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DETAILED DESCRIPTION OF SARCOPSIDE FROM EAST ALSTEAD, NEW HAMPSHIRE[1]

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ABSTRACT

The name *sarcopside*, originally given by Websky to a mineral mixture from Michelsdorf, Silesia was shown by Čech, Paděra and Povondra to be an intergrowth of graftonite and another mineral which has now assumed the name *sarcopside*. In a restudy of this material and similar intergrowths from East Alstead and Deering, New Hampshire, a third mineral, vivianite, was found to be present. It appears certain that earlier chemical analyses were made on mixtures of graftonite, sarcopside and vivianite.

Data for sarcopside from East Alstead, New Hampshire follows. Electron probe analysis gives: FeO 50.2, MnO 6.9, MgO 3.5, P_2O_5 39.8, total 100.4. Formula: $(Fe, Mn, Mg)_3(PO_4)_2$. *X*-ray study yields: $a=10.47$ Å, $b=4.80$, $c=6.06$, $\beta\sim90°$, $P2_1/a$. $a:b:c=2.181:1:1.263$. Specific gravity 3.79 (meas.), 3.798 (cal. for two formula-units per unit cell). Optically biaxial (−); $\alpha=1.670$, $\beta=1.728$, $\gamma=1.732$, $2V=28°$. Optical orientation appears to be consistant with triclinic not monoclinic symmetry. Polysynthetically twinned on $\{001\}$.

The oriented lamellar intergrowth is viewed as the result of the breakdown of an original homogeneous phase, $(Fe, Mn, Ca, Mg)_3(PO_4)_2$, into two phases, sarcopside and graftonite. The present study established that all the CaO and a relatively high proportion of the MnO are concentrated in the graftonite.

INTRODUCTION

Although sarcopside was described by Websky as a new mineral in 1868, its true nature was not revealed until 1962. In that year, Čech *et al.* (1962) in writing on the *Sarcopside Problem*, pointed out that both the original material of Websky from Michelsdorf, Silesia, and that described by Holden (1920, 1924) from Deering, New Hampshire were mixtures of two minerals. One of these minerals is graftonite and the other sarcopside. Since the mixtures consisted of about equal amounts of the two minerals, the question might arise as to which, if to either, should the name *sarcopside* be given. With the adequate description and naming of one of these phases graftonite, by Penfield (1900), the other major mineral of the intergrowth from Michelsdorf and Deering has assumed the name sarcopside.

In their study of a pegmatite at Otov, near Domažlice, Bohemia, Čech *et al.* (1962) noted sarcopside-graftonite intergrowths and give a chemical analysis of the mixture. These authors believe that similar intergrowths described by Weber (1948) from Domažlice, Bohemia and by Laubmann and Steinmetz (1920) from Marchaney, near Tirschenreuth, Germany are also sarcopside-graftonite.

A fifth occurrence of sarcopside-graftonite is at the French King No. 2

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quarry, East Alstead, New Hampshire, reported by Peacor and Garske (1964). The present study of material from this last locality was well underway when the paper by Peacor and Garske appeared. Although the work was in part a duplication, it treats several aspects of the problem not considered by them which seem worthy of recording.

The French King No. 2 quarry is located in one of the many small pegmatites found in this area of New Hampshire. Quarrying operations for mica in 1961 revealed near the original surface a roughly spherical knot three feet in diameter composed essentially of iron-manganese phosphates. The dark brown to black altered exterior of the knot gave way toward the center to fresher material of a light brown to gray color. A number of secondary phosphates including strengite, metastrengite, rockbridgite, strunzite and vivianite were present at the border. The core was composed essentialy of what appeared to be a typical triphylite-graftonite intergrowth penetrated by dark blue to black veins of vivianite and associated pyrite. An optical examination revealed fresh graftonite but showed the "triphylite" as pointed out by Peacor and Garske (1964) to be sarcopside.

Vivianite appears to be commonly associated with sarcopside. Websky (1868) states that the original sarcopside was coated with a thin film of vivianite, and both Holden (1920) and Weber (1948) record it as an alteration product. But no mention is made by these authors that vivianite occurs intimately associated with the sarcopside-graftonite intergrowths.

SARCOPSIDE-GRAFTONITE INTERGROWTH

The largest specimen examined from East Alstead measured 45×20×14 centimeters, and is composed of two types of sarcopside-graftonite intergrowths. The first is tabular in which alternating layers of the two minerals 0.1–1.0 millimeter thick can be traced with only minor interruptions across the surface from 10 to 20 centimeters (Fig. 1a). (In this type the ratio of graftonite to sarcopside is about 50:50.) The second type of intergrowth is more intimate and less well-defined (Fig. 1b) with a fibrous to columnar habit and evidence of cleavages both parallel to and across the length. Macroscopically it is difficult to distinguish the two minerals that occur in the ratio of graftonite to sarcopside about 40:60. Although the two types of intergrowths occur at both Michelsdorf and Deering, it is undoubtedly the fibrous aggregate that Websky (1868) and Holden (1920) assumed to be a single species.

Sarcopside has good {100} and {001} cleavage and in Type 2 intergrowth at both Deering and East Alstead {100} cleavage is parallel to the length of the fibers and {001} cleavage across the length. In this type

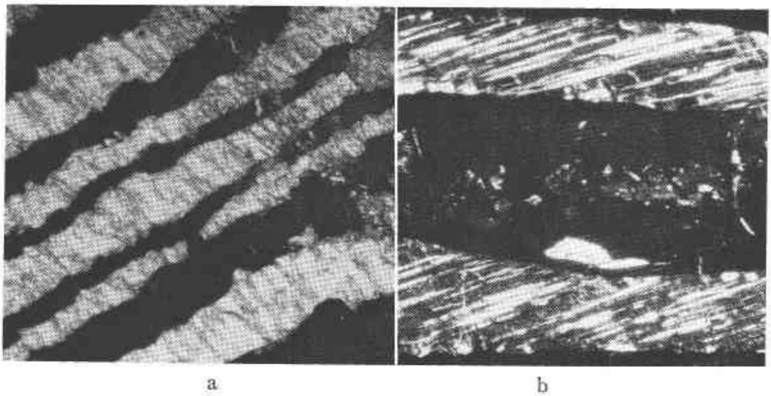

FIG. 1. Type 1, coarsely laminated graftonite-sarcopside intergrowth, East Alstead, New Hampshire a. Graftonite, black; light bands sarcopside. Vivianite veinlet crosses at right angle to lamellae. Crossed polars. Area 1.5×1.5 mm. b. Graftonite, black; gray bands sarcopside with vivianite (white) along cleavage cracks. Crossed polars. Area 0.5×0.5 mm. a. and b. from same specimen but sections at right angles to one another

[001] and [010] of graftonite are respectively parallel to [001] and [010] of sarcopside. In the platy, Type 1, intergrowth {100} cleavage is always at right angles to the graftonite-sarcopside interface which is {010} of graftonite. In all of this type of intergrowth from Deering the {001} cleavage makes an angle of approximately 59° with {010} of graftonite. For East Alstead material the {001} cleavage of sarcopside makes varying angles with {010} of graftonite. Most frequently observed are 17°,

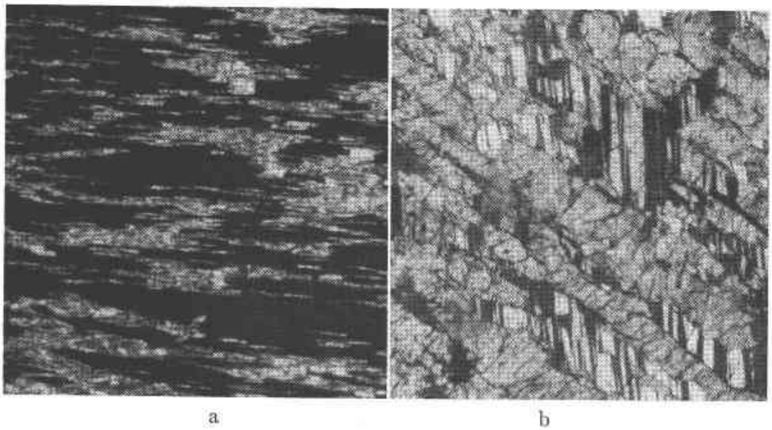

FIG. 2. Type 2, fibrous graftonite-sarcopside intergrowth, East Alstead, New Hampshire. a. Graftonite, black; sarcopside, gray. Crossed polars. Area 1.5×1.5 mm. b. Graftonite gray, sarcopside shows polysynthetic twinning. Crossed polars. Area 0.5×0.5 mm.

32° (most common), 59°, and 90°. Thus the following planes of sarcopside are approximately parallel to {010} of graftonite: 17°, {014}; 32°, {012}; 59°, {043}; 90°, {010}.

The physical properties of sarcopside from East Alstead can be summarized as follows: cleavage {001} and {100} good, {010} poor. Hardness 4. Specific gravity 3.79 (meas.). Colorless when fresh but usually gray to brown due to slight alteration.

Optical Properties

In thin section one can see that the contact between the two minerals in the platy type of intergrowth is not a plane but an undulating surface essentially parallel to {010} of graftonite (Fig. 1a). In the fibrous type the intergrowth is more intimate and individual lamallae of sarcopside are interrupted and discontinuous (Fig. 2a). The graftonite shows a uniform extinction over large areas but the appearance of the sarcopside varies greatly depending on the orientation. In some, polysynthetic twinning resembling that of plagioclase feldspar with twin plane {001} is strikingly observed (Fig. 2b). In others the sarcopside does not show sharp extinction because the light travels through several of the twin individuals (Fig. 1a). This polysynthetic twinning can be considered characteristic of sarcopside since it has been observed on the mineral from all known localities.

Table 1. Optical Properties of Sarcopside

	1	2[1]	3[1]	4[1]
α	1.675	1.675	1.670	1.676
β	1.728	1.730	1.728	1.730
γ	1.730	1.734	1.732	1.733
Sign	(−)	(−)	(−)	(−)
Orientation	z=b X∧c=45°	—	See Fig. 3	—
2V	Small	26°	28°	26°
Dispersion	r>v	r>v	r>v	r>v

1. Deering, New Hampshire data from Larsen and Berman (1934).
2. Deering, New Hampshire, this study.
3. East Alstead, New Hampshire, this study.
4. Michelsdorf, Silesia, this study.

[1] Indices reported for sodium light ±0.001.

With the exception of the data given by Larsen and Berman (1934), the optical properties of sarcopside have been inadequately reported. This

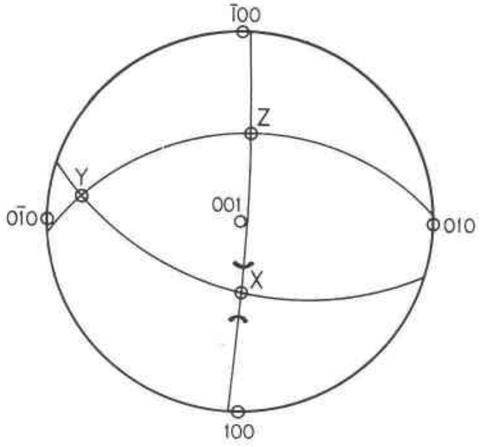

FIG. 3. Apparent optical orientation of sarcopside.
X—ϕ 86°, ρ 42°; Y—ϕ −172°, ρ 80°; Z—ϕ −74°, ρ 50°

undoubtedly is due in part to the universal polysynthetic twinning that makes it nearly impossible to obtain even a very small single crystal fragment.

Sarcopside is monoclinic as clearly shown by precession and Weissenberg *x*-ray photographs. Thus a crystal fragment lying on the {100} cleavage should show parallel extinction against the {001} cleavage. This is not the case. On such a fragment the twins are visible and give symmetrical extinction of 10° against the trace of the twin plane. Furthermore there is symmetrical extinction of 8° on {001} and 42° on {010}. The apparent optical orientation is shown in Fig. 3. Such an orientation obviously belongs to a triclinic crystal but efforts to resolve the inconsistency of crystal system and optical orientation were unsuccessful.

X-RAY STUDY

Unit cell dimensions of sarcopside from East Alstead were determined from Weissenberg and precession diffraction data. They are given in Table 2 with those obtained on Michelsdorf material by Mrose and Appleman (1961) and those determined on East Alstead and Deering material by Peacor and Garske (1964).

The crystals on which the determinations were made (Col. 1, Table 2) were polysynthetically twinned but the lattice is so neary orthogonal that the photographs appear as though obtained from single crystals.

There is such a strong resemblance between sarcopside-graftonite intergrowths and triphylite- or lithiophilite-graftonite intergrowths that

TABLE 2. UNIT CELL DIMENSIONS OF SARCOPSIDE

	1	2	3	4	5
a	10.47Å	10.46Å	10.49Å	10.48Å	6.10Å
b	4.80	4.80	4.82	4.80	10.46
c	6.06	6.05	6.07	6.06	4.74
β	90°	90°30′	90°	90°45′	
Space group	$P2_1/a$	$P2_1/a$	$P2_1/a$	$P2_1/a$	$Pmnb$
	Sarcopside			Lithiophilite	
	$a:b:c=2.181:1:1.263$			$b:c:a=2.206:1:1.280$	

1. East Alstead, present study.
2. East Alstead, Peacor and Garske (1964).
3. Deering, Peacor and Garske (1964).
4. Michelsdorf, Mrose and Appleman (1961).
5 Lithiophilite, synthetic, Geller and Durand (1960)

one may easily be confused with the other. Structurally triphylite and lithiophilite are very closely related to sarcopside as pointed out by Mrose and Appleman (1961). This similarity is shown by the unit cell dimensions of synthetic lithiophilite determined by Geller and Durand (1960) which are given in Table 2 for comparison with those of sarcopside. Moreover the two best cleavages of lithiophilite {100} and {010} correspond respectively to {001} and {100}, the two best cleavages of sarcopside.

Čech *et al.* (1962) give x-ray powder data on sarcopside-graftonite mixtures from Michelsdorf, Deering, Domažlice and Otov and compare them with those published by McConnell (1942), for Deering sarcopside. Of these, McConnell's data are in closest agreement with those obtained during the present study. The others are all very similar to one another and indicate, as is expected, graftonite lines but vivianite spacings are even more abundant. All the d spacings given for material from the four localities are accountable as having arisen from the three minerals: sarcopside, graftonite, and vivianite. In Table 3 are given the observed d spacings on carefully selected sarcopside from East Alstead from which vivianite had been separated by means of heavy liquids. Even using this material, the strongest vivianite line (d=6.71 Å) was present, but is omitted from the table.

CHEMISTRY

All evidence points to the fact that the chemical analyses of "sarcopside" from Michelsdorf (Websky, 1868) and Deering (Holden, 1920) were made on mixtures containing both sarcopside and graftonite. Weber (1948) recognized two distinct phosphate minerals at Domažlice which he

TABLE 3 X-RAY POWDER DATA FOR SARCOPSIDE FROM EAST ALSTEAD, NEW HAMPSHIRE (FeK$\bar{\alpha}$=1.93728Å; FeKα_1=1.93597Å; Mn FILTER)

I	d (obs)	d (calc)	hkl	I	d (obs)	d (calc)	hkl
50	6.06	6.060	001	15	2.047	2.052	221
20	5.24	5.235	200	5	1.885	1.881	022
						1.885	203
30	4.37	4.363	110				
				20	1.833	1.833	113
40	3.95	3.961	201			1.831	412
15	3.76	3.763	001	20	1.769	1.771	222
						1.769	420
80	3.54	3.538	210				
		3.541	111	5	1.744	1.745	600
100	3.03	3.030	002	10	1.694	1.698	421
50	2.819	2.832	310	10	1.601	1.600	030
10	2.610	2.618	400	5	1.579	1.578	520
30	2.558	2.562	012	10	1.544	1.546	023
		2.559	311				
				10	1.529	1.530	230
25	2.486	2.489	112				
				5	1.513	1.512	602
20	2.400	2.400	020				
				10	1.450	1.452	701
15	2.340	2.339	120				
				10	1.425	1.428	710
10	2.301	2.301	212				
		2.298	410	10	1.413	1.415	032
10	2.180	2.182	220	5	1.361	1.365	430
		2.182	121				

Unit cell dimension a=10.47Å, b=4.80Å, c=6.06Å, β=90°. The calculated d values were obtained on an I.B.M. 7094 Computer using a program for calculation of all possible d spacings. Computer time was obtained on N.S.F. Grant No. GP-2723, Harvard University.

was unable to separate and analyzed a mixture of the two. Likewise, Čech *et al.* (1962) give an analysis of material recognized by them as a sarcopside-graftonite aggregate, from Otov. These analyses are given in Table 4.

Macroscopic inspection of the sarcopside-graftonite intergrowth from

TABLE 4. CHEMICAL ANALYSES OF SARCOPSIDE-GRAFTONITE MIXTURES

	1	2	3	4	5	6
CaO	3.40	4.38	5.23	4.43		4.29
MgO		0.68	0.62	0.23	3.44	1.44
MnO	20.57	10.83	16.42	19.43	10.85	17.66
FeO	30.53	39.87	36.15	34.26	34.37	33.10
ZnO				0.49		
Fe_2O_3	8.83	1.70		0.20	4.30	1.22
Al_2O_3				0.66		
Li_2O					1.33	0.23
SiO_2						0.26
P_2O_5	34.73	33.26	40.20	40.46	40.57	41.08
H_2O^+	1.94	1.53	1.07	0.42	2.85	0.20
H_2O^-			0.1	0.45	2.43	0.35
F		4.35		0.01		
Insol.		3.22	0.45			
Total	100.00	99.82	100.29	100.44	100.12	99.83
Sp. Gr.	3.73	3.64	3.70–3.72	3.651	3.53	3.71

1–4 Sarcopside-graftonite mixtures

1. Michelsdorf, Silesia; Websky (1868)
2. Deering, New Hampshire; Holden (1920)
3. Domažlice, Bohemia; Weber (1948)
4. Otov, near Domažlice, Bohemia; Čech *et al.* (1962)

5 Sarcopside—vivianite mixture; East Alstead, New Hampshire; Jun Ito, analyst (1964).

6 Graftonite, East Alstead, New Hampshire; Jun Ito, analyst (1964).

East Alstead indicated that the well-laminated material of the two minerals could be separated. It was coarsely crushed and the gray sarcopside was hand picked from the reddish-brown graftonite. Chemical analyses of these are given in columns 5 and 6 of Table 4.

In comparing the analysis of the East Alstead "sarcopside" with the sarcopside-graftonite aggregates, two striking differences are noted. First it contains no CaO, and second it has a much higher percentage of H_2O. This would indicate that the CaO of the aggregates was contributed entirely by the graftonite and that the other mineral, presumably sarcopside, is hydrous. If it is assumed that the aggregate analyses were made on 50–50 mixtures, and graftonite is anhydrous, it would indicate that double the reported H_2O is present in the sarcopside. This raises it to amounts that cannot be ignored.

A thin section study of both East Alstead and Deering intergrowths showed a third mineral, vivianite, to be universally present. It occurs along cleavage planes of the sarcopside and along the contacts between

TABLE 5. ELECTRON MICROPROBE *X*-RAY ANALYSES

	1	2	3	4			
				Analysis	Mol. Ratios	Atomic Ratios	Atoms per Cell
CaO	0.1	4.4	0.0	0.0			
MgO	2.5	1.0	2.7	3.5	.0853	.0853	0.59
MnO	7.4	16.4	6.2	6.9	.0968	.0968	0.67 } 6.10
FeO	34.0	36.9	51.3	50.2	.6959	.6959	4.84
P_2O_5	28.7	41.4	39.7	39.8	.2793	.5586	3.89
Total	72.7	100.1	99.9	100.4			
H_2O (by difference)	27.3						

C. Klein, analyst. Analyses made with Applied Research Laboratories instrument using graftonite (anal. 6, Table 4) as a standard. Because of the similarity in composition of the standard and the phases analysed, only background corrections were made.

1. Vivianite, East Alstead.
2. Graftonite, Deering, New Hampshire.
3. Sarcopside, Deering, New Hampshire.
4. Sarcopside, East Alstead, New Hampshire.
   For sarcopside: $M = V. d. N$, $V = 304.6$, d (meas) $= 3.79$, $N = 6.02252$, $M = 695.3$.
   Calculated density 3.797, $Z = 2$.

the two minerals. (Fig. 1b). Although vivianite is largely associated with the sarcopside, in places veinlets of it are seen crossing both sarcopside and graftonite (Fig. 1a). The water reported in the several analyses of the aggregates undoubtedly is contributed by vivianite which contains a high percentage (*ca.* 29% H_2O). The intergrowth of vivianite and sarcopside is so intimate that a complete heavy liquid separation of the two minerals proved impossible. Accordingly, electron microprobe analyses of sarcopside and vivianite from East Alstead and Deering were made on polished thin sections, coated with a layer of carbon several hundred Ångstroms thick. The results are given in Table 5.

It will be noted that analyses 3 and 4 (Table 5) are very similar. The formula derived from the chemical analysis (4, Table 5) closely approximates $(Fe, Mn, Mg)_3(PO_4)_2$. With $Z = 2$, the unit cell content is $2[(Fe, Mn, Mg)_3(PO_4)_2]$. From crystallographic and structural consideration Mrose and Appleman (1961) derived the formula $2[(Fe, Mn, Ca)_3(PO_4)_2]$. Except for the inclusion of CaO in the latter formula and MgO in the former, the two are the same. Čech *et al.* in discussing the results of the chemical analyses of sarcopside-graftonite aggregates from Domažlice and Otov give a ratio of $RO{:}P_2O_5$ as 3:1. They argue that since this is the ratio in both graftonite and in the mixture, it follows it must also be the ratio in sarcopside. It seems certain that vivianite was also present as a third phase in the aggregates; but since the ratio of $RO:P_2O_5$ in that mineral is also 3:1, this conclusion remains valid.

It appears that the graftonite-sarcopside intergrowths are the result of exsolution as suggested by Peacor and Garske (1964). Although in most specimens the amount of sarcopside exceeds that of graftonite, the uniform orientation of graftonite indicates that it is the host. Exsolution resulted in two anhydrous minerals, graftonite and sarcopside from a parent phase, $(Fe, Mn, Ca, Mg)_3(PO_4)_2$. Although iron and manganese are present in both, the sarcopside contains a higher percentage of FeO and the graftonite a higher percentage of MnO than did the parent. The major chemical difference between the two is the complete absence of CaO in sarcopside and its concentration in graftonite. Also there is a considerable concentration of MgO in sarcopside compared to the parent phase. The vivianite, universally present, is a much later alteration product.

ACKNOWLEDGMENTS

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REFERENCES

ČECH, F., K. PADĚRA AND P. POVONDRA, (1962) The sarcopside problem: *Acta Univ. Carolinae Geol.* **3.**

HOLDEN, C. F. (1920) An American occurrence of sarcopside. *Am. Mineral.* **5,** 99–102.

——— (1924) Further notes on sarcopside. *Am. Mineral.* **9,** 205–207.

LARSEN, E. S. AND H. BERMAN (1934) The microscopic determination of the nonopaque minerals. *U. S. Geol. Survey Bull.* **848.**

LAUBMANN, H. AND H. STEINMETZ (1920) Phosphatführende Pegmatite des Oberpfälzer und Bayerischen Waldes. *Zeit. Kryst.* **55,** 523–586.

MCCONNELL, D. (1942) X-ray data on several phosphate minerals. *Am. Jour. Sci.* **240,** 649–657.

MROSE, M. E. AND D. E. APPLEMAN (1961) Crystal structure and crystal chemistry of sarcopside, $(Fe, Mn, Ca)_3(PO_4)_2$. *Prog. Am. Cryst. Assoc. Ann. Meet.* 18–19.

PEACOR, D. R. AND D. GARSKE (1964) Sarcopside from Deering and East Alstead, New Hampshire. *Am. Mineral.* **49,** 1149–50.

PENFIELD, S. L. (1900) Graftonite a new mineral. *Am. Jour. Sci.* 4th ser. **9,** 20–32.

WEBER, A. (1948) The phosphates in the pegmatites of S.W. Bohemia. *Bull. Inter. Acad. Tehèque* **58,** No. 1.

WEBSKY, M. (1868) Sarkopsid, ein neues Mineral aus Schlesien. *Neues Jahbr. Mineral.* 606–607.