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BEUSITE, A NEW MINERAL FROM ARGENTINA, AND THE GRAFTONITE-BEUSITE SERIES[1]

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ABSTRACT

Beusite, $(Mn, Fe, Ca, Mg)_3(PO_4)_2$ is the manganese analogue of graftonite and with it forms a continuous series. The new mineral was found in granite pegmatites in three localities in San Luis Province, Argentina: Los Aleros, Amanda and San Salvador. The mineral from Los Aleros has the following properties: It occurs in rough prismatic crystals up to 30 cm long, interlaminated with lithiophilite. Beusite is monoclinic, $2/m$; space group $P2_1/c$, $a=8.78$, $b=11.52$ and $c=6.15$ Å, $\beta=99°25'$, $a:b:c=0.7621:1:0.5338$; volume 613.7 Å^3; Z=4. Strongest lines in X-ray powder photograph are in Å: 3.50 (100), 2.863 (100), 2.708(60), 3.13(40), 1.924(40), 3.01(35), 2.89(30), 2.402(30).

The new mineral is optically biaxial, positive, $\alpha=1.702$, $\beta=1.703$, $\gamma=1.722$, $2V=25°$, $r>v$ strong, $X=b$ $Z\wedge c=37°$. The color is reddish-brown, cleavage: {010} good, {100} fair. The hardness is 5; density 3.702 (meas), 3.715 (calc).

A wet chemical analysis recalculated to 100 percent is: CaO, 4.78; MgO, 2.64; FeO, 14.62; MnO, 36.56: P_2O_5, 41.40. DTA shows one endothermic peak at 960°C resulting from fusion.

Optical properties, specific gravity and analyses by X-ray fluorescence and atomic absorption show beusite from San Salvador and Amanda to be similar to that from Los Aleros.

The differences in the properties that result from changes in FeO:MnO ratio are offset by MgO and CaO making a chemical analysis necessary to distinguish between graftonite and beusite.

The interlaminated lithiophilite is interpreted as exsolved from a high temperature disordered phase. A wet chemical analysis of this mineral from Los Aleros recalculated to 100 percent is: Li_2O, 9.58; Na_2O, 0.03; FeO, 13.04; MnO, 23.02; MgO, 6.45; P_2O_5, 47.88. Optical properties of triphylite-lithiophilite from five localities and of graftonite from Ranquel and Cacique Canchuleta, all from San Luis, are presented.

Beusite is named in honor of Professor Alexey Beus, formerly Professor of Mineralogy and Geochemistry, Moscow Polytechnical Institute.

INTRODUCTION

During a field study of granite pegmatites in Argentina (1964 and 1965) specimens of what appeared to be graftonite–triphylite intergrowths were collected from four localities in the Province of San Luis (Fig. 1). The most remarkable specimens, because of size and freshness, came from the small pegmatite locally known as Los Aleros. The others came from the mines: San Salvador, Amanda, and Cacique Canchuleta. An additional specimen showing a similar intergrowth from the Ranquel mine in the same province was given to us by Dr. María A. R. Benyacar.

The physical properties and X-ray powder photographs of the "graf-

[1] Mineralogical Contribution No. 457, Harvard University.

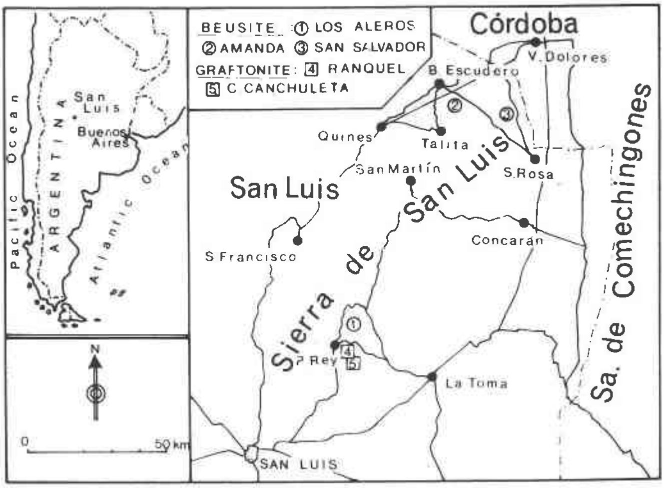

FIG. 1. Beusite and graftonite localities, San Luis, Argentina.

tonite" pointed to the presence of this mineral in all specimens. However, chemical analyses of the graftonite-like mineral from the first three aforementioned localities showed MnO to be in excess of FeO rather than the reverse which is characteristic of graftonite. This indicated the necessity of discriminating between graftonite and the manganese analogue.

A review of the literature shows uncertainty regarding the names applied to the minerals whose general formula can be expressed as $(Fe, Mn, Ca, Mg)_3(PO_4)_2$. De Jesús (1933) described as mangualdite a mineral whose chemical analysis yielded a formula close to $2MnO \cdot CaO \cdot P_2O_5$, but whose physical properties were somewhat different from those of graftonite. Mason (1941) mentions the "graftonite-mangualdite group" (p. 119) thus suggesting a series existed between the two minerals. However, in an addendum to the same paper (p. 175) he found by X-ray examination of type material that mangualdite is a member of the apatite group.

In 1950 Beus determined the weight percentages of oxides in a graftonite-like mineral as: FeO, 16.95: MnO, 30.77; CaO, 0.54; MgO, 9.50. The principal lines in a X-ray powder photograph of this mineral check with those of graftonite, but the physical properties are incomplete. Beus stressed the high content of MgO by naming the mineral magniophilite, although his was the first analysis of a graftonite-like mineral in which MnO was greater than FeO. Brooks and Shipway (1960) also presented a chemical analysis (p. 522) of a "member of the graftonite isomorphous series" in which MnO exceeds FeO.

Since the mineral of Brooks and Shipway (Australia) and the minerals from Los Aleros, San Salvador and Amanda (Argentina) are very low in MgO (1.2 to 2.56 wt. %) the name magniophilite is inapplicable to them. Recent chemical analyses suggest (see Fig. 5) that a complete solid solution exists, as in many other phosphates, between iron and manganese but only partial solid solution with regard to magnesium and calcium. To avoid further confusion in the nomenclature, we propose the name beusite for those members of the series in which the weight percent of MnO is greater than FeO.

Beusite[1] (pronounced bay′ oosite) is named in honor of Alexey Beus, the first to report a mineral in the graftonite series in which Mn exceeded Fe. Dr. Beus, formerly Professor of Mineralogy and Geochemistry, Moscow Polytechnical Institute, is at present a Technical Adviser to the United Nations Secretariat.

Geological Setting

The beusite and graftonite localities in San Luis Province, Argentina are located on the eastern slope of the Sierra de San Luis. These mountains, part of the Sierras Pampeanas, begin at the city of San Luis and extend to the Sierra de los Comechingones, approximately 150 kilometers to the northeast. They are fault-block mountains with sharp escarpments to the northwest but tilted toward the southeast and rise above sea level to an elevation of 2000 meters, or 1500 meters above the surrounding plains.

The basement complex of the Sierra de San Luis is formed essentially of schists, gneisses, and quartzites, that have been intruded by granite with the formation of migmatites. The metamorphic rocks strike N–S with, in general, an easterly dip ranging from 40° to 90°. Genetically associated with the granite are abundant pegmatites and aplites. The age of the basement rocks is given as pre-Cambrian (González Bonorino, 1950; Linares, 1959) but other authors consider it Lower to Middle (?) Paleozoic. (Pastore and Ruiz Huidobro, 1952; Pastore and Gonzáles, 1954). The erosion following the uplift of the sierra during the Tertiary removed most of the pre-Tertiary and Tertiary sedimentary rocks leaving only minor patches of Permian rocks. Finally, minor effusions of Tertiary andesitic rocks and Quarternary basalts complete the general geologic picture of the sierra.

For details of the geology of the region one is referred to the papers by Pastore and Ruiz Huidobro (1952). Pastore and González (1954), González (1957) and Methol.[2]

[1] The mineral and name have been approved by the Commission on New Minerals and Mineral Names, IMA.

[2] Methol, E. (1964) Descripción geológica de la Hoja 22 h, Santa Rosa, Provincia de San Luis, *Argent. Repub. Dir. Nac. Minería.* Unpublished.

Occurrence

The pegmatites of the Sierra de San Luis are tabular or lenticular, concordant bodies, generally zoned and many contain lithium and beryllium minerals. (Angelelli and Rinaldi, 1963; Herrera, 1963). All of them at which beusite or graftonite were found have commercial amounts of spodumene, beryl or muscovite, a characteristic of two-thirds of the reported graftonite localities.

The obscure Los Aleros pegmatite located in the Departamento de Pringles, San Luis Province, is 800 meters to the west of the large pegmatite and beryl mine known as Santa Ana. This mine can be reached by following a secondary road 35 kilometers from La Toma toward Paso del Rey and from this point following the mine road for 8 kilometers to the north.

The Los Aleros pegmatite is tabular with N.S. strike and 80° dip to the east conforming to the enclosing mica schist. At the southern end of a small prospect pit (14 m long, 1.5 m wide, 5 m deep) rough prismatic crystals of beusite up to 30 centimeters in length were collected. Triplite and tourmaline were found in addition to quartz, microcline, plagioclase and muscovite.

In the northern part of the Sierra de San Luis, approximately 100 kilometers from Los Aleros in the Departamento Junín, there are two beryl mines known as Amanda and San Salvador. On the dumps at both of these pegmatites, specimens of beusite were collected. Amanda is approximately 36 kilometers northwest of Santa Rosa south of the road between this town and Balde de Escudero. San Salvador is approximately 20 kilometers NNW of Santa Rosa, west of the road from Santa Rosa to Punta del Agua.

A few kilometers south of Los Aleros and south of the Paso del Rey—La Toma road are the pegmatites of Ranquel and Cacique Canchuleta operating for beryl and muscovite. Graftonite was collected from the dump at Cacique Canchuleta but that from Ranquel was given to us.

All the beusite and graftonite from these Argentine localities are fresh with the exception of graftonite from Cacique Canchuleta which has partially altered to heterosite. This change is similar to the first stage of alteration reported by Stanek (1955).

Physical and Optical Properties

Beusite. Fresh beusite from Los Aleros is reddish-brown with the cleavages: {010} good and {100} fair. Its hardness is 5 and specific gravity, measured on the Berman Balance is 3.702 ± 0.005. The luster is vitreous and the streak pale pink. The optical properties are given in column 12 of Table 1. The physical properties of beusite from Amanda

TABLE 1. RELATION OF DIVALENT METAL OXIDES TO OPTICAL PROPERTIES AND SPECIFIC GRAVITY OF GRAFTONITE AND BEUSITE[a]

	Graftonite									Beusite		
	1	2	3	4	5	6	7	8	9	10	11	12
CaO[b]	14.02	7.59	22.22	15.94	9.20	10.24	12.25	14.44	8.13	21.70	5.79	8.15
MgO[b]	0.93	2.55		0.69	1.17	0.17	4.77	4.74		4.32	3.97	4.50
FeO[b]	57.45	58.60	50.07	52.94	53.18	52.38	45.33	42.24	47.92	29.88	31.07	24.96
MnO[b]	27.60	31.26	27.71	30.43	36.45	37.21	37.65	38.58	43.95	44.10	59.17	62.39
α	1.705	1.711	1.695	1.700	1.710	1.709	1.700	1.698	1.709	1.695	1.708	1.702
β	1.708	1.713	1.699	1.705	1.716	1.714	1.701	1.700	1.714	1.696	1.711	1.703
γ	1.722	1.728	1.719	1.724	1.735	1.736	1.720	1.722	1.733	1.715	1.723	1.722
$2V$	43°	40°	50°	55°	50°	53°	20°	30°	55°	25°	45°	25°
$G.$	3.71	3.71	—	3.672	3.756	3.775	—	3.738	3.783 (av)	—	3.698	3.702

[a] Arranged according to decreasing ratio of FeO:MnO.

[b] Weight percent as recalculated from analyses, Tables 5 and 6.

1. Brissago, Switzerland, Parker, *et al.* (1939). 2. East Alstead, N.H., U.S.A., Hurlbut, (1965); optics, this study. 3. Rice Mine, N.H., U.S.A., Lindberg (1950). 4. Grafton, N.H., U.S.A., Penfield (1900) and Lindberg (1950). 5. São Luiz do Paraitinga, São Paulo, Brazil, Franco and Porto (1952). 6. Nickel Plate Mine, South Dakota, U.S.A., Lindberg (1950). 7, 8, 10, 11 and 12 respectively: Ranquel, C. Canchuleta, Amanda, San Salvador and Los Aleros. All from San Luis, Argentina. This study. Indices: Na light, ±0.001. 9. Greenwood, Maine, U.S.A., Glass and Fahey (1937).

and San Salvador are similar to those from Los Aleros; their optical properties are summarized in the same table, columns 10 and 11 respectively.

To compare the optical properties and specific gravities of the minerals of the graftonite-beusite series, selected sets of values are given in Table 1 with FeO, MnO, CaO and MgO expressed as weight percentage of the total amount of the divalent metal oxides. Included with these are data on graftonite from two new localities in Argentina, Ranquel and Cacique Canchuleta, columns 7 and 8 respectively. All members of the series are optically positive and have strong to very strong dispersion with $r>v$. No pleochroism was observed in the minerals from Argentina.

No clear cut relations could be established between optical properties, specific gravity and variation in chemical composition. However, as is to be expected in an iron-manganese series, there is a trend for both indices of refraction and specific gravity to increase with increasing percentage of iron. At the same time the effect of calcium and magnesium is to markedly decrease these values offsetting the differences related to iron and manganese. Consequently, optical and physical properties are not diagnostic in distinguishing even those members of the series having greatly different Fe: Mn ratios. For example, compare columns 4 and 12 of Table 1. Although, there are insufficient data to generalize, a small axial angle may result from a high manganese content.

Intergrown mineral. Lithiophilite was identified as the mineral interlaminated with beusite found in all the San Luis localities. The identification of this mineral from Los Aleros was made by chemical analysis and physical properties. The lithium mineral from the other localities was determined by optical properties and/or its alteration products. However, for certain identification of triphylite-lithiophilite, the determination should be verified by chemical means since the triphylite-lithiophilite series is subject to the same variation in properties as is this graftonite-beusite series. The optical properties and alteration products of the lithiophilite are summarized in Table 2.

Lithiophilite from Los Aleros is unusually fresh, with gray color, cleavage: {100} perfect, {010} fair, and {011} poor. The measured specific gravity is 3.365. The strongest lines in an X-ray powder photograph are in Å: 3.013 (100), 2.525 (62), 4.287 (62), 3.488 (48), 5.149 (32), 2.778 (22), 3.921 (22) and 2.463 (20).

Because of their high quality the specimens from this locality offered an excellent opportunity to study the relationship of the interlaminated mineral. Individual layers of uniform thickness extend for more than 10

TABLE 2. OPTICAL PROPERTIES AND ALTERATION PRODUCTS OF TRIPHYLITE-LITHIOPHILITE[a] INTERLAMINATED WITH BEUSITE AND GRAFTONITE FROM SAN LUIS, ARGENTINA

Locality	α	β	γ	$2V$	Sign	Dispersion	Alteration
Los Aleros	1.665	1.669	1.672	80°	—	$r<v$	fresh
San Salvador	1.672	1.673	1.683	25°	+	$r<v$	partially to sicklerite
Amanda	1.673	1.675	1.680	70°	+	$r<v$	partially to sicklerite and purpurite
C. Canchuleta	—	—	—	—	—	—	completely to purpurite or heterosite
Ranquel	1.669	1.676	1.678	55°	—	$r<v$	partially to ferrisicklerite and heterosite

[a] Na light ± 0.001.

centimeters (see Fig. 2) with their thicknesses roughly inversely proportional to their density distribution.

Observations made on three mutually perpendicular thin sections from a large fragment indicate that all the beusite layers have a common crystallographic orientation. The lithiophilite on the other hand presents several optical orientations, as seen in Figure 3. The interface of the layers is an undulating surface essentially parallel to the best cleavage, {010}, of beusite.

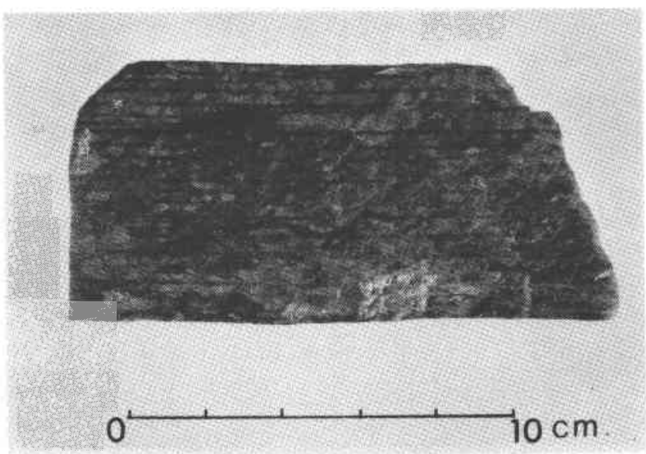

FIG. 2. Fragment of beusite-lithiophilite from Los Aleros, San Luis. The narrower bands are lithiophilite, darkened by a slight surface alteration.

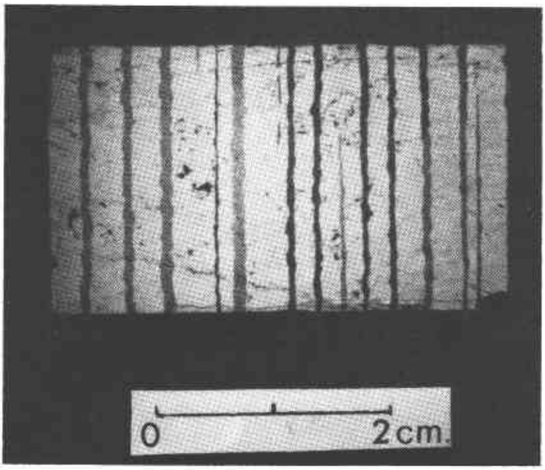

FIG. 3. Beusite-lithiophilite thin section from the center of a crystal. Note the lithiophilite (dark) shows two orientations whereas the beusite is constant throughout. Crossed polars.

To establish the crystallographic relationship of the two minerals, fragments were selected composed of both phases in which the orientation of beusite was known. Using the optical goniometer the cleavages of lithiophilite were identified and three types of intergrowth were established. Given in order of decreasing frequency these are:

	Beusite		Lithio.		Beusite		Lithio.
1.	(010)	‖	(110)	and	[101]	‖	[$\bar{1}$10]
2.	(010)	‖	(522)	and	[102)	‖	[0$\bar{1}$1]
3.	(010)	‖	(121)	and	[100]	‖	[2$\bar{1}$0]

Toward the edges of the rough crystals the regular banding gives way to a fine granular intergrowth of the same phases (see Fig. 4). All the characteristics of the intergrowth argue more strongly for exsolution from a parent phase than does rhythmic deposition as suggested by Penfield (1900) or replacement along graftonite cleavages by late stage pegmatitic solutions. The granular texture is interpreted as rapid cooling from crystal boundaries with reduced ionic mobility.

The mineral intergrown with graftonite at Ranquel was established as triphylite by an electron microprobe analysis (Mn:Fe). That from Cacique Canchuleta is completely altered to purpurite or heterosite.

X-RAY STUDY OF BEUSITE

Beusite is monoclinic, $2/m$. The extinctions in single crystal X-ray precession photographs (Mo/Zr) taken with b and c as the precession axes yield the space group $P2_1/c$ the same as reported for graftonite by

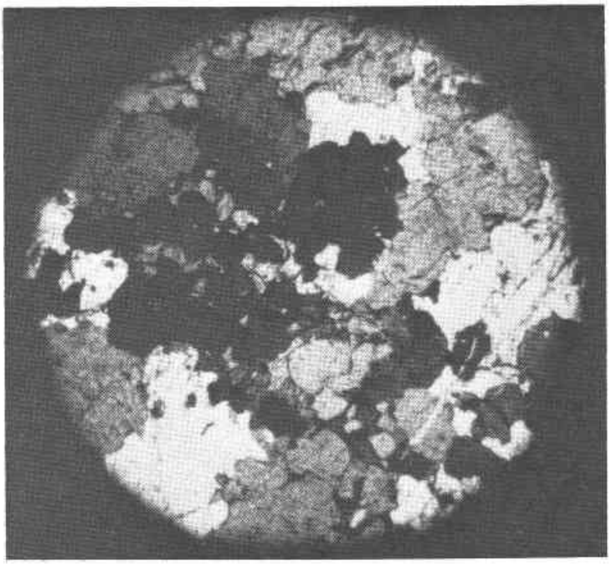

FIG. 4. Photomicrograph of thin section of the granular intergrowth of beusite-lithiophilite from the edge of a crystal. Crossed polars. Diameter of field 2 mm.

Lindberg (1950). Table 3 presents the cell dimensions of beusite from Los Aleros, San Luis and of graftonite from the Nickel Plate Mine, South Dakota.

The spacings of beusite given in Table 4 were derived from powder

TABLE 3. UNIT-CELL DATA FOR BEUSITE AND GRAFTONITE

	Beusite (Los Aleros—San Luis)	Graftonite[a] (Nickel Plate Mine, South Dakota)
a	8.78 ±0.01 Å	8.87 Å
b	11.52 ±0.01 Å	11.57 Å
c	6.15 ±0.01 Å	6.17 Å
β	99° 25′ ± 15′	99° 12′ ± 15′
$a:b:c$	0.7621:1:0.5338	0.766:1:0.533
Cell volume Å^3	613.7	625
Z	4	4
Space group	$P2_1/c$	$P2_1/c$
Density:		
measured	3.702 ± 0.005	3.775
calculated for $(Mn_{1.77}Fe_{0.70}Ca_{0.29}Mg_{0.22})(PO_4)_2$	3.715	

[a] Lindberg (1950).

TABLE 4. X-RAY POWDER DATA FOR BEUSITE AND GRAFTONITE
(Fe Kα = 1.93728 Å, Fe Kα₁ = 1.93597 Å; Mn filter) Camera diameter 114.59 mm

Beusite[a]				Graftonite[b]	
Los Aleros, San Luis, Argentina				Nickel Plate, S.D., U.S.A.	
I	d (obs.) Å	d (calc)[c] Å	hkl[c]	I	d (obs.) Å
20	4.29	4.293	111	2	4.31
		3.607	121	1	3.61
100b	3.49	3.510	130	9	3.50
		3.462	220		
—	—	—	—	1	3.36
40	3.13	3.130	$\bar{1}31$	1	3.17
—	—	—	—	1	3.08
35	3.01	3.021	$\bar{1}02$	4	3.02
25	2.94	2.955	131	4	2.956
		2.934	012		
30	2.89	2.887	300	2	2.902
		2.880	040		
100b	2.863	2.873	230	10	2.860
20	2.846	2.850	221	1	2.810
60	2.708	2.712	$\bar{3}11$	7	2.715
		2.701	$\bar{2}02$		
—	—	—	—	1	2.550
5	2.502	2.511	$\bar{3}21$	1	2.510
		2.494	231		
30	2.402	2.402	311	3	2.412
		2.398	240		
5	2.372	2.375	132	2	2.377
5	2.301	2.303	$\bar{2}41$	1	2.311
5	2.273	2.286	$\bar{3}02$	1	2.271
		2.268	212		
5	2.222	2.227	150	1	2.230
		2.224	132		
5	2.137	2.147	222	2	2.133
		2.128	410		
5	2.064	2.063	151	2	2.067
10	2.038	2.039	340	2	2.042
		2.034	250		

Beusite[a]				Graftonite[b]	
Los Aleros, San Luis, Argentina				Nickel Plate, S.D., U.S.A.	
I	d (obs.) Å	d (calc)[c] Å	hkl[c]	I	d (obs.) Å
5	1.967	1.970	$\bar{2}42$	1	1.970
		1.965	$\bar{3}32$		
40	1.926b	1.932	$\bar{2}13$		
		1.927	$\bar{1}23$	2	1.927
		1.920	060		
5	1.891	1.891	$\bar{4}12$	1	1.892
5	1.874	1.876	113	1	1.875
		1.879	$\bar{4}31$		
10	1.832	1.831	061	1	1.836
		1.832	$\bar{1}52$		
5	1.802	1.801	350	1	1.802
		1.803	242		
		1.805	$\bar{1}33$		
—	—	—	—	1	1.788
5	1.754	1.755	260	2	1.757
		1.753	$\bar{2}52$		
5	1.732	1.733	431	1	1.733
		1.732	500		
		1.731	440		
5	1.712	1.713	510	1	1.711
5	1.680	1.680	351	2	1.687
5	1.654	1.655	043	1	1.658
		1.654	223		
20	1.635	1.640	402	—	—
		1.632	252		
		1.630	$\bar{3}33$		
10	1.616	1.617	170	2	1.617
5	1.598	1.599	360	1	1.600
		1.596	$\bar{4}42$		
Plus 12 additional lines.				Plus 30 additional lines	

[a] This study.
[b] Lindberg (1950).
[c] Calculated on an IBM 7094 Computer.

photographs (Cu/Ni) but with intensities obtained from diffractometer charts. The calculated *d* values and indices were determined with an IBM 7094 Computer. A comparison of these with spacings of graftonite from the Nickel Plate Mine given in the same table, shows no clear cut relation with chemical composition. The same is true for all the published *d* values of members of the series.

CHEMICAL ANALYSES

Beusite. Beusite and lithiophilite from Los Aleros were separated for chemical analysis. Because the bands are comparatively wide and easily

TABLE 5. CHEMICAL ANALYSIS OF BEUSITE FROM LOS ALEROS, SAN LUIS, ARGENTINA

	Wt % 1	Wt % recalculated 2	Atomic proportions 3		4 (P=2)
CaO	4.64	4.78	Ca	0.0852	0.2920
MgO	2.56	2.64	Mg	0.0655	0.2246
FeO	14.2	14.62	Fe	0.2035	0.6976
MnO	35.5	36.56	Mn	0.5154	1.7668
P_2O_5	40.2	41.40	P	0.5834	2.0000
Li_2O	0.14		O	2.3111	8.0020
Na_2O	none				
SiO_2	1.5				
H_2O (−110°C)	0.17				
H_2O (+110°C)	0.8				
Total	99.71	100.00			

1. Dr. Jun Ito, analyst, by wet methods. A spectrographic analysis showed traces of Al, Na, Zn, Ag, Cu and Bi.
2. Analysis recalculated to 100 percent disregarding Li_2O, SiO_2 and H_2O.

split along the interface, relatively pure samples could be obtained by hand picking. Wet chemical analyses were made by Dr. Jun Ito on samples that were estimated to be at least 98 percent pure. The results are given for beusite in Table 5 and for lithiophilite in Table 7.

In column 4 of Table 5 are given the atomic proportions of beusite disregarding Li_2O, SiO_2 and H_2O. These values yield the empirical formula $(Mn_{1.77}Fe_{0.70}Ca_{0.29}Mg_{0.22})(PO_4)_2$ or $(Mn,Fe,Ca,Mg)_{2.98}(PO_4)_2$ which is very close to the theoretical formula $R_3^{2+}(PO_4)_2$.

The graftonite-like minerals from Amanda, San Salvador, Ranquel and Cacique Canchuleta, were analyzed by Dr. D. L. Giles. CaO, MnO, FeO were determined by X-ray fluorescence, and MgO by atomic absorption. The results given in Table 6 show that the first two are beusite (columns 15 and 17) and the last two are graftonite (columns 12 and 13) with high manganese content.

In Dana's System of Mineralogy Vol. 2, 1951, it is stated that, "A limited isomorphous series extends between Fe, Mn and Ca, - - -". Since that time new analyses have become available. These, as well as older analyses are summarized in Table 6 and graphically presented in Figure 5, in percentages of the total divalent metal oxides. They suggest that a complete series extends between Fe and Mn with a partial substitution by Ca and Mg. Because the molecular weights of FeO and MnO are very close, the 50 weight percent boundary between graftonite and

TABLE 6. CHEMICAL ANALYSES[a] OF THE GRAFTONITE-BEUSITE SERIES ARRANGED ACCORDING TO DECREASING RATIO OF FeO:MnO (WT. PERCENT)

	Graftonite									
	Synthetic	Meteoritic			Pegmatitic					
	1	2	3	4	5	6	7	8	9	10
CaO		none	none	none	7.95	4.29	12.80	9.23	5.50	6.00
MgO		none	none	none	0.53	1.44		0.40	0.70	0.10
FeO	60.29	60.04	54.44	56.46	32.58	33.10	28.84	30.65	31.80	30.70
MnO		3.10	4.48	5.29	15.65	17.66	15.96	17.62	21.80	21.81
P_2O_5	39.71	36.86[b]	41.08[b]	38.25[b]	40.81	41.08	41.65	41.20	38.20	39.66
H_2O						0.55		0.75	0.60	0.60
Rem.					2.60	1.71		0.33	1.30	0.89
Total	100.00	100.00	100.00	100.00	100.12	99.83	99.25	100.18	99.90	99.76
FeO:MnO Wt. %	1:0	1:0.05	1:0.08	1:0.09	1:0.48	1:0.53	1:0.55	1:0.57	1:0.69	1:071

	Graftonite				Beusite					
	Pegmatitic									Synthetic
	11	12	13	14	15	16	17	18	19	20
CaO	4.50	6.7	7.9	4.71	12.2	0.54	3.3	5.1	4.64	
MgO		2.61	2.59	none	2.43	9.50	2.26	1.2	2.56	
FeO	32.33	24.8	23.1	27.78	16.8	16.95	17.7	15.2	14.2	
MnO	23.22	20.6	21.1	25.48	24.8	30.77	33.7	35.9	35.5	59.99
P_2O_5	38.94	45.29[b]	45.31[b]	40.03	43.77[b]	42.53	43.04[b]	40.8	40.2	40.01
H_2O	0.54			0.60		0.42		0.7	0.97	
Rem.				1.22				0.6	1.64	
Total	99.63	100.00	100.00	99.82	100.00	100.71	100.00	99.5	99.71	100.00
FeO:MnO Wt. %	1:0.72	1:0.83	1:0.91	1:0.92	1:1.48	1:1.82	1:1.90	1:2.36	1:2.50	1:∞

[a] Analysis by wet methods; except as indicated.
[b] By difference.
1. Values calculated for $Fe_3(PO_4)_2$. Synthesized by Korinth and Royen, 1961.
2–4. Mexican meteorites: 2. Bella Roca I; 3. Chupaderos; 4. Bella Roca II. E. O. Olsen analyst, by microprobe in Olsen and Fredriksson, 1966, recalculated from values given as wt. % of Fe and Mn.
5. Brissago, Switzerland, J. Jakob, analyst, in Parker et al., 1939.
6. East Alstead, New Hampshire, U.S.A. Jun Ito, anal st, in Hurlbut, 1965.
7 and 10. 7. Rice Mine, New Hampshire, U.S.A.
10. Nickel Plate Mine, South Dakota, U.S.A. M. L. Lindberg, analyst in Lindberg, 1950.
8. Grafton, New Hampshire, U.S.A. S. L. Penfield, analyst, in Penfield, 1900.
9. São Luiz do Paraitinga, São Paulo, Brazil. B. A. Ferreira, analyst, in Franco and Porto, 1952.
11. Olgiasca, Italy. P. Gallitelli, analyst, in Grill, 1955. Described as *repossite* (=graftonite, Strunz, 1939).
12, 13, 15 San Luis, Argentina. 12. Ranquel Mine. 13. Cacique Canchuleta Mine. 15. Amanda Mine. 17. San Salvador Mine. D. L. Giles, analyst, CaO, MnO, FeO by X-ray fluorescence, MgO by atomic absorption. This study.
14. Greenwood, Maine, U.S.A. J. J. Fahey, analyst, in Glass and Fahey, 1937.
16. Kyrk-Bulaka, Turkestan Mountains, U.S.S.R. A. A. Beus, analyst, in Beus, 1950.
18. Beryl King Mine, Queensland, Australia in Brooks and Shipway, 1960.
19. Los Aleros, pegmatite San Luis, Argentina. Jun Ito, analyst, from Table 5, column 1. This study.
20. Values calculated for $Mn_3(PO_4)_2$. Synthesized by Dow Chemical Co.

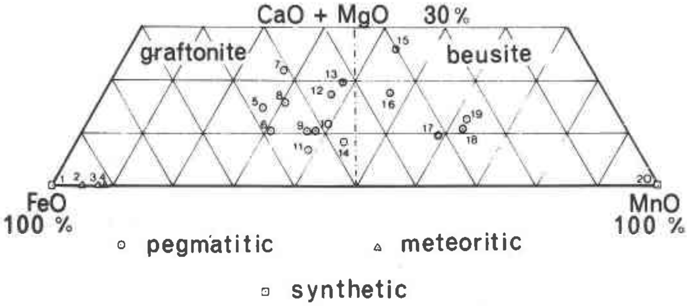

FIG. 5. Composition of minerals in the graftonite-beusite series, in weight percent of total divalent metal oxides. Note the limited fields in which both the pegmatitic and meteoritic members fall.

beusite is essentially equivalent to 50 mole percent of the same oxides

A differential thermal analysis of beusite from Los Aleros shows only one thermal reaction, an endothermic peak at 960°C resulting from fusion. The product is a black amorphous pellet, slightly magnetic. Like graftonite, beusite is soluble in acids.

It has already been mentioned that it is impossible to distinguish unequivocally between graftonite and beusite by physical and X-ray means. This is because ferrous and manganous ions convey similar properties to the minerals and because small percentages of calcium and magnesium greatly effect these properties. We, therefore, wish to stress that only through some quantitative determination of iron and manganese is it possible to distinguish between members of the series. For this reason, beusite may be as abundant as graftonite but has been overlooked in the past and misidentified by physical means as graftonite.

Lithiophilite. The chemical analysis of lithiophilite from Los Aleros is given in column 1 of Table 7. From the atomic proportions in column 4 the following empirical formula results: $Li_{0.95}(Mn_{0.48}Fe_{0.27}Mg_{0.22})\ PO_{3.95}$ which is close to $Li(Mn,Fe,Mg)PO_4$. A DTA curve obtained using this mineral shows a sharp endothermic peak at 890°C which is attributed to fusion.

Parent Mineral

Lindberg (1950) was unable to rationalize the axial ratios of graftonite obtained by X-ray methods with those obtained by Penfield from morphology. This indicated the possibility that Penfield was dealing with a pseudomorph of graftonite-triphylite after a high temperature mineral. With the hope of arriving at the composition of the parent mineral the relative percentages of the two phases at Los Aleros were

TABLE 7. CHEMICAL ANALYSIS OF LITHIOPHILITE FROM LOS ALEROS, SAN LUIS, ARGENTINA

	Wt %	Wt % recalculated		Atomic proportions (P=1)	
	1	2		3	4
Li_2O	9.40	9.58	Li	0.6412	0.9505
Na_2O	0.03	0.03[a]	Na	0.0010	0.0015[a]
FeO	12.8	13.04	Fe	0.1815	0.2690
MnO	22.6	23.02	Mn	0.3245	0.4810
MgO	6.33	6.45	Mg	0.1510	0.2238
P_2O_5	47.0	47.88	P	0.6746	1.0000
CaO	none				
SiO_2	0.78		O	2.6646	3.9498
Al_2O_3	0.50				
$H_2O-110°C$	0.10				
$H_2O+110°C$	0.15				
	99.69	100.00			

[a] The amount of Na_2O is so small that it is omitted in the empirical formula.
1. Dr. Jun Ito, analyst, by wet methods. A spectrographic analysis showed traces of Cu, Bi, Ba, Sr, and Ag.
2. Analysis recalculated to 100 percent disregarding SiO_2, Al_2O_3 and H_2O.

determined from thin sections. In both lamellar and granular intergrowth the volume percentages were: beusite 82, lithiophilite 18. Using these volumes, the chemical analyses of Tables 5 and 7, and the measured specific gravities, we arrive at a composition of the original material that can be expressed as $(Li_{0.96}Mn_{1.62}Fe_{0.67}Mg_{0.27}Ca_{0.24})(PO_{3.99})_2$ or $(Li,Mn,Fe,Mg,Ca)_{3.16}(PO_4)_2$. This suggests that the parent phase was a disordered high temperature lithium graftonite rather than a different mineral.

In the formation of the low-temperature phases all the lithium became concentrated in the lithiophilite whereas all the calcium went to beusite. At the same time there was a substantial migration of Mn^{2+} and Fe^{2+} from the space now occupied by lithiophilite toward the beusite portion, and of Mg^{2+} in the opposite direction.

In a study of the banded graftonite-sarcopside from Alstead, New Hampshire, Hurlbut (1965) assumed a migration of Ca^{2+} and Mn^{2+} to graftonite and of Mg^{2+} and Fe^{2+} toward sarcopside. He reported the parent phase to be a graftonite-like mineral. It seems reasonable to conclude that when the parent pegmatitic material does not contain lithium the exsolved mineral is sarcopside. But when lithium is present triphylite or lithiophilite is exsolved depending on the Fe:Mn ratio.

In all graftonite intergrowths reported (Penfield, 1900; Parker *et al*, 1939; Glass and Fahey, 1937; Berman, 1927) the associated mineral is triphylite. In the 5 intergrowths from Argentina mentioned in this paper all have triphylite-lithiophilite. Chemical analyses show that triphylite is present with graftonite at Ranquel but that lithiophilite is associated with beusite at Los Aleros.

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References

Angelelli, V. and C. A. Rinaldi (1963) Yacimientos de minerales de litio de las Provincias de San Luis y Córdoba, *Argent. Repub., Com. Nac. Energía Atómica, Informe*, **91**, 1–79.

Berman, H. (1927) Graftonite from a new locality in New Hampshire. *Amer. Mineral.*, **12**, 170–172.

Beus, A. A. (1950) Magniophilite and mangankoninckite, two new minerals from pegmatites. *Dokl. Akad. Nauk S.S.S.R.*, **73**, 1267–1279 [In Russian].

Brooks, J. H. and C. H. Shipway (1960) Mica Creek pegmatites, Mount Isa, North-Western Queensland, *Aust, Queensland Gov. Mining J.*, **61**, 511–522.

Franco, R. R. and M. C. Porto (1952) Graftonite de São Luiz de Paraitinga, São Paulo, Brazil. *Avais Acad. Brasil Cienc.*, **24**, 267–271.

Glass, J. J. and J. J. Fahey (1937) Graftonite from Greenwood, Maine. *Amer. Mineral.*, **22**, 1035–1039.

Gonzáles, R. R. L. (1957) Descripción geológica de la Hoja 22g., Quines, Provincia de San Luis. *Argent. Repub., Dir. Nac. Minería, Bol.*, **87**, 1–51.

González Bonorino, F. (1950) Algunos problemas geológicos de las Sierras Pampeanas. *Rev. Asoc. Geol. Argent.*, **5**, 81–110.

Grill, E. (1935) Su un fosfato di ferro e di manganese delle pegmatiti di Olgiasca. *Period. Mineral. Roma*, **6**, 19–23.

Herrera, A. O. (1963) Las pegmatitas de la Sierra de San Luis, Estructura interna, mineralogía y génesis. *Rev. Asoc. Geol. Argent.*, **18**, 42–71.

Hurlbut, C. S., Jr. (1965) Detailed description of sarcopside from East Alstead, New Hampshire. *Amer. Mineral.*, **50**, 1689–1707.

Jesús, A. M. De (1933) Pegmatites mangano-Litiniferas da regiao de Mangualde. *Com. Serv. Geol. Portugal*, **19**, 65–210.

Korinth, J. and P. Royen (1961) Reaktionen im system Fe_2O_3/Fe PO_4. *Z. Anorg. Allq. Chem.*, **313**, 121–137.

Linares, E. (1959) Los métodos geocronológicos y algunas edades de minerales de la Argentina obtenidas por medio de la relación plomo-uranio. *Rev. Asoc. Geol. Argent.*, **14**, 181–217.

Lindberg, M. L. (1950) Arrojadite, huhnerkobelite and graftonite. *Amer. Mineral.*, **35**, 59–76.

MASON, B. (1941) Minerals of the Varuträsk Pegmatite. *Geol. För. Förh.*, **63,** 117–175.

OLSEN, E. AND K. FREDRIKSSON (1966) Phosphates in iron and pallasite meteorites. *Geochim Cosmochim. Acta*, **30,** 459–470.

PALACHE, C., H. BERMAN AND C. FRONDEL (1951) *System of Mineralogy . . . , 7th ed., Vol.* 2, John Wiley and Sons, N. Y.

PARKER, R. L., F. DE QUERVAIN AND F. WEBER (1939) Über einige neue und seltene Mineralien der Schweizeralpen. *Schweiz. Mineral. Petrogr. Mitt.*, **19,** 293–306.

PASTORE, F. AND O. J. RUIZ HIUDOBRO (1952) Descripción geológica de la Hoja 24 g. Saladillo (San Luis). *Argent. Repub., Dir. Nac. Minería, Bol.* **78,** 1–63.

——— AND R. R. L. GONZÁLEZ (1954) Descripción geológica de la Hoja 23 g, San Francisco (San Luis). *Argent. Repub., Dir. Nac. Minería, Bol.* **80,** 1–62.

PENFIELD, S. L. (1900) On graftonite, a new mineral from Grafton, New Hampshire and its intergrowth with triphylite. *Amer. J. Sci.*, **9,** 20–32.

STANĚK, J. (1955) K paragenesi fosfatů Cyrilova u Velkého Meziříčí. *Acta Musei Moraviae*, **40,** 69–80.

STRUNZ, H. (1939) Pulverdiagramme von Amblygonit, Fremontit, Graftonit, Repossit und Karyinit. *Zentralbl. Mineral. Geol. Paleontol., Abt. A* 248–251.

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