

# Wagnerite with isokite from the Benson Mines, west-central Adirondack Highlands, New York

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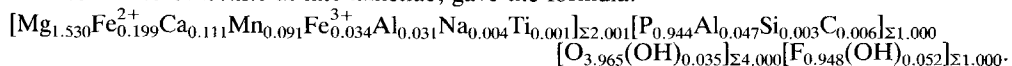
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## Abstract

The rare fluophosphate minerals wagnerite, ideally  $Mg_2(PO_4)F$ , and isokite, ideally  $CaMg(PO_4)F$ , are intimately associated with magnetite-hematite deposits in sillimanite-, garnet-, and pyroxene-rich paragneisses and migmatites at the Benson Mines, near Star Lake in the west-central Adirondack Highlands of New York State. Coarsely crystalline wagnerite occurs in lenticular masses, typically  $4 \times 8$  cm, delineated by sharply cross-cutting, sinuous, 2 cm-wide veins of fine-grained, fibrous to platy isokite and granular fluorapatite. These also penetrate transverse fractures across wagnerite lenses. Isokite formed from the introduction of Ca- and O-rich hydrothermal solutions into wagnerite. Both minerals are monoclinic: wagnerite crystallises in space group  $P2_1/a$  with  $a = 11.945$ ,  $b = 12.717$ ,  $c = 9.70$  Å,  $\beta = 108.18^\circ$ ,  $V = 1400.2$  Å<sup>3</sup>,  $D(\text{calc}) = 3.291$  g/cm<sup>3</sup> for  $Z = 16$ ; isokite crystallises in space group  $A2/a$  with  $a = 6.909$ ,  $b = 8.746$ ,  $c = 6.518$  Å,  $\beta = 112.20^\circ$ ,  $V = 364.7$  Å<sup>3</sup>,  $D(\text{calc}) = 3.248$  for  $Z = 4$ . Optical properties for wagnerite are:  $\alpha = 1.5845$ ,  $\beta = 1.5875$ ,  $\gamma = 1.6010$ ,  $2V = 51^\circ$  (calc.) disp =  $r < v$  weak, absorption  $\alpha < \beta > \gamma$  with  $\alpha = \text{col.}$ ,  $\beta = \text{pale yel.}$ ,  $\gamma = v$ . pale yel. For isokite only a mean index of refraction,  $n = 1.598$ , could be measured. Wet chemical analysis of wagnerite containing a calculated 11.4% of isokite as fine lamellae, gave the formula:



KEYWORDS: wagnerite, isokite, Benson mines, Adirondack Highlands, Grenville Province, New York.

## Introduction and geologic setting

IN 1971 the senior author and the late Leo M. Hall collected several large rock specimens from the Benson Mines, near Star Lake, in the west-central Adirondack Highlands, New York, where magnetite and hematite were mined from 1889 until the mid-1970s. Iron ores are associated with sillimanite-, garnet-, and pyroxene-rich paragneisses and migmatites, all of which are infolded in hornblende granitic and alaskitic orthogneisses that characterise this part of the Adirondack Highlands in the Grenville Province of Middle Proterozoic age. Associated with gneisses are fluorite-bearing granite pegmatite dikes and veins

of diverse mineralogy that carry fluorite, calcite, quartz, malachite and other copper minerals. Buddington (1977), who favoured a hydrothermal origin for the ores, noted that the pegmatites are of two ages, older bodies that were regionally metamorphosed with the ore, and the gneisses and younger bodies that post-date the metamorphic rocks. Palmer (1970) considered that the ores were of sedimentary origin.

One large slab, roughly  $15 \times 20 \times 30$  cm, collected at the surface of a pegmatite dike adjoining sillimanite-martite(hematite)-feldspar gneiss, contains the rare fluophosphate minerals wagnerite,  $Mg_2(PO_4)F$  (Coda *et al.*, 1967, Sheridan *et al.*, 1976) and isokite,  $CaMg(PO_4)F$  (Deans *et al.*, 1955, Fisher, 1957). Apparently monomineralic, vitreous, red-brown wagnerite occurs as typically  $4 \times 8$  cm lenticular masses

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sharply cross-cut by 2 cm-wide veins of a fine-grained, dark gray rock. A fracture lineation in the veins, parallel to their walls, transects prominent fractures developed across the short dimension of the wagnerite lenses (Fig. 1). Fibrous to short-prismatic plates and radial sprays of isokite are developed along vein contacts within fractured wagnerite. Fine-grained, granular fluorapatite is concentrated toward the vein interiors along with a small amount of hematite.

#### Chemical, optical and X-ray data

When optical, X-ray powder diffraction, and spectroscopic tests made in 1971 indicated that the lenticular masses were composed of the rare fluophosphate mineral wagnerite, a complete wet chemical analysis of the material was carried out in 1973 (Table 1). Allowing for minor substitutions, the atomic ratios show close correspondence with published data for wagnerite. Several extraneous reflections measured on the X-ray powder pattern, not accounted for by published data for wagnerite, were not identified and the

study was set aside. It was not resumed until after the retirement of the senior author in 1990, when a grain sample was sent to the U.S. Geological Survey for further X-ray study. There a Guinier-Hägg pattern was prepared, from which 69 reflections were measured. Of these, 53 indexed on the wagnerite lattice, 11 on the isokite cell, and 5 weak reflections remain unidentified. The patterns were made with Cr- $K\alpha_1$  radiation using Si powder (NIST SRM640a) as an internal standard. The wagnerite and isokite patterns were indexed with the aid of patterns calculated from the known crystal structures, as noted in Tables 2 and 3. The intensities were estimated from peak heights on densitometer traces made with a NONIUS Model II Microdensitometer. All these data are given in Table 3.

It was noted that the X-ray sample, although a mixture, appeared microscopically quite homogeneous, as did the material in the original 1971-73 examination; therefore, further microscopic work was carried out. Study of both thin sections and grain immersion mounts revealed that very thin plates, radial sprays, and anhedral grains of

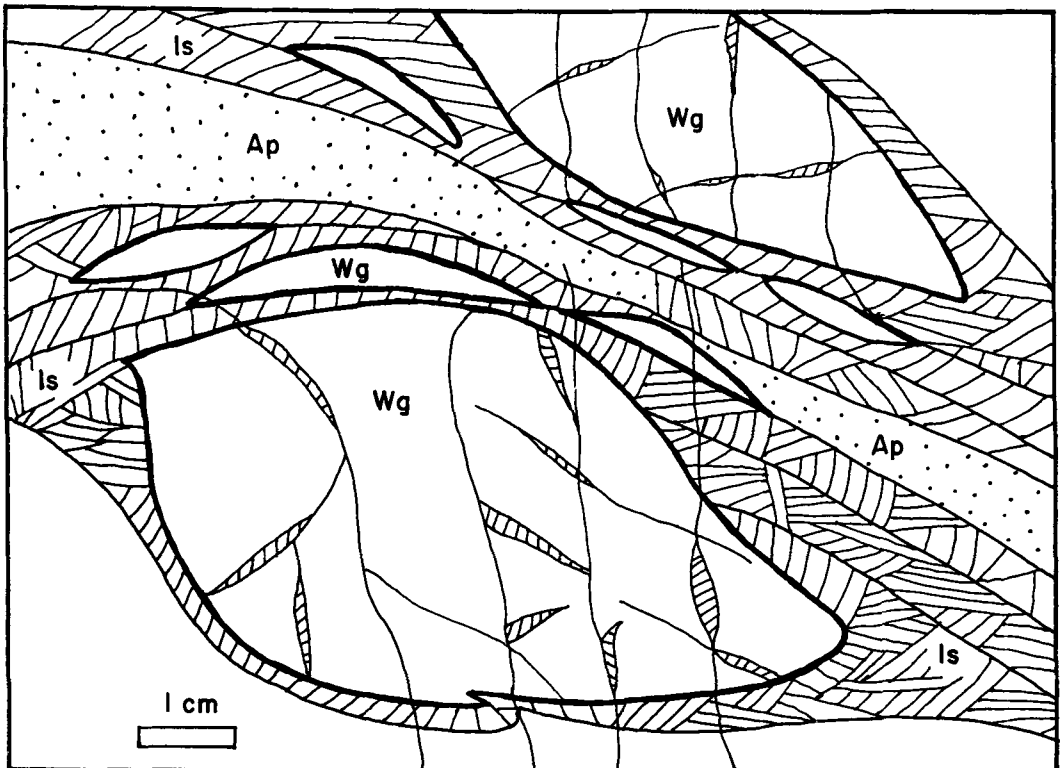


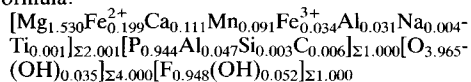
Fig. 1. Fractured wagnerite lenses (clear areas—Wg), transected by fine-grained veins carrying isokite (barred—Is) and fluorapatite (dotted—Ap). Large wagnerite lens is 4 × 8 cm.

Table 1. Chemical analysis of wagnerite, specimen no. 71-JSL-2, Benson Mines, New York

Oxides	wt. %	Atoms per 5[O, (OH), F]	
P <sub>2</sub> O <sub>5</sub>	38.58	P	0.944
As <sub>2</sub> O <sub>5</sub>	0.01	As	0.000
SiO <sub>2</sub>	0.10	Si	0.003
CO <sub>2</sub>	0.15	C	0.006
Al <sub>2</sub> O <sub>3</sub>	2.30	Al <sup>IV</sup>	0.047
		Al <sup>VI</sup>	0.031
TiO <sub>2</sub>	0.03	Ti	0.001
Fe <sub>2</sub> O <sub>3</sub>	1.59	Fe <sup>3+</sup>	0.034
FeO	8.23	Fe <sup>2+</sup>	0.199
MnO	3.70	Mn	0.091
MgO	35.52	Mg	1.530
CaO	3.59	Ca	0.111
Na <sub>2</sub> O	0.08	Na	0.004
K <sub>2</sub> O	0.01	K	0.000
H <sub>2</sub> O	0.45	H	0.087
F	10.36	F	0.948
Sum	104.70		
O = 2F	-4.36		
Total	100.34		

Analyst: Shiro Imai, Japan Analytical Co.

Formula:



Ratios:

$$\text{Mg}/(\text{Mg} + \text{Fe}^{2+} + \text{Mn} + \text{Fe}^{3+}) = 0.825$$

$$\text{Mg}:\text{Fe}^{2+}:\text{Mn}:\text{Fe}^{3+} = 0.825:0.107:0.050:0.018$$

another mineral, isokite, were enclosed and sporadically distributed in host wagnerite.

Because isokite has indices of refraction that overlap those of wagnerite, it is difficult to resolve in fine grains and thin plates. Much of the wagnerite also contains a maximum of one per cent of thin (<0.05 μm), discontinuous lamellae of an unidentified phase with higher index of refraction, and low to negligible birefringence; it may be associated with the unidentified reflections in the X-ray powder pattern. A rare grain of wagnerite contains very small (<0.5 μm), equidimensional inclusions of fluorite, and occasionally magnetite. Optical data for wagnerite and isokite are given in Table 4.

Wagnerite from the Benson Mines would contain 11.4% isokite if the 3.59 wt. % of CaO of the chemical analysis (Table 1) is contained entirely in this phase. Because wagnerites from Bodenmais (Propach, 1976) and from Santa Fe Mountain (Sheridan *et al.*, 1976) contain 4.1 and 1.36 wt. % CaO respectively, not all of the CaO in the Benson Mines sample need reside in isokite. Microscopic examination suggests that 11.4% isokite impurity may be high, although reasonable in regard to the X-ray patterns. X-ray and optical data in Tables 2 and 4 allow calculation of specific refractivities, *K*, for wagnerite and isokite from the Gladstone and Dale equation (Table 5). *K* may also be calculated directly from the chemical analysis (Table 1) by summing the specific refractivity constants (Jaffe, 1988) in proportion to the weight percentages of the analytical components (Table 5). Because the *k*-constant for CaO is greater than that for either MgO, FeO, or MnO (Table 5), replacement of

Table 2. Unit cells of wagnerite and isokite

Mineral Formula Space group Unit cell	Wagnerite (Mg, Fe) <sub>2</sub> [PO <sub>4</sub> ]F P2 <sub>1</sub> /a		Isokite CaMg[PO <sub>4</sub> ]F A2/a	
	Refined <sup>a</sup>	Werfen <sup>b</sup>	Refined <sup>c</sup>	N. Rhodesia <sup>d</sup>
<i>a</i> , Å	11.945(1)	11.957(8)	6.909(1)	6.91
<i>b</i> , Å	12.717(1)	12.679(8)	8.746(2)	8.75
<i>c</i> , Å	9.702(1)	9.644(7)	6.518(2)	6.52
β, deg.	108.18(1)	108.3(2)	112.20(2)	112.1
<i>V</i> , Å <sup>3</sup>	1400.2(2)	1388.1	364.7(1)	365.25
<i>D</i> (X-ray)	3.291	3.135	3.248	3.247

<sup>a</sup> Least squares analysis of 47 wagnerite lines from specimen 71-JSL-2, Benson Mines, New York (Table 3), from composite pattern of mixed wagnerite and isokite.

<sup>b</sup> Parameters of Coda *et al.* (1967), material from Werfen, Austria.

<sup>c</sup> Least squares analysis of 13 isokite lines (Table 3) from composite pattern of New York material.  $\sigma(2\theta) = 0.036$  deg.

<sup>d</sup> Parameters of Deans and McConnell (1955) from Weissenberg patterns of amterial from Northern Rhodesia. Standard setting, transformed from their cell by (101/010/100). Similar unit cell dimensions for wagnerite were obtained by Propach (1976) on material from Bodenmais (Bavarian Forest), by Novák and Povondra (1984) from pyrope-rich rock from Skřínáňov, central Czechoslovakia, and by Irouschek and Armbruster (1984) on material associated with sillimanite gneiss from Tessin, Switzerland.

Table 3. Calculated X-ray powder data for wagnerite and isokite compared with observed data for specimen from Benson Mines, N.Y.

Wagnerite <sup>a</sup>					Isokite <sup>b</sup>					Observed <sup>c</sup>		
<i>h</i>	<i>k</i>	<i>l</i>	<i>d</i> (clc)	<i>I</i> (clc)	<i>h</i>	<i>k</i>	<i>l</i>	<i>d</i> (clc)	<i>I</i> (clc)	<i>d</i> (obs)	<i>I</i> (obs)	2 $\theta$
0	2	1	5.234	12						5.237	8	25.254
-2	2	1	4.240	19						4.236	11	31.356
0	3	1	3.851	7						3.846	2	34.634
2	2	1	3.547	7						3.547	11	37.658
										*3.527 <sup>d</sup>	2	37.881
1	3	1	3.510	1						3.509	5	38.075
					1	1	1	3.439	72	3.442	2	38.852
1	2	2	3.306	36						3.307	53	40.509
3	2	0	3.251	16						3.251	8	41.240
					2	0	0	3.198	29	3.199	10	41.937
0	4	0	3.180	1	-2	2	2	3.176	5	3.178	15	42.234
2	0	2	3.131	57						3.130	75	42.903
-2	3	2	3.016	5	0	0	2	3.017	100	3.019	25	44.577
2	3	1	3.010	4								
-1	4	1	2.981	100						2.982	100	45.148
-4	0	2	2.844	71						2.844	89	47.468
4	0	0	2.836	6						2.839	2	47.503
-2	2	3	2.818	11						2.818	8	47.936
										*2.800	5	48.268
					-2	0	2	2.781	31	2.781	5	48.616
2	4	0	2.774	7						2.775	11	46.736
0	2	3	2.766	36						2.766	28	48.896
-4	2	1	2.703	16						2.704	28	50.107
										*2.625	19	51.707
0	4	2	2.617	2						2.615	4	51.919
					2	2	0	2.582	44	2.582	11	52.650
-2	4	2	2.555	3						2.555	8	53.250
-3	4	1	2.479	15						2.480	14	54.992
-2	0	4	2.414	7						2.414	5	56.621
0	0	4	2.304	4						2.305	5	59.575
					1	3	1	2.2995	7	2.2995	11	59.718
-1	2	4	2.2533	10						2.2531	2	61.077
-1	5	2	2.2502	2						2.2512	2	61.134
2	4	2	2.2309	8						2.2309	8	61.752
0	5	2	2.2268	3						2.2250	2	61.934
					-2	3	1	2.2156	10	2.2158	11	62.222
-5	2	2	2.2017	20						2.2014	14	62.671
-3	2	4	2.1751	4						2.1752	2	63.511
										*2.1636	2	63.894
-3	5	1	2.1401	1						2.1369	2	64.791
-4	4	2	2.1198	8						2.1199	11	65.374
1	1	4	2.1029	1						2.1039	4	65.934
1	6	0	2.0835	4								
1	4	3	2.0828	10						2.0827	17	66.694
					1	4	0	2.0691	16	2.0690	4	67.191
0	6	1	2.0646	10						2.0658	17	67.311
										*2.0391	5	68.311
-2	6	1	1.9858	5						1.9858	11	70.413
-6	0	2	1.9802	5						1.9801	5	70.647
2	0	4	1.9349	11						1.9347	19	72.531
-2	4	4	1.9224	4						1.9217	11	73.133
2	6	1	1.8988	5						1.8983	11	74.184
6	0	0	1.8914	7						1.8917	11	74.504
-6	2	1	1.8890	11						1.8888	17	74.618
1	5	3	1.8693	1						1.8795	2	75.475
0	4	4	1.8658	4						1.8656	5	75.710
-6	2	3	1.8172	3						1.8171	5	78.104

Table 3—continued

Wagnerite <sup>a</sup>					Isokite <sup>b</sup>					Observed <sup>c</sup>		
<i>h</i>	<i>k</i>	<i>l</i>	<i>d</i> (clc)	<i>I</i> (clc)	<i>h</i>	<i>k</i>	<i>l</i>	<i>d</i> (clc)	<i>I</i> (clc)	<i>d</i> (obs)	<i>I</i> (obs)	2θ
5	1	2	1.8047	2						1.8050	2	78.732
-5	4	3	1.7975	8						1.7975	11	79.126
-4	4	4	1.7788	4						1.7783	8	80.149
0	2	5	1.7706	3						1.7707	5	80.566
-2	6	3	1.7574	3								
-4	2	5	1.7570	5						1.7571	14	81.320
5	2	2	1.7526	2						1.7524	5	81.584
0	6	3	1.7447	9						1.7441	8	82.531
5	4	1	1.7287	7								
-4	6	1	1.7284	11						1.7281	25	82.983
					2	2	2	1.7197	22	1.7188	14	82.531
					-2	4	2	1.7189	13			
					-4	0	2	1.7043	16	1.7041	5	84.417
3	2	4	1.6795	16						1.6790	22	85.977
-5	5	3	1.548	1						1.6552	8	87.525
-3	7	1	1.6513	3						1.6517	5	87.759
3	6	2	1.6322	2						1.6325	2	89.062

<sup>a</sup> Intensities calculated for wagnerite crystal structure of Coda *et al.* (1967), using refined unit cell of specimen no. 71-JSL-2 from Benson Mines, New York (footnote c).

<sup>b</sup> Intensities calculated for titanite crystal structure of Taylor and Brown (1976), and chemistry of isokite (CaMgPO<sub>4</sub>F), in refined unit cell of New York material (footnote c).

<sup>c</sup> Measured *d*-spacings (Å) obtained from a Guinier-Hägg pattern, made with Cr-Kα<sub>1</sub> radiation (λ = 2.2897 Å) and Si internal standard, of specimen 71-JSL-2 from Benson Mines, New York. Peak intensities measured with a Nonius Model II Microdensitometer. Refined unit cells for wagnerite and isokite are given in Table 2.

<sup>d</sup> Reflections marked by an asterisk are not indexed by either wagnerite or isokite.

Table 4. Optical properties of wagnerite and isokite

	Wagnerite			Isokite N. Rhodesia <sup>d</sup>
	New York <sup>a</sup>	Sante Fe Mt. <sup>b</sup>	Werfen <sup>c</sup>	
α	1.5845	1.565–1.571	1.5678	1.590
β	1.5875	1.567–1.572	1.5719	1.595
γ	1.6010	1.578–1.585	1.5824	1.615
2Vγ	51° (calc)	28–33°	28°; 64° (calc)	52°; 54° (calc)
Disp.	r < v weak	r > v weak	r > v	r > v

<sup>a</sup> This report; pleoch.: α col., β pale golden yel., γ v. pale yel.; abs. α < β > γ, β = *b*, OAP (010); clvg. (010) impf., (100) impf. For enclosed isokite plates, mean *n* = 1.598.

<sup>b</sup> Sheridan *et al.* (1976).

<sup>c</sup> Hegemann and Steinmetz (1927).

<sup>d</sup> Deans and McConnell (1955); αΛc = 32°.

wagnerite by isokite, as postulated here, should result in an increase in specific refractivity. Data of Table 5 verify that the specific refractivity calculated from the chemical analysis, 0.1803, is slightly larger than that for wagnerite, 0.1796, and much smaller than that for isokite, 0.1841. If the *k*-values for wagnerite and isokite are proportioned in the ratio 88.6:11.4, the resulting *K* = 0.1801 is close to that calculated from the chemical analysis and tends to verify X-ray estimates of the isokite impurity.

### Paragenesis

We suggest the paragenetic sequence to be: (1) growth of large wagnerite masses in pegmatite followed by (2) deformation of the pegmatite with infolded gneisses and magnetite deposits during regional metamorphism, with development of lenses or augen of wagnerite, and (3) fracturing of wagnerite with pervasive introduction of hydrothermal Ca- and O-rich solutions resulting in the partial conversion of wagnerite to isokite in

Table 5. Specific refractivity data for wagnerite, isokite, and their mixture

	Wagnerite	Isokite
<i>n</i> (mean) <sup>a</sup>	1.591	1.598
<i>D</i> (X-ray) <sup>b</sup>	3.291	3.248
<i>K</i> (meas.) <sup>c</sup>	0.1796	0.1841
<i>K</i> (chem. analysis) <sup>d</sup>		0.1803
<i>K</i> (88.6:11.4) <sup>e</sup>		0.1801

<sup>a</sup>  $(\alpha + \beta + \gamma)/3$ , from Table 4.

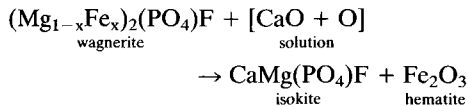
<sup>b</sup> From Table 2.

<sup>c</sup> Specific refractivity, from law of Gladstone and Dale,  $K = (n - 1)/D$ .

<sup>d</sup> Specific refractivity calculated from chemical analysis (Table 1), where  $K = \sum kp$ ,  $k$  is the specific refractivity constant and  $p$  is weight per cent of each oxide constituent. Some relevant  $k$ -values are: for CaO, 0.226; for MgO, 0.200; for FeO, 0.185; for MnO, 0.190 (Jaffe, 1988).

<sup>e</sup> Weighted  $K$ -values for 88.6% wagnerite, 11.4% isokite.

fracture zones. Thus, ferroan wagnerite plus hydrothermal solutions might yield isokite plus hematite according to the scheme:



Wagnerite,  $\text{Mg}_2[\text{PO}_4]\text{F}$ , magniotriplite,  $(\text{Mg,Fe,Mn})_2[\text{PO}_4][\text{F,OH}]$ , triplite,  $\text{Mn}_2[\text{PO}_4]\text{F}$ , and triploidite,  $\text{Mn}_2[\text{PO}_4](\text{OH})$  are structurally related fluophosphate minerals commonly occurring in pegmatite and in hydrothermal vein

deposits. Coda *et al.* (1967) found that wagnerite from Werfen, Austria, crystallised in space group  $P2_1/a$  with  $Z = 16$  and a  $b$  axis of 12.679 Å (Tables 2 and 3). Tadini (1981), in a single-crystal study of magniotriplite from Albères in the Pyrénées, found that it crystallises in space group  $A2/a$  with  $Z = 8$  and a  $b$ -axis dimension of 6.432 Å, one-half that of wagnerite. Tadini (1981) concluded that these minerals are related by an order-disorder relationship, whereby F atoms are ordered in the wagnerite structure, and disordered in the  $A2/a$  structure of magniotriplite. On this basis they assigned the manganese fluophosphate minerals triploidite to  $P2_1/a$ , and triplite to  $A2/a$ .

As might be expected, the (Fe + Mn)-rich members have higher mean indices of refraction ( $n$ ), density ( $D$ ), molecular refractivity ( $R$ ), larger molar volume ( $V_m$ ), and  $b$ -axis dimensions than the Mg-rich members (Table 6).

In conclusion, it may also be noted that isokite ( $\text{CaMg}[\text{PO}_4]\text{F}$ ), titanite ( $\text{CaTi}[\text{SiO}_4][\text{F, O, OH}]$  above 220 °C, durangite ( $\text{NaAl}[\text{AsO}_4]\text{F}$ ), tilasite ( $\text{CaMg}[\text{AsO}_4]\text{F}$ ), and malayaite ( $\text{CaSn}(\text{SiO}_4)\text{O}$ ) are isostructural minerals that crystallise in space group  $A2/a$  or  $C2/c$  (Table 2, this report; Deans *et al.*, 1955; Speer and Gibbs, 1976; Taylor and Brown, 1976; Takenouchi, 1971).

#### Acknowledgements

We gratefully acknowledge the assistance of our esteemed colleague Mary E. Mrose, in providing critical advice and giving generously of her special knowledge of the mineralogy of the fluophosphates of magnesium, iron, and manganese. We are thankful also to Richard

Table 6. Systematic increase in unit cell dimensions, molar volume, density, mean index of refraction ( $n$ ), and molecular refractivity ( $R$ ) with decrease in Mg/(Mg + Fe + Mn) ratios in wagnerite and triplite

	Mg/(Mg + Fe + Mn)	$b$ , Å	$V_m$ , cm <sup>3</sup>	$D$ , g/cm <sup>3</sup>	$n$ (mean) <sup>a</sup>	$R$ , cm <sup>3</sup>
<i>Wagnerite, P2<sub>1</sub>/a, Z = 16</i>						
Werfen	0.98	12.679	52.25	3.14	1.574	29.99
Sante Fe Mt.	0.97	12.671	52.07	3.16	1.576	29.99
Benson Mines	0.825	12.717	52.71	3.29	1.591	31.14
<i>Magniotriplite, I2/a, Z = 8</i>						
Hällsjöberget <sup>d</sup>	0.66	12.762 <sup>b</sup>	53.06	3.43	1.618	32.73
Turkestan <sup>e</sup>	0.44	12.830 <sup>b</sup>	53.96	3.66	1.650	35.18
Albères <sup>f</sup>	0.44	12.864 <sup>b</sup>	54.01	3.68	1.655	35.37
<i>Triplite</i>						
Mica Lode <sup>g</sup>	0.35	12.908 <sup>b</sup>	55.98	3.62 <sup>c</sup>	1.653 <sup>c</sup>	36.34

<sup>a</sup> Mean index of refraction  $(\alpha + \beta + \gamma)/3$ .

<sup>b</sup> Value cited is  $2b$ . Triplite minerals ( $I2/a$ ) have  $b$  unit cell dimension 1/2 that of wagnerite ( $P2_1/a$ ).

<sup>c</sup> Values reduced where Mn > (Fe + Mg).

<sup>d</sup> Henriques (1957).

<sup>e</sup> Ginzburg *et al.* (1951).

<sup>f</sup> Fontan (1981).

<sup>g</sup> Waldrop (1967).

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### References

- Buddington, A. F. (1977) *Guidebook for field trips: Petrology and mineral deposits, northwestern and northern Adirondack Area*. A. F. Buddington, Princeton University, pp. 35–41.
- Coda, A., Giuseppetti, G., and Tadini, C. (1967) The crystal structure of wagnerite. *Atti Acc. Naz. Lincei., Serie VIII*, **43**, 211–24.
- Deans, T. and McConnell, J. D. C. (1955) Isokite,  $\text{CaMgPO}_4\text{F}$ , a new mineral from Northern Rhodesia. *Mineral. Mag.*, **30**, 681–90.
- Fisher, D. J. (1957) Isokite and triplite from Bohemia. *Ibid.*, **31**, 587–602.
- Fontan, F. (1981) La magniotriplite ferrifère du massif des Albères (Pyrénées-Orientales, France). Une nouvelle variété. *Bull. Mineral.*, **104**, 672–6.
- Ginzburg, A. I., Kruglova, N. A., and Moleva, V. A. (1951) Magniotriplite—a new mineral of the triplite group. *Dokl. Akad. Nauk. SSSR*, **76**, 97–100 (in Russian).
- Hegemann, F. and Steinmetz, H. (1927) Die Mineralgange von Werfen, im Salzkammergut. *Centralblatt Mineral. Geol. Pal.*, 1927A, 45–56.
- Henriques, Å. (1957) An iron-rich wagnerite, formerly named talktriplite, Hållsjöberget (Horrsjöberget), Sweden. *Arkiv Mineral. Geol.*, **2**, 149–53.
- Irouschek, A. and Armbruster, Th. (1984) Hydroxylhaltiger Wagnerit aus dem Ambra (Tessin, Schweiz). *Fort. Mineral.*, **62**, Beiheft 1, 109–10.
- Jaffe, H. W. (1988) *Crystal Chemistry and Refractivity*. Cambridge University Press, Cambridge and New York; ch. 11, pp. 118–46.
- Novák, M. and Povondra, P. (1984) Wagnerite from Skřínářov, central Czechoslovakia. *Neues Jahrb. Mineral., Mh.*, 536–42.
- Palmer, D. F. (1970) Geology and ore deposits near Benson Mines, New York. *Econ. Geol.*, **65**, 31–9.
- Propach, C. (1976) Wagnerit von Bodenmais (Bayerischer Wald). *Neues Jahrb. Mineral., Mh.*, 157–9.
- Sheridan, D. M., Marsh, S. P., Mrose, M. E., and Taylor, R. B. (1976) Mineralogy and geology of the wagnerite occurrence on Santa Fe Mountain, Front Range, Colorado. *U.S. Geol. Survey Prof. Paper*, **955**, 1–23.
- Speer, J. A. and Gibbs, G. V. (1976) The crystal structure of synthetic titanite,  $\text{CaTiO}[\text{SiO}_4]$ , and the domain textures of natural titanites. *Am. Mineral.*, **61**, 238–47.
- Tadini, C. (1981) Magniotriplite: its crystal structure and relation to the triplite-triploidite group. *Bull. Mineral.*, **104**, 677–80.
- Takenouchi, S. (1971) Hydrothermal synthesis and consideration of the genesis of malayaite. *Mineral. Deposita*, **6**, 335–47.
- Taylor, M. and Brown, G. E. (1976) High temperature structural study of the  $P2_1/a \leftrightarrow A2/a$  phase transition in synthetic titanite,  $\text{CaTiOSiO}_4$ . *Am. Mineral.*, **61**, 435–47.
- Waldrop, L. (1969) The crystal structure of triplite,  $(\text{Mn,Fe})_2\text{FPO}_4$ . *Zeit. Krist.*, **130**, 1–14.

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