

ZINCIAN AEGIRINE-AUGITE AND JEFFERSONITE FROM FRANKLIN, NEW JERSEY

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ABSTRACT

A coarsely crystallized dark colored monoclinic pyroxene found abundantly in skarn zones at Franklin and Sterling Hill, New Jersey, has long been known under the name jeffersonite. It has been classed as a diopsidic pyroxene, but four new chemical analyses (with accompanying x -ray and optical data) establish that it comprises highly zincian and manganous members of a series from aegirine-augite to sodian and ferrian augite. Both Mn^{2+} and Zn are much in excess of Fe^{2+} , with almost 40 atomic per cent Mn in the B position in one analysis. As Fe^{3+} and Na decrease the color changes from reddish brown and mahogany brown to dark olive green and greenish black. The original jeffersonite of Vanuxem and Keating (1822) probably referred to the latter material; the name lacks species or varietal significance and may be set aside.

INTRODUCTION

Three different types of pyroxene have been found in the so-called skarn zones in the orebodies at Franklin and Sterling Hill, New Jersey. The most common type is a manganous and sometimes also zincian variety of diopside. It generally contains MnO in the range from 4 to 10 weight per cent (Table 1, anal. 1 to 5). If little or no Zn is present, this material has been called schefferite, following the varietal name originally proposed by Michaelson (1863) for manganous diopside of similar composition from Langban, Sweden. Variants containing Zn in addition, amounting to about 3 weight per cent ZnO in the reported analyses, were named zinc-schefferite by Wolff (1900). These varieties of diopside are in general light colored, ranging from pale buff to light brown and brown and occur in coarse masses with a basal parting. The second type comprises material relatively high in manganese, falling into the compositional field of johannsenite (Table 1, anal. 9, 10). It occurs very sparingly in the same general association, and forms divergent groups of fibers up to 1 cm or so in length that are white, brownish yellow or pale brown in color.

A third type of pyroxene also occurs. It differs in being very dark in color, usually a dark mahogany brown to brownish or greenish black, and in possessing a somewhat resinous rather than vitreous luster. It occurs as large anhedral masses with an indistinct prismatic cleavage and as coarse crystals, up to a foot in size, of a typical augite habit. This material passes under the name jeffersonite, although, as noted beyond, its

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TABLE 1. OLDER ANALYSES AND OPTICAL CONSTANTS OF PYROXENES FROM FRANKLIN

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
SiO ₂	52.06	51.20	52.86	51.70		49.91	45.95	49.03	50.30	48.29
Al ₂ O ₃		0.27	1.08	.36		1.93	0.85	0.86		
Fe ₂ O ₃		1.50		.37				4.22		
FeO	1.41	1.65				10.53	8.91	3.95	2.59	tr
MnO	4.57	9.96	5.31	7.43	6.86	7.00	10.20	7.91	14.85	26.10
ZnO			3.38	3.31	3.01	4.39	10.15	7.14	3.27	
MgO	15.56	12.70	13.24	12.57		8.18	3.61	5.81	6.19	2.84
CaO	26.30	21.09	24.48	23.68		15.48	21.55	19.88	22.97	22.59
Na ₂ O		0.09		0.12						
H ₂ O+		1.35	0.45	0.65			0.35	0.70		
Rem.		0.32				1.20		0.60		
Total	99.90	100.13	100.80	100.19		98.82	101.57	100.10	100.17	99.82
S.G.				3.39		3.31	3.63	3.55		3.52
α	1.673	1.690	1.676						1.697	1.699
β	1.680	1.699	1.683						1.706	1.712
γ	1.700	1.721	1.705		1.723				1.725	1.734
2V	60° ± 1°	60°	60°							
Z/c	37° ± 1°	43°								46°

1. Diopside. Franklin. Jenkins and Bauer, analysts, cited by Palache (1937). FeO includes Al₂O₃.
2. Schefferite. Sterling Hill. Schaller, analyst, cited in Palache (1910). Recalculated to 100 after deducting 0.43 CO₂ as CaCO₃. Rem. is F 0.32.
3. Zinc-schefferite. Franklin. Wolff (1900).
4. Zinc-schefferite. Franklin. Hillebrand (1900).
5. Zinc-schefferite. Franklin. L. H. Bauer, unpublished analysis.
6. Jeffersonite. Franklin. Hermann (1849).
7. Jeffersonite. Franklin. Pisani (1873).
8. Jeffersonite. Franklin. Steiger, analyst, cited in Palache (1910). Rem. is H₂O—. Re-analysis cited in Table 2.
9. Johannsenite. Franklin. Fairchild, analyst, cited in Schaller (1938).
10. Johannsenite. Franklin. Bauer, analyst, cited in Frondel (1965).

identity with the original jeffersonite of Vanuxem and Keating (1822) is uncertain. It has been classed hitherto as a diopsidic pyroxene, distinguished from schefferite by the presence of Zn and of more than traces of Fe (Palache, 1937). Older analyses attributed to jeffersonite are given in Table 1, analyses 6 to 8. A survey of numerous specimens of this mineral preserved in the Harvard collections has now established that it contains variable and sometimes large amounts of trivalent iron and of sodium, and represents a solid solution extending from aegirine-augite to sodian and ferrian varieties of augite (Table 2, anal. 1 to 5). Considerable amounts of both Mn and Zn are present in all specimens. A description of

this material and a review of the history of jeffersonite is given in following sections.

DESCRIPTION OF SPECIMENS

The dark colored pyroxenes called jeffersonite occur locally in skarn zones in the orebodies and are not constituents of the normal franklinite-willemite-zincite ore. The typical associated minerals are andradite, rhodonite, hendricksite, bustamite, feldspar, apatite, franklinite, willemite and calcite. The indices of refraction of the jeffersonite vary considerably, with γ (Na) usually in the range from 1.74 to 1.78. The highest values were observed in dark brownish black and reddish brown masses up to 3 cm in size intergrown with barium feldspar and andradite. Numerous specimens of this type of material were obtained in 1954 when supporting pillars of ore in the Parker shaft area were mined out. A chemical analysis, cited in Table 2, column 1, establishes this material as a highly zincian and manganous variety of aegirine-augite containing about 40 per cent of the $\text{NaFeSi}_2\text{O}_6$ end-component.

A more common type of jeffersonite is a rich mahogany brown to dark brown in color. It often occurs as anhedral grains up to 3 or 4 cm in size with a more or less distinct parting, but sometimes is very coarsely crystallized. One broken mass showed a parting surface 7 inches across. Another broken single-crystal mass $4 \times 3 \times 2$ inches in size contained numerous rounded inclusions of calcite and of willemite ranging up to about 1 cm in size. Similar specimens have been seen in other collections, and they have been sold in trade under the incorrect name zinc-schefferite. They have a spectacular appearance in ultraviolet radiation, the calcite fluorescing bright salmon pink and the willemite green. An analysis of this material, cited in Table 2, column 2, showed that it is an aegirine-augite with a lower content of Fe^{3+} and Na than the preceding material. Another specimen of this color, the subject of an unpublished analysis by L. H. Bauer, made some years ago, showed jeffersonite associated with massive reddish willemite. The original analysis reported all of the iron as divalent, but a redetermination of the iron showed that the bulk of it is trivalent (Table 2, col. 3).

The jeffersonite analyzed by Steiger (cited in Palache, 1910) and here re-analyzed (Table 2, col. 4) has the lowest content of Fe^{3+} and the highest content of Mg. This material occurs as indistinct crystals embedded in pale pink calcite and has a dark olive black rather than brownish color in the hand specimen. The powder is grayish green instead of the usual brown. Basal parting is well developed. A number of other specimens were observed with a color grading from dark olive green to a dark brownish olive. All of this material has relatively low indices of refraction, with γ (Na) 1.74–1.75. Five specimens analyzed for their Mn con-

TABLE 2. CHEMICAL, OPTICAL AND X-RAY DATA FOR AEGIRINE-AUGITE AND AUGITE FROM FRANKLIN

	1.	2.	3.	4.	5.
SiO ₂	46.38	48.64	46.64	49.28	
TiO ₂	0.10	0.03		tr	
Al ₂ O ₃	1.36	1.42	1.68	1.22	
Fe ₂ O ₃	12.90	9.86	7.06	4.15	
FeO	1.35	0.77	1.10	3.74	
MnO	7.18	7.20	11.37	7.20	10.10
ZnO	8.77	6.89	8.40	7.73	6.46
MgO	1.18	3.55	3.23	5.90	
CaO	14.86	16.65	17.68	19.86	
Na ₂ O	4.99	4.09	2.38	1.05	
K ₂ O	0.18	0.04		0.02	
H ₂ O—	0.25	0.03			
H ₂ O+	0.55	0.73			
Total	100.05	99.90	99.54	100.15	
Si	1.904	1.947	1.903	1.952	
Ti	.003	.001			
Al	.066	.067	.081	.057	
Fe ³⁺	.398	.297	.216	.124	
Fe ²⁺	.046	.026	.038	.124	
Mn	.250	.244	.393	.242	
Zn	.266	.204	.253	.226	
Mg	.072	.212	.196	.348	
Ca	.654	.714	.773	.843	
Na	.397	.318	.188	.080	
K	.009	.002	—	.001	
S.G.	3.59	3.56	3.60	3.55	
α	1.741	1.732		1.714	
β	1.751	1.742		1.723	
γ	1.774	1.763	1.763	1.774	1.752
2V				74°	
Z \wedge c	~60°	~54°		~55°	
d(600)	1.564	1.564	1.565	1.569	1.570
d(440)	1.617	1.617	1.621	1.629	1.630
d(221)	2.514	2.516	2.519	2.524	2.529

- Zincian and manganoan aegirine-augite. Franklin. J. Ito, analyst, 1965.
- Augite. Franklin. Hitherto unpublished analysis by L. H. Bauer. Iron, originally reported entirely as FeO (8.30 weight per cent), redetermined by J. Ito, 1965.
- Augite. Franklin. J. Ito, analyst, 1965. Re-analysis of the material of Steiger, cited in Palache (1910). Original analysis is given in Table 1, column 8.
- Augite. Franklin. Unpublished partial analysis by L. H. Bauer.

tent only gave values between 8.4 and 9.6 weight per cent MnO. The green color probably reflects a low content of Fe³⁺ and increase in Fe²⁺ rather than of Mn²⁺ (Schüller, 1958). This type of material often occurs in rough crystals of a typical augite habit (*cf.* Figs. 77 and 79, Palache, 1937).

Optically, all of the dark brown to brownish black specimens examined were brown or yellowish brown in transmitted light. This material is moderately pleochroic in shades of brown and yellow brown, with absorp-

TABLE 3. X-RAY POWDER DIFFRACTION DATA FOR AEGIRINE-AUGITE

Material of analysis 2, table 2. Cu radiation, Ni filter, λ . Relative intensity in arbitrary chart units. Unit cell dimensions: a 9.776 \pm .006, b 8.939 \pm .006, c 5.270 \pm .008, β 106.20° \pm .05°. Error range refers to least squares standard error of the computation.

I/I.	2 θ	d meas.	hkl	I/I.	2 θ	d meas.	hkl
58	13.68	6.454 Å	110	5	44.30	2.045 Å	420
21	18.92	4.690	200*	4	44.64	2.030	041
16	19.84	4.474	020*	9	45.10	2.009	240
55	27.58	3.234	220*	5	47.86	1.899	51 $\bar{1}$
61	29.78	3.000	22 $\bar{1}$ *	10	48.94	1.859	331
100	30.25	2.955	310*	7	49.60	1.836	42 $\bar{2}$
22	30.76	2.907	31 $\bar{1}$	16	52.04	1.756	150
25	34.90	2.570	13 $\bar{1}$ *	4	54.70	1.676	042
11	35.40	2.536	002, 20 $\bar{2}$	7	54.95	1.670	22 $\bar{3}$
30	35.68	2.516	221*	14	56.44	1.629	44 $\bar{1}$
4	39.12	2.303	311	36	56.90	1.617	440
4	40.65	2.220	040, 122	21	59.02	1.564	600
31	41.85	2.156	330	9	59.58	1.550	35 $\bar{1}$
16	42.22	2.139	33 $\bar{1}$	23	61.34	1.510	060
14	42.72	2.115	42 $\bar{1}$ *	27	65.60	1.422	260

tion $X > Z$. Material with an olive cast of color in bulk is greenish brown in transmitted light and the absorption of X is olive brown. The indices of refraction of these minerals are considerably higher than those of ordinary aegirine-augite of comparable Fe³⁺ content, primarily owing to the content of Zn. It is seen from the data of Table 2 that the indices of refraction decrease with decreasing content of the NaFeSi₂O₆ end-component. This change is accompanied by an increase in the interplanar spacings of (600), (440) and (221) and by a change in color from reddish brown to dark brownish olive and olive green.

Indexed x -ray powder diffraction data for the material of analysis 2, Table 2, is given in Table 3. The indexing is based on that given for aegirine by Frondel and Klein (1965). The unit cell dimensions were obtained from selected reflections, indicated by an asterisk in Table 3, and were refined by the computer program of Burnham (1962).

There is no general agreement as to the nomenclatural boundaries in the series from aegirine through aegirine-augite to augite. Deer *et al.* (1963) have suggested that the boundaries be placed at 70 and 15 atomic per cent of the $\text{NaFeSi}_2\text{O}_6$ end-component, respectively. On this basis the material of analyses 1-3 in Table 2 is aegirine-augite. The dominant divalent cation in the B position is Mn in analyses 2 and 3 and Zn in analysis 1; the terms manganian and zincian are adequate to describe these chemical variations. The material of analysis 4 is a sodian and ferric augite. Divalent Fe is subordinate to Mn, Zn and Mg in all of the analyses. The material of analysis 3 comes close to representing the Mn analogue of ferroaugite (of Poldervaart and Hess, 1951).

Manganian varieties of aegirine have already been described from Chikla, India, with 4.72 weight per cent MnO (Bilgrami, 1956), and from Kachi Dani, India, with 3.60 per cent MnO (Hayden, 1916). The name blanfordite, given by Fermor (1909) to the latter material, is superfluous. Klein (1966) describes aegirine-augite from the Wabush iron district of Labrador, Canada, that contains up to 6.02 per cent MnO. It occurs in an assemblage with rhodonite, specularite, rhodochrosite and calderite. A manganian ferroaugite from a skarn deposit in western Karamazar, U.S.S.R., contains 9.65 per cent MnO (Zharikov and Podlessky, 1955). Both manganian and zincian varieties of aegirine have been synthesized (Schüller, 1958).

The dark pyroxenes here described are quite susceptible to alteration. This first appears as a dull black surface tarnish or coating and ultimately extends to a pseudomorphous conversion to an oxidic mixture, chiefly of Fe and Mn. Porous pith-like pseudomorphs of this kind were very abundant at Sterling Hill, and were called anomalite by Koenig (1879).

JEFFERSONITE

The name jeffersonite was originally given in 1822, for President Thomas Jefferson, by Vanuxem and Keating, two American naturalists. It was among the first given in this country to a supposed new mineral species. A crystallographic description by Troost (1823) clearly established the mineral as a pyroxene; the later crystallographic work on it has been summarized by Palache (1937). The original chemical analysis by Keating and an analysis by Seybert (1824) on a specimen authenticated by Vanuxem were faulty but creditable for the time (Table 4).

Numerous old specimens of jeffersonite that answer the original description of this mineral are preserved in the Seybert collection of the Academy of Natural Sciences of Philadelphia and in the Harvard collection. Some of these date to the first half of the 19th century, but none can be identified with certainty as being type material. There is little doubt

TABLE 4. ORIGINAL ANALYSES OF JEFFERSONITE

	1.	2.
SiO ₂	56.0	45.333
Al ₂ O ₃	2.0	2.000
Fe ₂ O ₃	10.0	9.333
FeO		
MnO	13.5	12.233
ZnO	1.0	2.000
MgO		4.333
CaO	15.1	20.666
Ign. loss	1.0	1.166
Total	99.0	98.064
S.G.	3.55	3.407

1. Keating analysis in Vanuxem and Keating (1822). Dark olive to brown color. Mg overlooked. Valence of Fe not determined.

2. Seybert (1824). Dark olive color, yellow brown powder. Valence of Fe not determined.

that the original material was a pyroxene of the general nature here described, in view of the similarity in chemical composition, aside from the low and perhaps erroneous value of Zn originally reported, and the general agreement in morphological and physical properties. The original material was described as dark green passing into brown in color, with a grayish streak and a light green powder. Most of the older specimens are of this nature. These characters suggest that the original jeffersonite was similar to the aegirine-augite and augite with a relatively low content of Fe³⁺ described in the present study. In any case the name jeffersonite lacks species significance and may be set aside. It does not seem appropriate to reserve the name for redefinition in reference to the manganese analogue of ferroaugite (of Poldervaart and Hess, 1951) should such material be found, as seems likely.

Analyses of material attributed to jeffersonite were later reported by Hermann (1849), Pisani (1873) and Steiger (cited in Palache, 1910). These analyses are cited in Table 1 columns 6, 7 and 8. The material of Steiger was available for study and was completely reanalyzed (Table 2, col. 4). This established the presence of alkalies and verified the other values originally reported; the mineral is here designated as a sodian, ferrian and relatively highly manganoan variety of augite. The analyses of Hermann and of Pisani did not report alkalies or trivalent iron, possibly through error, and it is uncertain whether their material represents a pyroxene of the type described here or pyroxenes in the diopside-hedenbergite-johannsenite series.

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REFERENCES

- BILGRAMI, S. A. (1956) Manganese silicate minerals from Chikla, Bhandura district, India. *Mineral. Mag.* **31**, 236.
- BURNHAM, C. W. (1962) Lattice constant refinement. *Ann. Rpt. Geophys. Lab., Carnegie Inst., 1961-62*, 132.
- DEER, W. A., R. A. HOWIE AND J. ZUSSMAN (1963) *Rock-forming Minerals*. vol. 2, John Wiley & Sons, N.Y., 80.
- FERMOR, L. L. (1906) *Trans. Min. Geol. Inst. India*, **1**, 78.
- FRONDEL, C. (1956) Johannsenite and manganoan hortonolite from Franklin, N.J. *Am. Mineral.* **50**, 780.
- AND C. KLEIN (1965) Ureyite, $\text{NaCrSi}_2\text{O}_6$, a new meteoritic pyroxene. *Science* **149**, 742.
- HAYDEN, H. H. (1916) General Rept. for 1915: Min. and Petrol. *Rec. Geol. Surv. India* **47**, 13.
- HERMANN, R. (1849) Untersuchungen einiger nordamerikanischer Mineralien. *Jour. prakt. Chem.* **47**, 13.
- HILLEBRAND, F. W. (1900) Mineralogical notes: Jeffersonite. *U.S. Geol. Surv. Bull.* **167**, 68-69.
- KLEIN, C. (1966) The mineralogy and petrology of the Wabush Iron Formation, southwestern Labrador. *Jour. Petrol.* (in press).
- KOENIG, G. A. (1879) Anomalite. *Naturalists Leisure Hour, Philadelphia* **3**, 1.
- PALACHE, C. (1937) The minerals of Franklin and Sterling Hill, Sussex County, N.J. *U.S. Geol. Surv. Prof. Paper* **180**, 61.
- (1910) Contributions to the mineralogy of Franklin, N.J. *Am. Jour. Sci.* **29**, 177-187.
- PISANI, F. (1873) Analyse d'une jeffersonite de-Franklin, N.J. *Compt. rend.* **76**, 237-238.
- POLDERVAART, A. AND H. H. HESS (1951) Pyroxenes in the crystallization of basaltic magma. *Jour. Geol.* **59**, 472.
- SCHALLER, W. T. (1938) Johannsenite, a new manganese pyroxene. *Am. Mineral.* **23**, 575-582.
- SCHÜLLER, K. H. (1958) Das Problem Akmit-Ägirin. *Beitr. Mineral. Petrogr.* **6**, 112.
- SEYBERT, H. (1824) Analysis of the pyroxene found at the Franklin Iron Works, near Sparta, N.J. *Am. Jour. Sci.* **7**, 145-149.
- TROOST, G. (1823) Account of the pyroxenes of the United States and descriptions of some new varieties of its crystalline forms. *Jour. Acad. Nat. Sci. Philadelphia* **3**, 105-124.
- VANUXEM, L. AND W. H. KEATING (1822) Account of the jeffersonite, a new mineral discovered at the Franklin Iron Works near Sparta in New Jersey. *Jour. Acad. Nat. Sci. Philadelphia* **2**, 194-204.
- WOLFF, J. E. (1900) Hardystonit und Zinnschefferit von Franklin Furnace, N.J. *Zeit. Krist.* **33**, 147-151.
- ZHARIKOV, V. A. AND K. V. PODELESSKY (1955) On the behavior of pyroxene as a mineral of variable composition in infiltration skarn zones. *Dokl. Acad. Sci. U.S.S.R.* **105**, 1096.