P., The Mineral Facies of Rocks: *Norsk Geologisk Tidskrift*, vol. **6**, p. 176, 1920.

[7] *op. cit.*, p. 171.

TABLE I. ANALYSES OF GARNETS FROM GLAUCOPHANE ROCKS

	I	II	III
SiO_2	38.26	38.69	38.15
TiO_2	0.00	—	—
Al_2O_3	19.93	19.10	22.18
Fe_2O_3	4.87	—	—
FeO	20.40	26.81	21.26
MnO	0.04	—	5.54
MgO	3.94	5.07	4.74
CaO	12.02	10.64	7.78
H_2O-	0.48	—	
H_2O+	00.12	—	ig. loss 0.31
	100.06	100.31	99.96
$RO:R_2O_3:SiO_2$	2.65:1:2.83	—	2.90:1:2.92
Sp. Gr.	3.821	3.818	4.011

I. Garnet from glaucophane schist collected by Professor G. D. Louderback near mouth of Russian River. Analyst, A. Pabst.

II. Garnet from "eclogite" on Coyote Creek, about 6 miles north of San Martin, Santa Clara County. Analyst, W. O. Clark. In J. P. Smith, *Proc. Am. Phil. Soc.*, vol. **XLV**, p. 194, 1907.

III. Garnet in glaucophane schist, Balade Mine, New Caledonia. Analyst, A. Liversidge, *Journ. & Proc. Roy. Soc. N. S. W.*, vol. **14**, p. 242, 1880. Occurring in a rock with glaucophane, quartz, epidote and white mica. No petrographic description is given.

A similar excess of R_2O_3 is not uncommon in garnets. Seven of twelve new analyses of garnets given by Eskola[8] depart in the same sense. This feature of garnet analyses has been discussed by Phillipsborn[9] and he suggests that it may not indicate analytical error.

Titanium was tested for only in the first garnet. The writer also tested garnets A and B of Table II. Only one yielded a trace of titanium. These observations are in agreement with the statement by Eskola,[10] "all eclogite-garnets are low in titanium, a very remarkable feature."

Table II shows the molecular proportions of the several constituent molecules present in the garnets of Table I and in two other

[8] Eskola, P., On the eclogites of Norway, Videnskapsselskapets Skrifter, I. *Mat.-Naturv. Kl.* No. **8,** Oslo, 1921.

[9] v. Phillipsborn, H., Beziehungen zwischen Lichtbrechung, Dichte und chemischer zusammensetzung in der Granatgruppe: *Sächs. Ak. Wiss. Abh. Mat.-Phys. Kl.*, vol. **XL,** No. 3, p. 34, Leipzig, 1928.

[10] *op. cit.*, p. 173.

TABLE II. CALCULATED COMPOSITION OF GARNETS IN MOL. PERCENTAGE OF END MEMBERS

	I	II	III	A	B
Grossularite	21	19	22	8	30
Andradite	15	10	n.d.	24	4
Almandite	48	51	47	48	56
Pyrope	16	20	19	20	10
Spessartite	—	n.d.	12	—	—

I. Same as table I.
II. Same as table I.
III. Same as table I.
A. Calculated from partial analysis of garnet in "eclogite" from Hilton Gulch, 5 miles east of Calaveras Valley, San Jose Quadrangle, described by J. P. Smith, *Proc. Am. Phil. Soc.*, vol. **XLV**, p. 202, 1907.
B. Calculated from partial analysis of garnet in glaucophane schist from the original lawsonite locality near Reed Station, Marin County, California.

garnets from California glaucophane rocks of which partial analyses were made. With the exception of the spessartite present in the garnet from New Caledonia all these garnets are very similar. Especially the proportion of almandite, the main constituent, varies but slightly.

TABLE III. COMPOSITION RANGES OF CERTAIN GARNETS AS FOUND BY DIFFERENT INVESTIGATORS

	Eclogite Garnets as found by Heritsch	Eclogite Garnets reported by Eskola	Garnets in Glaucophane rocks, Pabst
Number of analyses	6	4	4
Range of Grossularite	9–42%	9–20%	8–30%
Andradite	0–21%	3–11%	4–24%
Almandite	33–57%	26–61%	48–56%
Pyrope	19–37%	16–61%	16–20%
Spessartite	0– 3%	1– 2%	0– 1%

In Table III are given the ranges of variation of eclogite-garnets as found by Heritsch working with analyses from various sources,[11] as represented by the eclogite-garnets of Norway reported by Eskola, and as found by the writer for garnets from the glaucophane rocks of California. A comparison of the first two columns

[11] Heritsch, F., Studien ueber den Chemismus der Granaten: *Neues Jahrb., Beilbd. A*, **LV**, p. 74, 1926.

shows that there is a definite chemical group of "eclogite-garnets," though the range of variation is wide. The garnets of the glaucophane rocks fall entirely within this range and are especially characterized by the small variation in the percentage of their chief constituent, almandite.

The Physical Properties of the Garnets

As shown above there are three or four major constituents in the garnets of the glaucophane rocks. In order that they can be determined from physical measurements it is necessary to find two or three functions that vary in a suitable manner with changes in the percentage of each of the constituents. For garnets the following functions have been suggested: specific gravity, refractive index, dispersion, lattice constant, and relative intensities of certain lines in the X-ray diffraction patterns. Various writers have given diagrams for the graphical solution of such problems. All methods were tried for the identification of the garnets in the glaucophane rocks but they did not lead to any satisfactory results.

Table IV. Properties of Garnets in Glaucophane Schists and Related Rocks

	Maximum size	Density of rock	Density of garnet	Refractive index, N_{Na}	Lattice constant
I	15 mm.	3.179	3.821	1.787±0.002	11.58Å±0.03Å
II	2.5 mm.	3.527	3.818	1.799±0.002	—
A	5 mm.	3.215	3.884	1.795±0.002	11.60Å±0.03Å
B	3 mm.	3.154	3.827	1.799±0.002	11.59Å±0.03Å
C	2 mm.	3.178	3.787	1.799±0.002	—
D	2 mm.	3.230	3.719	1.803±0.002	—
E	3 mm.	3.115	3.658[a]	1.805±0.002	—

[a] Probably low due to inclusion of alteration products.

I. Same as Table I.

II. Same as Table I. Determinations made on material kindly supplied by Professor A. F. Rogers from the original collections of the late Professor J. P. Smith.

A. Same as Table II.

B. Same as Table II.

C. Data for garnet in glaucophane schist near Junction School House, 2 miles southwest of Healdsburg, Sonoma County, California.

D. Garnet in glaucophane schist near Camp Meeker, Sonoma County, California.

E. Garnet in glaucophane schist north of Berkeley, in Contra Costa County, California.

The essential data are shown in Table IV. Several of the functions mentioned can be dropped as of no value in the present case. The comparison of intensities of lines in the diffraction patterns can only be used where notable differences are found. Mr. W. H. Dore kindly prepared powder diffraction patterns of garnets I, A and B. No difference was observable in the relative intensities of the several lines on the different patterns and lacking other material for comparison no use could be made of this method suggested by Stockwell.[12] The lattice constants, determined from the best alpha lines calibrated against lines of KCl mixed in the preparation, are nearly the same. This is not a good indicator of the proportions of almandite and pyrope as the lattice constants of almandite, 11.497Å[13] and pyrope, 11.446Å[14], are too close together.

The indices of refraction were determined by the dispersion method at constant temperature. The prism method, which sometimes allows greater precision, could not be used because the garnets are for the most part too dull and fractured. Though the method used permits the determination of the dispersion of the garnets the differences are within the limits of error and so the indices are given in the table for sodium light only.

The density determinations are useful for distinguishing pyrope and almandite but not for distinguishing grossularite, sp. gr. 3.530, from pyrope, sp. gr. 3.547.[15] Similar considerations apply to the indices of refraction.

This leaves the indices of refraction and the density as suitable indicators of the composition of garnets C, D, and E. These data are insufficient for defining a composition in a four component system. They merely determine a certain range of composition that can be read from the tetrahedral diagrams of Phillipsborn. Still the properties of all the garnets examined are so nearly alike that it seems fairly certain that the compositions of C, D, and E also fall within the range of the analyzed specimens.

[12] This journal, vol. **12**, pp. 335 and 336, 1927.

[13] Menzer, G., Die Kristallstruktur der Granate; *Zeit. f. Krist.*, vol. **69**, p. 389, 1928.

[14] The value for pyrope is extrapolated from the constant and analysis of an impure pyrope given by Menzer, using his data for the other end members. This is necessary and possible because no pure pyrope is known but sufficiently pure examples of all the others are reported by Menzer. Stockwell uses the value 11.430Å for pyrope.

[15] Calculated from the extrapolated lattice constant.

Associations and Habits of the Garnets

The uniformity in chemical composition of these garnets is in harmony with the constancy of their habits and association. The garnets in the glaucophane rocks are always in distinct red dodecahedrons. No trace of any other form, no notably distorted forms, no anhedrons (except those due to alteration) and not one poikilitic garnet were found among the hundreds examined in the present study. The maximum and common size of the garnets from different rocks is 2 to 3 mm. except in a few cases (Table IV). Of course, the garnets are larger in the coarser rocks. The density of the rocks (Table IV) gives a measure of the proportion of garnet present, all other constituents being much lighter.

In the following are given brief notes on the rocks containing the garnets listed in Table IV:

I. Russian River. Coarse (0.30–0.50 mm. average diameter) groundweb of actinolite with some glaucophane fringes. Titanite in rough grains partly surrounding rutile. Garnets carry very fine undetermined original inclusions. Chlorite and white mica in patches, partly altered from garnet.

II. San Martin. Coarse (0.15–0.25 mm.) diablastic web of long needles of zoned omphacite, green core, colorless edge. Some epidote, less titanite, in part with rutile, and only traces of glaucophane present. Garnet apparently fresh but bordered here and there by a little chlorite, partly with zoned inclusions of omphacite.

A. Hilton Gulch. Diablastic web (0.20–0.30 mm.) of actinolite fringed with glaucophane. Epidote and titanite in part very coarse. Garnets partly fresh, partly altered to chlorite, carry some inclusions of the other rock minerals.

B. Tiburon. Coarse web (0.13–0.20 mm.) of glaucophane tending to diablastic texture. White mica, epidote and titanite abundant. The mica tends to be aggregated around the garnets which are fresh but crowded with very fine undetermined inclusions in the interior and having a cleaner border.

C. Junction School House, fine (0.02–0.03 mm.) schistose web of glaucophane and epidote traversed by zones of chlorite and a little white mica, magnetite and titanite. Garnets enclosed in chlorite halos and crowded with fine undetermined inclusions. Structures in the groundmass bend around the garnets.

D. Camp Meeker. Diablastic (0.10–0.15 mm.) glaucophane and actinolite dominant with some white mica, epidote, magnetite, titanite and rutile. Garnets clean but much altered to chlorite with some white mica.

E. Contra Costa County. Very fine (0.02–0.03 mm.) diablastic groundweb of glaucophane with epidote and a little titanite. Garnets originally clean but now traversed by fibrous chlorite veinlets and surrounded by coarse epidote filling former space. Some patches of chlorite.