FASSAITE FROM NEAR HELENA, MONTANA

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ABSTRACT

The aluminous pyroxene fassaite, along with spinel, garnet, and the brittle mica clintonite, forms a lode 400 feet long and 8 feet thick, 12 miles southeast of Helena, Montana. The fassaite contains more Al_2O_3 (15.75 per cent) and Fe_2O_3 (6.10 per cent) than any natural fassaite recorded. It strikingly illustrates Tilley's thesis that monoclinic pyroxene associated with spinel in metamorphosed limestone can be expected to contain a notable amount of alumina.

INTRODUCTION

Fassaite is the name applied to diopsidic pyroxene relatively high in alumina and ferric oxide, practically devoid of alkalis, and having a content of CaO essentially that of the ideal diopside (Tilley, 1938, p. 87). The balancing of the electric charge in fassaite is accomplished by substitution of aluminum for silicon and of aluminum and ferric iron for magnesium.

Fassaite is found only in environments poor in silica, being usually associated with spinel in contact-metamorphosed limestones. It is probably more widespread than the few descriptions available in the literature would indicate (Tilley, 1938, p. 81). The senior author, who has previously reported fassaite from the contact zone of the Boulder bathylith (Knopf, 1953, p. 1114, 1117), recognized the present occurrence and turned the material over to the junior author for detailed study.

The chemical analysis of the fassaite here given was made possible by the Shell Oil Company through the Shell Grant for Fundamental Research. The writers are indebted also to Dr. C. O. Hutton for helpful advice offered during this study.

GEOLOGIC OCCURRENCE

A vertical tabular mass of spinel and silicates occurs on the Knapp ranch, in Lewis and Clark County, Montana. It is several hundred yards southwest of the old Economy mine, 12 miles by road southeast of Helena.

The spinel mass is 8 feet thick; it trends N. 60° W. and dips steeply, probably vertically. It extends 400 feet or more southeastward from the creek bottom to the summit of the ridge, where it ends in a mass composed mainly of vesuvianite, with calcite, diopside, and chondrodite. The spinel mass separates a body of olivine gabbro on the northeast from a body of granogabbro on the southeast occurring along the northern boundary of the Boulder bathylith. It is interpreted to be a limestone septum that has been pyrometasomatically altered.

The spinel lode, as it can be called, consists of black spinel and pale

green silicates in roughly equal amounts by volume. The minerals appear to be fairly uniformly distributed and a representative specimen of the rock has a density of 3.45. The spinel is in subhedral crystals which are a millimeter or two in size and are more or less clustered together. The silicates were not identifiable megascopically, except that a micaceous mineral is recognizable, subsequently determined to be the brittle mica clintonite.

Under the microscope the spinel is seen to be associated with pyroxene, garnet, and clintonite, with traces of phlogopite and muscovite, and a secondary mineral resembling jarosite. The mineral that immediately attracts attention is the pyroxene fassaite. It is of most un-pyroxenic appearance, chiefly because of the poor development of its cleavage. It was seen to have a powerful dispersion comparable to that of sphene. The optic axis B emerging on sections with rectangular cleavage shows strong dispersion, but the optic axis A, emerging perpendicularly on (100), shows no dispersion. Because of its striking properties it was thought desirable to have the fassaite chemically analyzed. Purification of the sample and the quantitative determination of the physical properties of the fassaite and associated minerals is largely the work of the junior author.

Mineralogy

Techniques.—All optical properties listed were measured in sodium light, and specific gravity values were determined in Clerici solution by means of the suspension method. (In the case of clintonite, methylene iodide was used as the heavy liquid.) Amperage readings for the Frantz Isodynamic Separator are quoted as a measure of paramagnetic susceptibility of the various minerals; in every case the readings apply to a track setting of slope 15° and tilt 12°.

Fassaite.—About three grams of fassaite were purified for analysis and a powder diffraction pattern was obtained for a split from the pure material; this pattern proved to correspond to that of an analyzed diopside, with slight differences in spacing resulting from compositional differences. Other determinations, all made on the material prepared for analysis, are: specific gravity 3.325–3.355 $\pm$ .01, average 3.34; $\alpha = 1.712 \pm .003$, $\beta = 1.719 \pm .003$, $\gamma = 1.736 \pm .003$; $\gamma - \alpha = .024$; and dispersion $r > v$, strong. Optic axial angles were measured on the universal stage for five crystals and both axes were observed in every case. The results, all (+), are: 51, 56, 56, 57, and 58°. $Z \wedge c$, the mean of 10 readings made on a section showing a centered flash figure, is 46°; in white light it was determined to be 47°. Only a few of the grains (100-mesh size) were attracted at 0.45 ampere, but all were attracted at 0.60 ampere.

The analysis is given in Table A; earlier fassaite analyses have been

brought together by Tilley (1938, p. 84). The present example is appreciably higher both in Al_2O_3 (15.75%) and $Al_2O_3+Fe_2O_3$ (21.85%) than any natural fassaite previously recorded. Several studies of synthetic pyroxenes have been made in order to determine the amount of Al_2O_3 that diopside can contain (see for example Schumoff-Deleano, 1917; Zvetkov, 1945; and Segnit, 1953). The results of these studies are not in complete

TABLE A. FASSAITE, LEWIS AND CLARK COUNTY, MONTANA
Analyst: Eileen H. Oslund

	Weight per cent	Metal atoms	
SiO_2	41.36	1.537	2.00
Al_2O_3	15.75	.689 = .463 + .226	2.00
TiO_2	.76	.021	1.00
Fe_2O_3	6.10	.170	1.00
MgO	10.34	.576	1.00
FeO	.24	.007	1.00
MnO	.03	.001	1.00
CaO	25.27	1.006	1.01
Na_2O	.06	.004	1.01
K_2O	.03		
H_2O^+	.10		
H_2O^-	.00		
Total	100.04		

accord, but all indicate that the present occurrence represents at least an approach to the limit of alumina that can be accommodated by the diopside structure. Aside from its low content of SiO_2 and high Al_2O_3 and Fe_2O_3, the Montana fassaite is notable for its extremely high ratio of Fe_2O_3:FeO.

The refractive indices, $Z \wedge c$, and specific gravity of the Montana specimen are all higher than any values previously reported for fassaite. However, several compositional variables are involved, and analytical data are still too few for graphs to be constructed of physical properties against composition.

Spinel.—Spinel comprises about 50 per cent of the rock by volume. The spinel composition appears to average about 30 molecular per cent hercynite and 60 molecular per cent spinel proper, but the compositions suggested by specific gravity, refractive index, and unit cell edge are not mutually consistent. Thus it is apparent that here these properties do not all vary directly with composition in the $FeAl_2O_4$–$MgAl_2O_4$ series. A probable reason is the partial substitution of ferric iron for aluminum and a small amount of other elements for magnesium and divalent iron. A

semi-quantitative spectrographic analysis shows about 0.5 per cent Mn. 0.4 per cent Ca, and traces of Cr, Ni, V, Ti, and Ba. Lines for both Mg and Fe are strong, but those for Mg are the more intense.

The mineral is black in grains of 100-mesh size and grass green in thin section; most of the grains are attracted at 0.45 ampere and all are attracted at 0.53 ampere. The following data were recorded: Specific gravity = 3.67–3.77; R.I. = 1.750 ± .004, and the unit cell edge = 8.111 Å ± .002.

Garnet.—On the basis of physical properties and a semi-quantitative spectrographic analysis, the following composition of the garnet is deduced: grossularite, 76–80; andradite (including a possible minor amount of almandite), 15–18, and pyrope, 3–7. Zoning in a few individual grains was noted, but this is rare.

Practically all of the garnet has a specific gravity of 3.60–3.66; further, over 90 per cent is included in the more narrow range of 3.62–3.64. Therefore the latter material was selected for study, and the following properties and values refer to that garnet with a specific gravity of 3.63 ± .01: R.I. = 1.755 ± .005, and unit cell edge = 11.87 Å ± .01. In grains of 100-mesh size the mineral is off-color white, with a slight suggestion of a yellowish hue; as powder, it is chalk-white. The first grains are drawn off at 0.45 ampere, and all are attracted at 0.55 ampere. Thus the paramagnetic susceptibility of the garnet is very like that of the fassaite. Spectrographic analysis shows that the mineral contains about 5 per cent iron, less than 0.05 per cent manganese, and perhaps as much as 2 per cent magnesium.

Clintonite.—The portion of the sample crushed for fractionation work contained about 5 per cent micaceous materials, but some thin sections suggest that this figure is low as an average for the whole rock. Most of this mica has a specfic gravity of 3.08–3.15; a small portion is between 3.00 and 3.08, and practically none has a gravity of less than 3.00 or more than 3.15. The crushed material is leek green in color. In thin section the mineral shows very faint pleochroism, with X = light orange, Y and Z = pale green. Refractive indices are $\alpha = 1.646 \pm .004$ and $\gamma = 1.659 \pm .004$. Cleavage flakes give centered interference figures with $2V = 5–10°(-)$. The mica is identified as clintonite. This species has previously been reported in contact rocks from the Boulder bathylith: xanthophyllite near Butte by Felts (1947) and clintonite, probably near seybertite, from many localities by Knopf (1953).

Conclusion

The notable features of this rock, in addition to the unusual composition of the fassaite, are the complete absence of carbonate and overall

simplicity of the mineralogy. Practically the entire rock is composed of four minerals, and so by way of summary the main components of these minerals, as they are known or can be approximated, are listed in Table *B*. Since spinel makes up about half the rock, and none of the silicates present contains as much SiO_2 as anorthite, the overall silica content of the rock must be less than 20 per cent.

TABLE B. COMPOSITIONS OF MINERALS IN FASSAITE-SPINEL LODE, HELENA, MONTANA
(Stanford Mineralogy Research Collection Number 7960)

	Weight per cent			
	1	2	3	4
SiO_2	41.36	39–41	—	17–20
Al_2O_3	15.75	18.5–19.5	66–70	39–43
TiO_2	.76	—	Tr	—
Total iron as Fe_2O_3	6.37	4.5– 5.5	9–15	1–4
MgO	10.34	1–3	17–22	20–21
MnO	.03	> .05	.3–.7	—
CaO	25.27	33–35	.4(?)	10–14

1. Analyzed fassaite.
2. Garnet, composition deduced from physical properties and semi-quantitative spectrographic analysis.
3. Spinel, composition estimated from physical properties and semi-quantitative spectrographic analysis, but somewhat problematical.
4. Clintonite, composition as suggested by five clintonite analyses listed by Koch (1935, p. 460).

REFERENCES

1. FELTS, W. M. (1947), Xanthophyllite near Butte, Montana: *Geol. Soc. Am., Bull.* **58,** 1179 (abstract)
2. KNOPF, ADOLPH (1953), Clintonite as a contact-metasomatic product of the Boulder bathylith, Montana: *Am. Mineral.*, **38,** 1113–1117.
3. KOCH, G. (1935), Chemische und physikalisch-optische Zusammenhänge innerhalb der Sprödglimmergruppe: *Chemie der Erde,* **9,** 458–461, esp. p. 460.
4. SCHUMOFF-DELEANO, V. (1917), Synthetische Versuche zur Pyroxengruppe: *Zentralbl. f. Min., Geol. u. Pal.*, 290–304, esp. pp. 295–299.
5. SEGNIT, E. R. (1953), Some data on synthetic aluminous and other pyroxenes: *Mineral. Mag.*, **30,** 218–226.
6. TILLEY, C. E. (1938), Aluminous pyroxenes in metamorphosed limestones, with chemical analyses by H. C. G. Vincent: *Geol. Mag.*, **75,** 81–86.
7. ZVETKOV, A. I. (1945), Synthesis of alumina pyroxenes and dependence of their optics on composition: *Mem. Soc. Russe Min.*, Ser. 2, **74,** 215–222. (With English summary, p. 222.) *Mineral. Abstracts,* **XI,** 92 (1952).

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