MINERALOGY

GUGIAITE, $Ca_2BeSi_2O_7$, A NEW BERYLLIUM MINERAL AND ITS RELATION TO THE MELILITE GROUP*

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INTRODUCTION

The specimens collected early in 1959 near the village of Gugia by one of the writers (R. L. Tsao) from the skarn rocks adjacent to an alkaline syenite, contained a number of well crystallized minerals. Preliminary laboratory study on one of the minerals showed that its optical properties match no known minerals, but its X-ray powder pattern is similar to that of melilites. A semiquantitative spectrochemical analysis showed the presence of beryllium. Further investigation revealed that this material was a new mineral having the composition $Ca_2BeSi_2O_7$ and the same crystal structure as that of the melilite group. It is named gugiaite (gü-gia-ite) after the locality.

The discovery of gugiaite is significant because it is the first beryllium mineral ever found in the skarn zones of alkaline rocks. Its relationship to the melilites is also interesting because Be plays the same role of substituting for (Mg, Al) in the melilite structure as Zn in hardystonite, $Ca_2ZnSi_2O_7$, which is also a member of the melilite group.

OCCURRENCE OF GUGIAITE

Gugiaite was found in skarn rocks with melanite, orthoclase, idocrase, aegirine, sphene, apatite, and prehnite. It occurs as clear tetragonal tablets, mostly 2—3 mm across and 0.3—0.5 mm thick in cavities and disseminated in melanite (Figs. 1 & 2). The carbonate rocks are of Cambrian age, and are intruded by an alkaline syenite belonging to an alkaline igneous complex of the area.

CRYSTALLOGRAPHY

Morphology. Gugiaite occurs as thin tetragonal tablets parallel to the well developed base. Five crystals of gugiaite were examined on a two-circle goniometer with the c-axis parallel to the axis of the goniometer head. In

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Fig. 1. Gugiaite crystals.

addition to the base $c\{001\}$, the forms present are $e\{011\}$ and $p\{111\}$, both of which give only fair to poor reflections. Binocular microscopic inspection of some other crystals occasionally shows development of $m\{110\}$, but it is too narrow to give reflection on the goniometer. The average of the measured interfacial angles agrees closely with the calculated values (Table 1). The axial ratio determined from the goniometric data is: $a : c=1 : 0.6843$, against $1 : 0.6742$ as calculated from the theoretical values for the angles. The appearance of gugiaite crystals is shown in Fig. 3.

Table 1

Morphological Data for Gugiaite Crystal System—Tetragonal

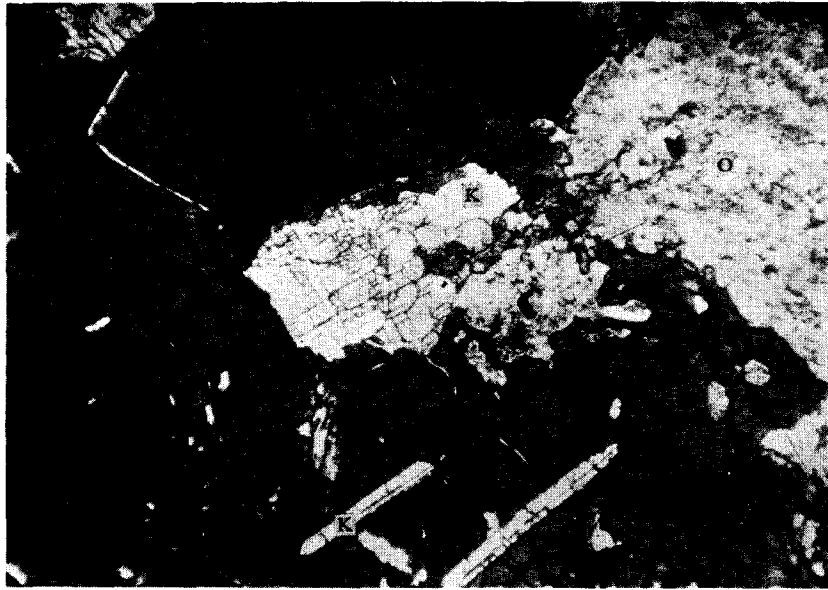| Form	Quality	Range Measured		Average Meas.		Calculated	
		ρ	ϕ	ρ	ϕ	ρ	ϕ
$c\{001\}$	good					0°00'	
$e\{011\}$	poor	33°08'—35°14'	0°00'	34°23'	0°00'	34°00'	0°00'
$p\{111\}$	fair to poor	43°16'—43°59'	44°45'—46°20'	43°35'	45°00'	43°38'	45°00'

Fig. 2a. Crystals of gugiaite (K). The crystals in the centre of the photograph are approximately parallel to the base (001), showing {010} cleavage. The two prismatic crystals at the bottom are nearly parallel to the c-axis, showing both {001} and {010} cleavages. The white mineral (O) at the right-hand margin of the field is orthoclase. The doubly terminated prism at the upper left corner is apatite. The rest of the field (dark) is melanite. Thin section, ordinary light. × 37.
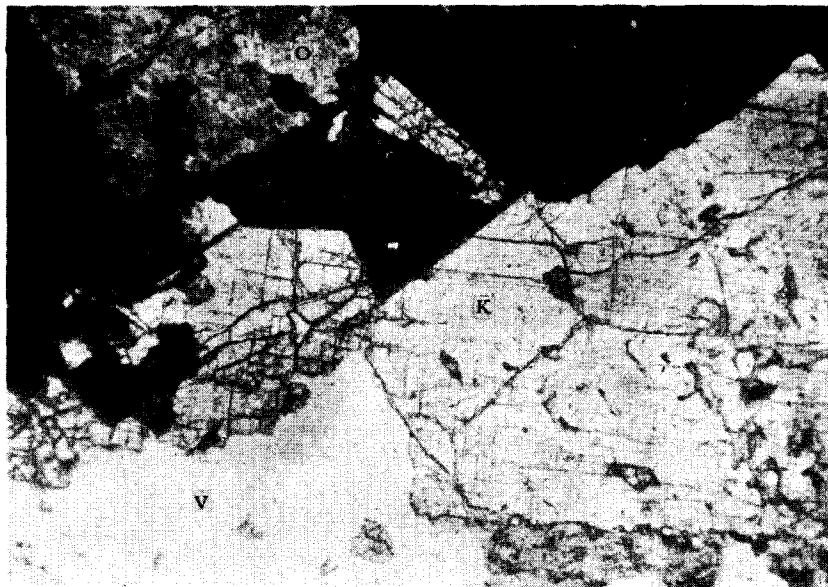

Fig. 2b. Crystals of gugiaite (K) nearly parallel to the base (001), showing the well developed {010} cleavage. (O), orthoclase. The dark mineral is melanite. (V), cavity. Thin section, ordinary light. × 37.

The crystals of gugiaite appear holohedral in habit. Since they gave strong piezoelectric response in the Giebe-Scheibe apparatus[1], it would appear that the crystal class may be either disphenoidal-$\bar{4}$, trapezohedral-422 or scalenohedral-$\bar{4}2\,m$. On the basis of the space group as derived from X-ray diffraction data and the structural relation of gugiaite to melilites (see below), the crystal class established is scalenohedral-$\bar{4}2\,m$. The gugiaite crystals show no twinning, but regular grouping of crystals parallel to the base is fairly common.
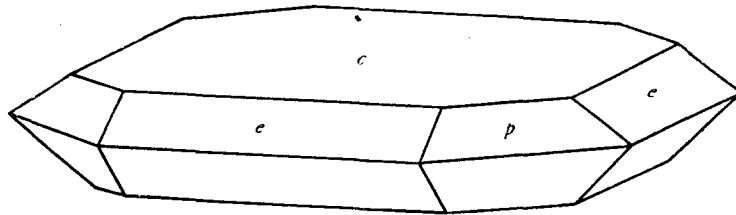

Fig. 3. Crystal habit of gugiaite[2].
Crystal forms:

$c\,\{001\}$, $e\,\{011\}$, and $p\,\{111\}$.

Single-crystal X-ray data. Several crystals of gugiaite were studied by the rotation and Weissenberg methods using Cu-$K\alpha$ radiation. Photographs were taken about the c, a, and a^* axes. The Weissenberg photographs indicated the lattice as tetragonal. The only systematic extinctions observed are for $h00$ with $h=2n+1$. The space group is thus either D_4^2-$P42_12$ (No. 90) or D_{2d}^3-$P\bar{4}2_1m$ (No. 113). Since gugiaite has the same structure as that of melilites, which according to Warren (1930), cannot be built on the space group $P42_12$, the only possibility is therefore $P\bar{4}2_1m$. The cell dimensions are: $a_0=7.48\pm0.02$ Å, $c_0=5.044\pm0.003$ Å; the cell volume is: 282.21 Å^3; and the axial ratio: $a_0:c_0=1:0.6743$. The axial ratio thus calculated is in good agreement with that derived from the goniometric measurements.

X-ray powder data. The X-ray powder pattern of gugiaite taken in a 114.59 mm diameter Debye-Scherrer camera with Cu/Ni radiation ($\lambda=1.5418$Å) is presented in Table 2. The pattern was indexed on the basis of tetragonal symmetry. Interplanar spacings were calculated from cell dimensions obtained from single-crystal data. The spacings are compared with the measured d spacings in Table 2. The intensities were estimated visually.

Crystal structure. The X-ray powder pattern of gugiaite is remarkably similar to that of melilites (Fig. 4 and Table 2). Their cell dimensions and axial ratios are also compared (Table 6). From these and the fact that gugiaite and the melilites have analogous chemical formulas, there can be little doubt that gugiaite has a structure similar to that of the melilite group. Using the

1) The test was run by Mr Lin Chuo-ran.
2) The figure was drawn from the goniometric data by Mr Gu Hsung-fei.

Table 2

Comparison of X-ray Powder Data for Gugiaite, Gehlenite, Meliphanite and Leucophanite

Gugiaite[1] (Present study)				Gehlenite[2] (Artificial)		Meliphanite[3] (Langesundfiord, Norway)			Leucophanite[3] (Langesundfiord, Norway)		
hkl	d meas.	d calc.	I	d meas.	I	hkl	d meas.	I	hkl	d meas.	I
110	5.250	5.289	4	5.456	4				101	6.1606	w
001	5.040	5.044	2	5.082	4	200	5.3510	vvw	110	5.4222	vw
101				4.218	3	002	5.0836	vw	002	5.2140	w
200	3.700	3.740	3						111	4.8421	vvw
111	3.610	3.650	3	3.670	20	112	4.1945	vw	102	4.2380	vvw
210	3.310	3.345	2	3.430	1	211	4.3280	w			
201	2.970	3.004	4	3.070	25	202	3.6668	m			
211	2.765	2.787	10	2.846	100				112	3.7000	ms
220				2.722	4	310	3.3927	vw	201	3.5706	w
002	2.518	2.522	2	2.535	6				210	3.3927	vw
310	2.359	2.365	4	2.435	18				211	3.2317	vw
102				} 2.404	22	222	3.0172	m	103	3.0854	w
221	2.341	2.342	3	}		312	2.8101	s	202	3.0396	ms
112	2.315	2.276	4			400	2.6814	w	212	2.8101	vs
301	2.242	2.235	3	2.292	13				220	2.6640	w
311	2.208	2.142	4	2.195	1	402	2.3715	m	222	2.3579	s
320	2.115	2.075	3	} 2.126	1	332	2.0322	m	302	2.0222	m
202	2.066	2.091	3	}							
212	1.990	2.014	4	2.043	14						
321	1.900	1.919	1	1.967	1						
400	1.851	1.870	2	1.924	6						
410				1.864	4						
330				1.812	8						
222	1.794	1.825	1								
302	1.747	1.773	2								
312				1.754	34						
420				1.723	5						
331											
411	1.709	1.707	7								
003	1.695	1.681	4								
322	1.580	1.602	1	1.632	1						
113				1.616	3						
203											
213				1.519	14						
402	1.485	1.502	7								
332	1.431	1.445	1	1.475	1						
223	1.420	1.419	2	1.437	5						
422	1.376	1.394	2								
521	1.327	1.339	1	1.375	8						
440	1.311	1.322	1	1.361	3						
323				1.327	1						
502				1.316	1						
600				1.282	1						
004	1.256	1.261	2	1.267	3						
413				} 1.253	4						
104	1.220	1.243	2	}							
541	1.128	1.138	2								
224											
304	1.110	1.125	1								
602	1.101	1.118	1								
324	1.064	1.078	3								
542	1.051	1.060	3								
720	1.018	1.027	1								

1) Gugiaite, Cu/Ni radiation ($\lambda = 1.5418$Å), camera diameter 114.59 mm.

2) Gehlenite, Cu-$K\alpha$ radiation, Ervin and Osborn (1949).

3) Meliphanite and leucophanite. Spacings calculated from θ angles given by Zachariassen (1931).

atomic coordinates for a melilite given by Warren (1930) and later revised by Smith (1953), the authors have carried out a preliminary calculation of the intensities for reflections $h00$ and $hk0$, which check well with those observed. A detailed crystal structure study of gugiaite is now in progress.
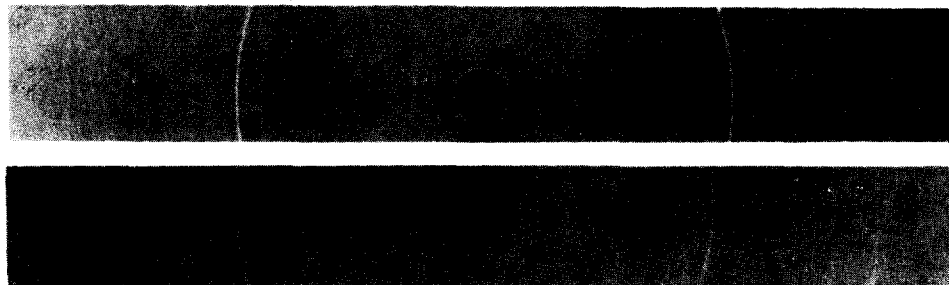

Fig. 4. X-ray powder photographs (Fe-$K\alpha$ radiation) of gugiaite (above) and gehlenite (below). The latter came from Austria.

PHYSICAL AND OPTICAL PROPERTIES

Gugiaite is colourless and transparent. Hardness is about 5; luster, vitreous; streak, white; and fracture, irregular. The specific gravity, as measured on fragments of gugiaite crystals by means of a pycnometer, is 3.0336 ± 0.0022 (an average of three different determinations). That calculated from the cell size and cell contents is 3.03 and from optical data $[d=(n-1)/k]$, 3.0628. The mineral has perfect b {010}, distinct c {001} and poor m {110} cleavages (Figs. 1 & 2). Under the microscope, the crystals of gugiaite show both fluid inclusions and needle-like microlites.

In transmitted light, gugiaite is colourless. The indices of refraction as determined by the standard immersion method using Na light are: $\omega=1.664$, $\epsilon=1.672$ (both ± 0.001), $\Delta=0.008$. The mineral is optically uniaxial positive (+). It shows a parallel extinction, but sometimes the extinction is slightly wavy. From the rule of Gladstone and Dale and using the pycnometric density, 3.0336 and k, 0.21768 (given by the recalculated chemical analysis in Table 5), we calculated the mean index of refraction, $n=dk+1$, to be 1.6594, which is very close to the experimental mean index, $(2\omega+\epsilon)/3= 1.6667$, with a difference of only 0.0073.

CHEMICAL COMPOSITION

Gugiaite is soluble in hot HCl, HNO_3 and H_2SO_4 (all in 1 : 1), with separation of some gelatinous silica. It fused at 950°C with Na_2CO_3 or NaOH.

A semiquantitative spectrochemical analysis was made of some fragments of gugiaite crystals with the following results:

Two samples of gugiaite, weighing about 1.6 g and 0.8 g respectively were chemically analysed at different times. The same procedure of crushing and hand-picking under the binocular microscope was conducted to prepare sample for the analyses. For the second analysis, however, the hand-picked material was further crushed, sieved, and then submitted to bromoform and methylene iodide separations to remove the closely associated minerals, particularly prehnite and melanite. As can be seen from Table 4, the results of the two analyses are in good agreement except that Na_2O, K_2O, and F were not determined in the first analysis, while no $(Zr, Hf)O_2$ was reported in the second one.

Table 3

Spectrochemical Analysis of Gugiaite
(Analyst: Shen Chian-sheng)

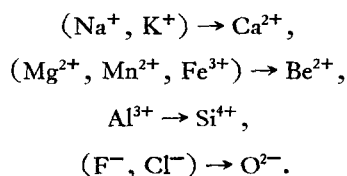| Elements	Per Cent	Elements	Per Cent
Si	> 5	Mg	> 0.1
Ca	$\geqq 5$	Mn	$= 0.03—0.1$
Na	> 0.3	Al	> 0.03
Be, Sr	$\cong 0.3$	Ti	$= 0.03$
K	< 0.3	Zr	$\ll 0.001$
Fe	$= 0.3—0.1$		

Looked for, not found: Li, Nb, Ba, Ta, Th, P, U, and TR.

As derived from the cell volume, 282.21 Å^3, measured density, 3.0336 and the recalculated analysis, No. 2 (Table 4, Column 4), the cell contents of gugiaite are:

$$Ca_{3.71}Na_{0.12}K_{0.02}Mg_{0.05}Mn_{0.01}Fe^{3+}_{0.01}Be_{1.97}Al_{0.22}Si_{3.88}P_{0.01}O_{13.91}F_{0.07}Cl_{0.03} \cdot 0.26H_2O.$$

This composition can be considered essentially as $Ca_4Be_2Si_4O_{11}$, and therefore, in each cell are contained two formula units of $Ca_2BeSi_2O_7$. This formula is equivalent to that of melilites, with Be in substitution for (Mg, Al) in the latter.

A comparison of the calculated and theoretical cell contents given above indicates the following ionic substitutions:

$$(Na^+, K^+) \rightarrow Ca^{2+},$$

$$(Mg^{2+}, Mn^{2+}, Fe^{3+}) \rightarrow Be^{2+},$$

$$Al^{3+} \rightarrow Si^{4+},$$

$$(F^-, Cl^-) \rightarrow O^{2-}.$$

It also seems likely that Al^{3+} may substitute for Be^{2+}. But it is evident that all these substitutions are of only very limited extents. The small amount of water may be present as OH^- replacing O^{2-} to make valence compensation for the substitution of (Na^+, K^+) for Ca^{2+}, or Al^{3+} for Si^{4+}, but it may be

Table 4

Chemical Analyses of Gugiaite and Computation of Formula

(1) Constituent	Weight Per Cent			(5) Molecular Ratios	(6) Atomic Ratios		Atoms Per Unit Cell		(9) Theoretical Composition (Weight %)
	(2) First Analysis	(3) Second Analysis	(4) (3) recalculated to 100%				(7) (6) $\times$M(M=515.7)	(8) Theoretical Values	
SiO_2	45.26	44.90	45.18	0.7519	Si	0.7519	3.88	4	46.70
Al_2O_3	1.08	2.17	2.18	0.0214	Al	0.0428	0.22		
Fe_2O_3	0.03	0.11	0.11	0.0007	Fe^{3+}	0.0064	0.01		
MnO	0.11	0.07	0.07	0.0010	Mn	0.0010	0.01		
MgO	0.39	0.38	0.38	0.0094	Mg	0.0094	0.05		
CaO	42.94	40.09	40.34	0.7193	Ca	0.7193	3.71	4	43.58
BeO	8.89	9.49	9.55	0.3818	Be	0.3818	1.97	2	9.72
Na_2O		0.72	0.72	0.0116	Na	0.0232	0.12		
K_2O		0.20	0.20	0.0021	K	0.0042	0.02		
H_2O^+	0.40	0.90	0.91	0.0505	H^+	0.1010	0.52		
H_2O^-	0.02	0.36							
F		0.25	0.25	0.0132	F	0.0132	0.07		
Cl	0.73	0.18	0.18	0.0051	Cl	0.0051	0.03		
P_2O_5		0.08	0.08	0.0006	P	0.0012	0.01		
TiO_2	0.02	Trace							
(Zr, Hf)O_2	0.45								
Volatile Matter		0.04							
Total	100.32	99.94	100.15						
Less O = 2Cl	−0.17	−0.04	−0.04						
Less O = 2F		−0.11	−0.11						
	100.15	99.79	100.00		$\Sigma O = 14.17$		$\Sigma O = 14$		100.00

(2) Analysis No. 1; analyst: Chang Lan-chuan, 1960.   (3) Analysis No. 2; analyst: Chiang Feng-liang, 1961.

(4) H_2O^- and volatile matter deducted.   (5), (6), (7), (8): Calculated from (4); in (7) $M = \dfrac{VG \times 10^{-24}}{1.6602 \times 10^{-24}} = \dfrac{282.21 \times 3.0336}{1.6602} = 515.7.$

Table 5

Comparison of Gugiaite, Meliphanite, Leucophanite, Aminoffite and Melilite

	(1) Gugiaite	(2) Meliphanite (Langesundfiord, Norway)	(3) Leucophanite (Langesundfiord, Norway)	(4) Aminoffite (Långbau, Sweden)	(5) Melilite (Capo di Bove, Italy)
Colour	colourless	yellow, rarely reddish	white, green, yellow	colourless	yellowish brown
Specific gravity	3.0336 ± 0.0022	3.006	2.96	2.94	2.95
Cleavage	$\{100\}$ perfect $\{001\}$ distinct $\{110\}$ poor	$\{001\}$ distinct	$\{001\}$ and $\{100\}$ perfect	$\{001\}$ poor	$\{001\}$ distinct $\{100\}$ indistinct
Optical data	$\omega_{Na}=1.664$ $\epsilon_{Na}=1.672$ $\Delta=0.008$ uniaxial(+)	$\omega_{Na}=1.612$ $\epsilon_{Na}=1.593$ $\Delta=0.019$ uniaxial (−); sometimes biaxial (−) $2E=36°$ (max.) ϵ=greenish yellow, $\omega>\epsilon$ ω=honey to brownish yellow	$\alpha=1.571$ $\beta=1.595$ $\gamma=1.598$ $\gamma-\alpha=0.027$ (−) $2V=39°$	$\omega=1.647$ $\epsilon=1.637$ $\Delta=\pm0.002$ uniaxial (−)	$\omega=1.638$ $\epsilon=1.634$ $\Delta=0.004$ uniaxial (−)
Symmetry	tetragonal; scalenohedral-$\bar{4}2m$	tetragonal; scalenohedral-$\bar{4}2m$ or disphenoid-$\bar{4}$	orthorhombic and pseudo-tetragonal; disphenoid-222(?)	tetragonal; dipyramidal-$4/mmm$	tetragonal; scalenohedral-$\bar{4}2m$
Space group	$P\bar{4}2_1m$	$P\bar{4}$ or $P\bar{4}2_1m$	$P2_12_12$ (?)	$14/mmm$	$P\bar{4}2_1m$
Cell constants	$a_0=7.48\pm0.02$ $c_0=5.044\pm0.003$ $c_0/a_0=0.67433$	$a_0=10.58\pm0.02$ Å $c_0=9.88\pm0.02$ Å $c_0/a_0=0.933$	$a_0=b_0=7.39$ $c_0=9.98$ $a_0:b_0:c_0=1:1:1.350$	$a_0=13.8\pm0.02$ Å $c_0=9.8\pm0.05$ Å $c_0/a_0=0.710$	$a_0=7.789\pm0.005$ Å $c_0=5.018\pm0.005$ Å $c_0/a_0=0.6442$
Cell contents	$2[Ca_2BeSi_2O_7]$	$8[(Ca, Na)_2Be(Si, Al)_2(O, F)_7]$	$4[(Ca, Na)_2BeSi_2(O, OH, F)_7]$	$12Ca_2(Be, Al)Si_2O_7(OH) \cdot H_2O$	$2[(Ca_{1.7}Na_{0.2}K_{0.1})_2(Mg_{0.6}Al_{0.4})Si_2O_7]$
References	present study (1962)	crystallographic data and formula: Zachariassen (1931) physical and optical data: Winchell and Winchell (1951).	crystallographic data and formula: Zachariassen (1931) physical and optical data: Winchell and Winchell (1951).	Hurlbut (1937)	Smith (1953)

also assumed to be non-essential because the electrical neutrality can be maintained by the presence of (F^-, Cl^-). The phosphorus is presumably non-essential.

The formula $Ca_2BeSi_2O_7$ gives the molecular weight of the cell as $2\times257.35=514.7$, which agrees excellently with that determined from the cell volume and measured density, namely, $M=515.7$ (weight of unit atomic weight$=1.6602\times10^{-24}$ g). The actual chemical analyses also approach closely to the theoretical composition as calculated from the formula (Table 4, Column 9).

Comparison of Gugiaite with the Melilite Group

As stated previously, gugiaite is similar to melilites in structure and chemical formula. Hence, it may be concluded that gugiaite is a new addition to the melilite family. It is compared with the natural melilite from Capo di Bove, near Rome, Italy, in Table 5. But gugiaite also differs from melilites in many respects. It is the beryllium analogue of melilites with only a small content of Al and negligible Mg. This would suggest that gugiaite probably cannot form solid solutions with the åkermanite-gehlenite series. The explanation apparently lies in the disparity in ionic radii between Be^{2+} (0.35 Å) and Mg^{2+} (0.66 Å) or Al^{3+} (0.51 Å).

Table 6

Cell Data for Gugiaite, Melilites and Hardystonite

	Gugiaite $Ca_2BeSi_2O_7$ (Present Study)	Gehlenite[1] $Ca_2AlSi_2O_7$ (Artificial)	Melilite[2] (Ca, Na, K)₂(Mg, Al)Si₂O₇ (Capo di Bove, Italy)	Åkermanite[1] $Ca_2MgSi_2O_7$ (Artificial)	Hardystonite[3] $Ca_2ZnSi_2O_7$ (Franklin, N. J., U.S.A.)
a_0(Å)	7.48	7.694	7.789	7.846	7.83
c_0(Å)	5.044	5.077	5.018	5.02	4.99
c_0/a_0	0.6743	0.660	0.6442	0.64	0.637
Volume (Å³)	282.21	300.55	304.44	309.03	305.94
Ionic radii(Å)[1]	$Be^{2+}=0.35$	$Al^{3+}=0.51$	(Mg^{2+}, Al^{3+})	$Mg^{2+}=0.66$	$Zn^{2+}=0.74$

1) Ervin and Osborn (1949).
2) Smith (1953).
3) Warren and Trautz (1930).
4) Ionic radii according to Ahrens (1952).

The smaller size of Be^{2+} also causes the cell volume of gugiaite to be appreciably smaller than that of the melilites. As can be seen from Table 6, the cell constants of gugiaite, melilites and hardystonite vary functionally with the radii of Be^{2+}, Al^{3+}, Mg^{2+}, and Zn^{2+} ions. It is worth noting from Table 6 that a_0 increases markedly from gugiaite through the melilites to hardystonite, while there is only a slight increase in c_0 in the same direction. This can be readily explained by the melilite structure as determined by Warren (1930). The structure consists essentially of sheets of SiO_4 tetrahedra linked in pairs parallel to the base (001). The Si_2O_7 groups in the same

sheet are linked together by Mg or Al atoms, which lie at corners and centres of the base. Therefore, the substitution of Mg by atoms of different sizes, such as Al, Zn or Be, would certainly result in a corresponding change in the a_0 dimension in the series. Since the same Ca atoms are situated in between the sheets in the structures of all these minerals, the c_0 dimension would remain constant for the mineral group. With the replacement of Si by Al, however, there would be a slight expansion of the lattice in the c_0 direction. The variation of cell dimensions with composition in artificially prepared melilites has been studied by Andrews (1948) and by Ervin and Osborn (1949), and the explanations given by them are similar to those just outlined.

The indices of refraction of gugiaite are higher than those of artificial pure åkermanite, but close to those of artificial pure gehlenite and hardystonite (Goldsmith, 1948; Palache, 1935; Winchell and Winchell, 1951). Gugiaite is the only mineral of the series which has perfect {010} cleavage in addition to distinct {001} cleavage.

It is well known that zinc, like beryllium, is 4-coordinated in its minerals and the two are often found in minerals which are isostructural, such as willemite Zn_2SiO_4 and phenacite Be_2SiO_4, zincite ZnO and bromellite BeO,

Table 7

Chemical Analyses of Gugiaite, Meliphanite, Leucophanite, and Aminoffite

	Gugiaite (Present study)	Meliphanite[1]	Leucophanite[1]	Aminoffite[2]
		(Langesundfiord, Norway)		(Långbau, Sweden)
SiO$_2$	44.90	43.60	48.50	42.49
TiO$_2$	Trace	—	—	—
Al$_2$O$_3$	2.17	4.61	0.45	4.41
Fe$_2$O$_3$	0.11	—	—	0.31
FeO	—	—	—	—
MnO	0.07	—	—	0.19
MgO	0.38	0.16	0.27	—
CaO	40.09	29.56	22.94	40.27
BeO	9.49	9.80	10.03	6.20
Na$_2$O	0.72	7.98	12.42	—
K$_2$O	0.20	0.23	—	—
H$_2$O$^+$	0.90	—	} 1.08	} 6.45
H$_2$O$^-$	0.36	—		
F	0.25	5.73	5.94	—
Cl	0.18	—	—	—
P$_2$O$_5$	0.08	—	—	—
Volatile Matter	0.04	—	—	—
Total	99.94	101.67	101.63	100.33

1) Zacharriassen (1931).
2) Hurlbut (1937).

in spite of their disparity in ionic size. The pair gugiaite-hardystonite now provides another example of the isostructural relation between Zn and Be minerals.

Although no melilites have ever been reported or suspected to contain beryllium, there are three beryllium silicates which are structurally related to the melilite group, i.e., meliphanite $(Ca, Na)_2Be(Si, Al)_2(O, F)_7$, leuco-phanite $(Ca, Na)_2BeSi_2(O, OH, F)_7$ (Zachariassen, 1931), and aminoffite $Ca_2(Be, Al)Si_2O_7(OH) \cdot H_2O$ (Hurlbut, 1937). These three are distinctly different from gugiaite. They contain about the same elements as gugiaite but in different proportions (Table 7). Both meliphanite and leucophanite have much higher contents of Na_2O and F, but lower content of CaO than gugiaite. Water is present in a large amount in aminoffite, but insignificant in gugiaite. They also differ noticeably in crystallographic data, physical and optical properties (Table 5). Furthermore, gugiaite is distinct from the other three beryllium minerals in geological occurrence. Meliphanite and leucophanite are characteristically found in nepheline syenite pegmatites (Goldschmidt, 1954). It appears that it is this occurrence that causes these two minerals to contain much more Na and F, but less Ca than the skarn mineral, gugiaite.

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References

[1]   Andrews, K. W. 1948   The lattice parameters and interplanar spacings of some artificially prepared melilites, *Mineral. Mag.*, **28**, 374—379.

[2]   Goldschmidt, V. M. 1954   *Geochemistry*, pp. 206—213.

[3]   Goldsmith, J. R. 1948   Some melilite solid solutions, *J. Geol.*, **56**, 437—447.

[4]   Hurlbut, C. S. Jr. 1937   Aminoffite, a new mineral from Långbau, *Geol. Fören. Förhandl.*, **59**, 290—294.

[5]   Palache, C. 1935   The minerals of Franklin and Sterling Hill, Sussex co., New Jersey, Prof. Pap. 180, *U.S. geol. Surv.*

[6]   Smith, J. V. 1953   Re-examination of the crystal structure of melilite, *Am. Mineral.*, **38**, 643—661.

[7]   Warren, B. E. 1930   The structure of melilite, *Zeit. Krist.* **74**, 131—138.

[8]   Warren, B. E. & Trautz, O. R. 1930   The crystal structure of hardystonite, *Zeit. Krist.*, **75**, 525—528.

[9]   Winchell, N. A. & Winchell, H. 1951   *Elements of Optical Mineralogy*, pt. II, Descriptions of Minerals, New York, John Wiley & Sons.

[10]   Zachariassen, W. H. 1931   Meliphanite, leucophanite and their relation to melilite, *Norsk. Geol. Tidskr.*, **12**, 577—581.