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GORMANITE, $Fe^{2+}_3Al_4(PO_4)_4(OH)_6{\cdot}2H_2O$, THE FERROUS ANALOGUE OF SOUZALITE, AND NEW DATA FOR SOUZALITE

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ABSTRACT

Souzalite, ideally $Mg_3Al_4(PO_4)_4(OH)_6{\cdot}2H_2O$, and gormanite, ideally $Fe^{2+}_3Al_4(PO)_4(OH)_6{\cdot}2H_2O$, are isostructural and form a solid-solution series. New analytical data for souzalite from the Corrego Frio pegmatite, Minas Gerais, Brazil, yield the composition $(Mg_{1.78}Fe^{2+}_{1.19}Mn_{0.03})_{\Sigma 3.00}(Al_{3.82}Fe^{3+}_{0.23})_{\Sigma 4.07}(PO_4)_{3.96}(OH)_{6.33}{\cdot}1.82H_2O$, whereas the composition of analyzed gormanite from the northeastern Yukon Territory is $(Fe^{2+}_{1.56}Mg_{1.26}Ca_{0.04}Mn_{0.03})_{\Sigma 2.89}(Al_{3.82}Fe^{3+}_{0.36})_{\Sigma 4.18}(PO_4)_{4.00}(OH)_{6.32}{\cdot}1.69H_2O$. Gormanite occurs as elongate blades in the fractures of an iron formation. Gormanite crystals have a hardness of 4–5, parting along planes {001}, poor {001} cleavage, density 3.13 g/cm³ (calc.) and 3.12 g/cm³ (meas.). The mineral is blue-green and has a pale green streak. Analyzed gormanite is biaxial, optically negative, with $2V$ 53° (meas.); α 1.619(3), β 1.653(3), γ 1.660(3); absorption: $X = Z < Y$; pleochroism: X colorless, Y blue, Z colorless; $Z \wedge b$ (elongation) = 14°. Gormanite is triclinic, $P1$ or $P\bar{1}$, a 11.79(1), b 5.11(1), c 13.61(1) Å, α 90°50(5)′, β 99°00(5)′, γ 90°05(5)′; $Z = 2$. The strongest six lines in the powder pattern [d in Å (I)(hkl)] are: 4.761(60)(011), 3.395(100)(0$\bar{1}$3), 3.154(60)(113,302), 3.062(40)($\bar{2}$13), 2.925(80)(311) and 2.554(90)(020,$\bar{4}$11).

Keywords: gormanite, souzalite, Yukon, phosphate, new mineral.

SOMMAIRE

La souzalite $Mg_3Al_4(PO_4)_4(OH)_6{\cdot}2H_2O$ et la gormanite, son analogue ferreux, sont isostructurales et forment une solution solide. Les nouvelles données analytiques obtenues sur la souzalite de la pegmatite Corrego Frio (Minas Gerais, Brésil) mènent à la composition $(Mg_{1.78}Fe^{2+}_{1.19}Mn_{0.03})_{\Sigma 3.00}(Al_{3.82}Fe^{3+}_{0.25})_{\Sigma 4.07}(PO_4)_{3.96}(OH)_{6.33}{\cdot}1.82\ H_2O$. Par contre, nous obtenons $(Fe^{2+}_{1.56}Mg_{1.26}Ca_{0.04}Mn_{0.03})_{\Sigma 2.89}(Al_{3.82}Fe^{3+}_{0.36})_{\Sigma 4.18}(PO_4)_{4.00}(OH)_{6.32}{\cdot}1.69\ H_2O$ pour la gormanite du Nord-Est du Yukon. Les cristaux de gormanite, en lames allongées, remplissent des fissures dans une formation de roches ferrugineuses. Dureté 4 à 5, plan de séparation {001}, clivage {001} indistinct, densité 3.13 (calc.), 3.12 (mes.). La gormanite est bleu-vert et donne une rayure vert pâle; optiquement, l'échantillon analysé est biaxe négatif, $2V$ 53° (mes.); α 1.619(3), β 1.653(3), γ 1.660(3); pléochroïque, absorption $X = Z < Y$; X incolore, Y bleu, Z incolore, $Z \wedge b$ (direction d'allongement) = 14°. La gormanite est triclinique, $P1$ ou $P\bar{1}$, a 11.79(1), b 5.11(1), c 13.61(1) A, α 90°50(5)′, β 99°00(5)′, γ90°05(5)′; $Z = 2$. Les six raies les plus intenses du cliché de poudre [d en Å (I)(hkl)] sont: 4.761(60)(011), 3.395 (100)(0$\bar{1}$3), 3.154 (60)(113, 302), 3.062(40)($\bar{2}$13), 2.925(80)(311) et 2.554 (90)(020,$\bar{4}$11).

(Traduit par la Rédaction)

Mots-clés: gormanite, souzalite, Yukon, phosphate, minéral nouveau.

INTRODUCTION

Several new minerals have been described from a phosphate–ironstone occurrence in the northeastern corner of the Yukon Territory. These are kulanite (Mandarino & Sturman 1976), baricite (Sturman & Mandarino 1976), penikisite (Mandarino *et al.* 1977), marićite (Sturman *et al.* 1977) and satterlyite (Mandarino *et al.* 1978). One of the first phosphate minerals examined from this occurrence is a green radiating species that is common in many outcrops in the deposit, but whose identification proved to be extremely difficult. A semiquantitative X-ray-fluorescence analysis and microscopic study indicated that although the optical properties and composition are similar to those of souzalite, the X-ray powder-diffraction data differ completely from those published for souzalite.

Souzalite, $(Mg,Fe^{2+})_3(Al,Fe^{3+})_4(PO_4)_4(OH)_6 \cdot 2H_2O$, was described by Pecora & Fahey (1949) from the Corrego Frio pegmatite, north of Divino, Minas Gerais, Brazil. One of us (M.E.M.) discovered that the X-ray powder-diffraction data given in the description are incorrect. We also had trouble reconciling the crystallographic data for souzalite given by Moore (1970) with those found in this study. Consequently, we have established new powder data and determined new optical and crystallographic data for souzalite from Brazil for the crystals from the type specimen, NMNH *C*5863 and ROM *M*34010 (NMNH refers to the National Museum of Natural History, Smithsonian Institution, Washington, D.C., and ROM, to the Royal Ontario Museum, Toronto). These new data for souzalite from Brazil are in very good agreement with those observed for crystals from the Yukon. The main difference is the great variation in the Mg:Fe ratio that was found in some crystals from the Yukon. Ideally, souzalite is $Mg_3Al_4(PO_4)_4(OH)_6 \cdot 2H_2O$, but many Yukon crystals have Fe^{2+} predominant. This new mineral, the ferrous analogue of souzalite, has an ideal composition $Fe^{2+}{}_3Al_4(PO_4)_4(OH)_6 \cdot 2H_2O$; it is named gormanite (GAWR•MENAIT) in honor of Professor D.H. Gorman, who has inspired interest in minerals and taught mineralogy to several generations of mineralogists and geologists at the University of Toronto. The name and the mineral were approved by the Commission on New Minerals and Mineral Names, I.M.A. Type material is deposited in the mineral collections of the Royal Ontario Museum (ROM *M*35123 and *M*35124) and the National Museum of Natural History (NMNH 137494 and 137495).

Many crystals in the specimens from the Yukon show strong chemical zoning wherein the composition changes from gormanite (Fe^{2+} predominant) to souzalite (Mg predominant) in a single crystal. Only a microprobe analysis shows whether gormanite or souzalite zones predominate. We could not determine any differences in appearance (color, crystal habit, *etc.*) between souzalite and gormanite in these specimens. Therefore, in describing the specimens from the Yukon, we recommend using the name gormanite–souzalite for crystals that have not been analyzed.

OCCURRENCE

Gormanite–souzalite crystals are very common in both the Rapid Creek and Big Fish areas in the northeastern part of the Yukon Territory. The mineral is seen in thin sections of the phosphatic ironstone beds as green, elongate crystals in radial aggregates, and in open fractures as elongate, blade-like crystals. In thin section, the mineral is similar to some of the chlorites, for which it can be easily mistaken.

In many fractures, gormanite–souzalite crystals constitute the only phosphate mineral and are generally accompanied by quartz and siderite. Elsewhere, gormanite–souzalite has been found in close association with ludlamite, arrojadite, kryzhanovskite and oxidized vivianite. In places, needles of gormanite–souzalite are included in quartz, giving the quartz crystals a green color. Phosphate minerals from the iron deposit in the northeastern Yukon, and the deposit itself, are briefly described in the paper on kulanite by Mandarino & Sturman (1976). The absence of any sign of metamorphism in the surrounding rocks indicates that these have crystallized at a low temperature.

CRYSTALLOGRAPHY

The largest gormanite crystals observed (ROM *M*35124) are elongate blades in fractures in the Big Fish area. Crystals are as much as 3 mm long, 0.5 mm wide and 0.1 mm thick. Crystals from other specimens are smaller and form radial aggregates in which the individual

TABLE 1. ANGLE TABLE FOR GORMANITE (M35123)

UNIT CELL:	Space group $P1$ or $P\bar{1}$; $Z = 2$		
	$a = 11.79(1)$		$d_{100} = 11.64(1)$
	$b = 5.11(1)$		$d_{010} = 5.11(1)$
	$c = 13.61(1)$		$d_{001} = 13.44(1)$
	$\alpha = 90^\circ 50(5)'$		$\alpha^* = 89^\circ 15(5)'$
	$\beta = 99^\circ 00(5)'$		$\beta^* = 81^\circ 00(5)'$
	$\gamma = 90^\circ 05(5)'$		$\gamma^* = 89^\circ 50(5)'$
COORDINATES:		ϕ	ρ
	(100)	89°47'	90°00'
	(010)	0°00'	90°00'
Forms	(001)	85°05'	9°02'
	(102)	88°46'	36°36'
	($\bar{1}$02)	-88°28'	23°04'
Principal vibration directions	X	163°	7°
	Y	-77½°	86½°
	Z	12½°	84°

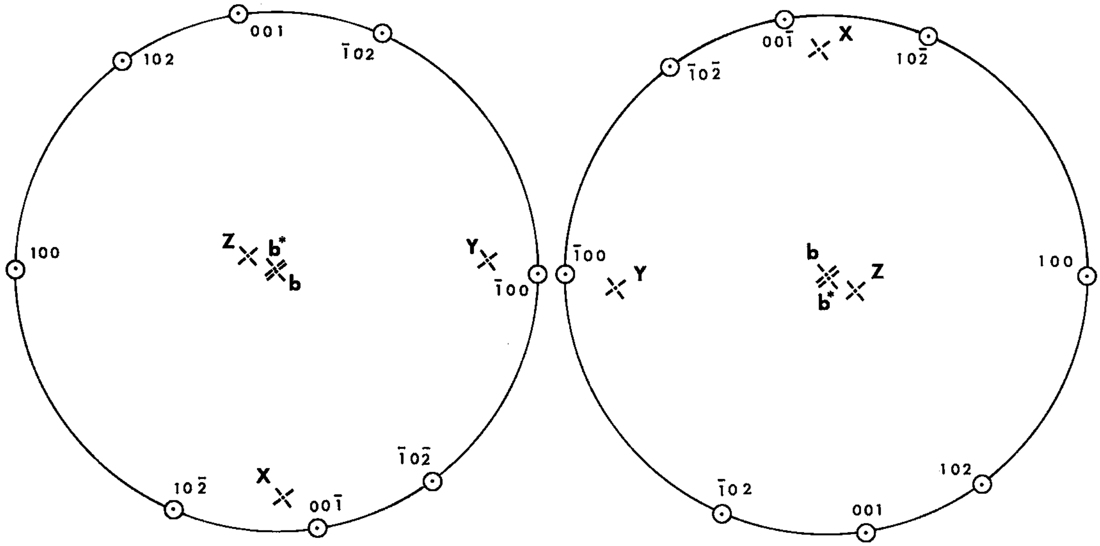

FIG. 1. Stereographic projections (with the *b* axis vertical) of the twinned lamellae in a gormanite crystal.

crystals are always bladed.

The blades are elongate [010], and the largest face (plane of the blade) is {001}. Other forms observed by optical goniometer and universal stage are small faces {100} and minute faces {102}, {$\bar{1}$02} and {010}. The calculated ϕ and ρ values for these forms are given in Table 1.

Pecora & Fahey (1949) described souzalite as probably monoclinic because of its optical properties. After a Weissenberg study of souzalite, Moore (1970) proposed a monoclinic cell that has the *b* axis (twofold axis) parallel to the elongation. Our study shows that all crystals of souzalite from Brazil and gormanite–souzalite from the Yukon are triclinic and are polysynthetically twinned with [010] as the twin axis. Figure 1 is a stereographic projection of a twinned crystal of gormanite with the *b* axis placed vertically to illustrate more clearly the relationship between the individuals. The composition plane is commonly irregular but is generally parallel to {001}.

The gormanite crystal used in this study was first examined on the optical goniometer and then was studied by means of the polarizing microscope, using a spindle stage modified to allow a goniometer head to be mounted. The optical properties show that the mineral is not monoclinic, with the *b* axis (two fold axis) parallel to the elongation, because none of the principal vibration directions parallels the axis of elongation. Furthermore, examination of

TABLE 2. UNIT-CELL PARAMETERS OF GORMANITE AND SOUZALITE

	Gormanite Yukon Territory, Canada			Souzalite Minas Gerais, Brazil	
	M35124		M35123	This study M34010	Moore (1970)
	Single crystal	Refined from powder data	Refined from powder data	Refined from powder data	Single crystal
a	11.76(1)Å	11.77(1)Å	11.79(1)Å	11.74(1)Å	12.58 Å
b	5.10(1)	5.11(1)	5.11(1)	5.11(1)	5.10
c	13.57(1)	13.57(1)	13.61(1)	13.58(1)	13.48
α	90°40(5)'	90°45(5)'	90°50(5)'	90°55(5)'	
β	99°10(5)'	99°15(5)'	99°00(5)'	99°05(5)'	113.0°
γ	90°10(5)'	90°05(5)'	90°05(5)'	90°20(5)'	
V	803.41 Å^3	805.48 Å^3	809.78 Å^3	804.53 Å^3	796.10
Space group	$P1$ or $P\bar{1}$	—	—	—	$A2/m$ or $A2$
Z	2	2	2	2	2

other crystals on the universal stage showed the twin axis to be parallel to the elongation, another indication that the elongation axis cannot be the *b* axis of the monoclinic cell. Finally, a single-crystal X-ray-diffraction study, by Weissenberg and precession methods, proved that the mineral is triclinic, although the twinned crystals show pseudomonoclinic symmetry.

The triclinic unit cell given in Table 2 reflects the pseudosymmetry of the twinned crystals. The space group is either $P1$ or $P\bar{1}$. The monoclinic unit cell of Moore (1970) can be derived from the triclinic cell in the following way: $b_{\text{mon}} = -b_{\text{tric}}$; $a^*_{\text{mon}} = -a^*_{\text{tric}}$; $c^*_{\text{mon}} = [\bar{1}02]_{\text{tric}}$ (see Fig. 1).

A search for an untwinned crystal of either souzalite or gormanite suitable for single-crystal X-ray study proved fruitless, even though many crystals from several specimens from the Yukon were examined under the microscope in immersion liquids and, later, on the precession camera. Finally, a small crystal fragment composed of one large individual and a small one adhering to it was chosen for study. Because of the greatly differing sizes of the individuals, the respective diffraction spots were readily distinguishable. This crystal was taken from ROM specimen *M*35124; it was impossible to separate sufficient pure material from this specimen for a full chemical analysis; only a microprobe analysis was done. A complete chemical analysis of gormanite was made of material from ROM specimen *M*35123, which is slightly different chemically and crystallographically from that in ROM *M*35124. Chemical data for crystals from these two specimens are given in Table 5, and their unit-cell parameters in Table 2.

Although we were unable to find a suitable crystal for the single-crystal study of the type souzalite from Brazil, we conclude that it also is triclinic, for the following reasons: (1) Many crystals from the Yukon localities show variable compositional zoning from gormanite to souzalite; souzalite and gormanite are isostructural and form a solid-solution series. The triclinic unit cell determined for gormanite is certainly valid for the souzalite zones on the crystals from the Yukon. (2) Souzalite from Brazil and gormanite–souzalite crystals from the Yukon have practically identical powder patterns; small differences in *d* values represent small differences in unit-cell dimensions caused by small variations in chemical composition. (3) Souzalite from Brazil and gormanite–souzalite crystals from the Yukon show twinning and have optical properties indicating a triclinic unit cell.

X-Ray Powder-Diffraction Data

The X-ray powder-diffraction data for souzalite given by Pecora & Fahey (1949) were incorrectly calculated. The powder pattern was prepared with Fe radiation, but the *d* values were calculated as if Cu radiation had been used. The *d* values for souzalite given in the right column of Table 3 were recalculated from the data reported by Pecora & Fahey (1949). These powder data are comparable to our Guinier powder data (Table 3) for Brazilian souzalite. Guinier powder data for gormanite from the Yukon (ROM *M*35124) also are given in Table 3. The powder patterns of gormanite and souzalite are similar; small differences in *d*

TABLE 3. X-RAY POWDER DIFFRACTION DATA FOR SOUZALITE AND GORMANITE

Gormanite, Yukon M35123				Souzalite, Brazil M34010			
Guinier camera				Guinier camera this study		Recalculated from Pecora & (Fahey (1949)	
I	$d_{\text{obs.}}$	$d_{\text{calc.}}$	*hkl*	*I*	$d_{\text{obs.}}$	*I*	$d_{\text{obs.}}$
30	6.72	6.72	*002	30	6.72	S	6.72
5	4.79	4.80	$0\bar{1}1$	5	4.78		
		4.79	$\bar{2}02$				
60	4.761	4.754	*011	60	4.760	S	4.76
1	4.495	4.495	*$\bar{1}11$	1	4.490	F	4.48
5	4.094	4.095	*202	5	4.080	W	4.08
1	3.802	3.803	$\bar{2}\bar{1}1$	1	3.795		
		3.794	$\bar{2}11$				
10	3.614	3.612	*$2\bar{1}1$	10	3.614		
10	3.580	3.581	*211	10	3.581	W	3.584
100	3.395	3.394	*$0\bar{1}3$	100	3.386	VS	3.381
1	3.361	3.365	*$\bar{1}\bar{1}3$	1	3.358		
10	3.346	3.345	013	30	3.341		
d60	3.154	3.161	$1\bar{1}3$	60	3.152		3.148
		3.155	302				
20	3.123	3.131	*$\bar{2}04$	10	3.121	S	3.101
20	3.117	3.118	*113	10	3.104		
30	3.093	3.093	*$\bar{2}\bar{1}3$	20	3.086		
40	3.062	3.063	*$\bar{2}13$	40	3.060		3.061
5	2.944	2.944	*$3\bar{1}1$	d80	2.921	M	2.920
80	2.925	2.924	*311				
1	2.838	2.838	$\bar{4}02$	1	2.836	F	2.842
d90	2.554	2.555	*020	d90	2.553	S	2.547
		2.551	$\bar{4}11$				
5	2.417			5	2.400	W	2.380
10	2.362			10	2.359		
10	2.348			10	2.343	W	2.343
						F	2.254
d1	2.098					F	2.092
10	2.051			d10	2.045	MW	2.047
10	2.044						
5	2.023			5	2.024		
1	1.976			1	1.976	W	1.978
d10	1.925			d10	1.924	MW	1.922
d10	1.901			d10	1.900	W	1.899
10	1.820			5	1.820	M	1.819
5	1.805			5	1.804		
5	1.783			1	1.782	F	1.782
1	1.732			1	1.732	F	1.729
1	1.696			1	1.692	F	1.694
15	1.660			20	1.658	MW	1.659
10	1.545			10	1.543	M	1.543
10	1.528			10	1.529	MW	1.530
1	1.491			1	1.491	W	1.486
10	1.471			10	1.470		
5	1.281			5	1.278		

Intensities were estimated by eye; d-double line. CuKα radiation was used with Guinier cameras, and Fe-radiation and Debye-Scherrer camera were used by Pecora & Fahey (1949). Intensity of the line 3.346 and 3.341 probably depends on the amount of the admixed quartz. *Lines used for the least-squares refinement of the unit cell. Three of these (6.72, 4.495 and 3.361) were given lower weightings than other lines in the refinement programme.

values can be observed only when the two Guinier patterns are placed side by side. The small differences in the intensities of the lines in the two patterns are within the range of experimental error. Many spacings could be multiply indexed; single-crystal films were used to determine the appropriate Miller indices.

PHYSICAL AND OPTICAL PROPERTIES

Gormanite and souzalite are blue-green, and the streak is pale green. Changes in the color of zoned crystals are not related to the variation in chemical composition. The lustre is vitreous, and the mineral is nonfluorescent under short- and long-wave ultraviolet light. A hardness of 4 to 5 was determined on a sawn surface of a gormanite–souzalite aggregate. This is less than the range of 5½–6 given for souzalite from Brazil by Pecora & Fahey 1949) and is probably lower owing to the breaking of individual blades in the aggregate.

Poor cleavage parallel to {001} was observed in a few grains in thin sections of the gormanite–souzalite crystals from the Yukon. Pecora & Fahey (1949) reported two cleavages in souzalite, a good one at about 90° to the poor one. In the crystals from the Yukon and Brazil, we could find only the one poor cleavage parallel to {001}. When souzalite or gormanite crystals are crushed, however, they break along the composition plane of the twins, thus giving the false impression of a good cleavage parallel to the composition plane {001}. This may explain the good cleavage reported by Pecora & Fahey (1949), but we cannot account for the poor cleavage at 90° to this.

Pecora & Fahey (1949) gave a measured density of 3.09 g/cm^3 for souzalite from Brazil, and we have calculated a value of 3.07 g/cm^3, using their chemical analysis and our refined unit-cell dimensions. Determination of the density of analyzed gormanite by means of the Berman microbalance gave values from 2.98 to 3.02 g/cm^3, but examination of thin sections of gormanite aggregates showed that fragments weighing only 5 to 10 mg contain admixed quartz, and voids are present between grains. To avoid the problem caused by impurities and voids, we crushed the samples; the density of small grains of pure material was determined by immersion in calibrated heavy liquids. The values thus obtained are 3.10(3) g/cm^3 for *M*35124 and 3.13(2) g/cm^3 for *M*35123. The density calculated for *M*35124 is 3.10 g/cm^3, and for *M*35123 is 3.12 g/cm^3, using the refined unit-cell data (Table 2) and chemical composition (Table 5). Crystals from specimen *M*35123 showed only small variation in chemical composition, whereas strong zoning in crystals from *M*35124 indicates considerable variation in composition. Table 5 gives the average composition for *M*35124 that was used to calculate the density of the whole crystal.

The value of $2V$ and the orientation of the indicatrix, crystal faces and composition plane were determined by means of the universal stage. Because of small grain-size and twinning, neither the spindle stage nor the methods of Sturman (1973) could be used to determine the indices of refraction. Consequently, α was determined as the smallest observed index of many grains in immersion mounts, and γ as the largest index. The value of β was measured directly from crystals lying on blade faces because Y lies almost in that plane. The previously determined orientation of the indicatrix and pleochroism were useful in choosing suitably oriented grains. The complete optical data for gormanite *M*35123 are given in Table 4, where they are compared with the optical data for Brazilian souzalite determined in this study and by Pecora & Fahey (1949).

This method probably gave reasonably accurate optical data for crystals from *M*35123 (Yukon) and *M*34010 (Brazil) that show only weak zoning. On the other hand, the small, irregular size of the zones and their variation in chemical composition and twinning made correlation between optical data and composition of the zones impossible for material from *M*35124; they are not included in Table 4.

Dispersion of the optic axes is very strong, with $r > v$. Principal vibration direction Z for Na-light makes an angle of about 14° with the elongation in gormanite *M*35123. Instead of showing an extinction angle of 14° on the blade face, this extinction is replaced by the change in color from reddish to blue in such a way as to indicate that $Z\Lambda b$ is much smaller for red light than for violet light; $Z_r\Lambda b < Z_v\Lambda b$.

Gladstone–Dale calculations were made for both gormanite and souzalite to determine the compatibility of the data as outlined by Mandarino (1976, 1979). The data used for gormanite are the chemical analysis of specimen *M*35123, the mean index of refraction (1.644) and the calculated density (3.12 g/cm^3). For souzalite, the chemical analysis given by Pecora & Fahey (1949) was used, with the mean index (1.637) determined in this study and the density calculated in this study (3.07 g/cm^3). The results for gormanite are $K_C = 0.212$ and $K_P = 0.206$, which give a value for $1-(K_P/K_C)$ of

TABLE 4. OPTICAL PROPERTIES OF GORMANITE AND SOUZALITE

	Gormanite Yukon Territory, Canada	Souzalite Minas Gerais, Brazil	
	M35123	M34010 This study	Pecora & Fahey (1949)
α	1.619 (3)	1.617 (3)	1.618
β	1.653 (3)	1.642 (3)	1.642
γ	1.660 (3)	1.653 (3)	1.652
$2V_x$(calc.)	56°	66°	68°
$2V_x$(meas.)	$53(2)^{\circ}$		
Dispersion	r>v		r>v, symmetric
Pleochroism			
X	colourless	colourless	green
Y	blue	blue	blue
Z	colourless	colourless-pale yellow	yellow
Absorption	X = Z < Y	X = Z < Y	
Orientation	X nearly normal to composition plane; Z nearly parallel to elongation (*b*-axis) $Z\wedge b = 14^{\circ}$	X nearly normal to composition plane; Z nearly parallel to elongation (*b*-axis) $Z\wedge b = 10^{\circ}$	X normal to cleavage; Z = elongation (near *a*?)
Polysynthetic twinning	composition plane {001}; twin axis |010|; maximum extinction 14°	composition plane {001}; twin axis |010|; maximum extinction 10°	composition plane parallel to good cleavage; maximum extinction 12°

TABLE 5. RESULTS OF ANALYSES OF GORMANITE AND SOUZALITE

	Gormanite Yukon Territory, Canada			Souzalite Minas Gerais, Brazil
	M35123		M35124	
	chemical(1)	electron microprobe(2)	electron microprobe(2)	chemical(3)
MgO	6.65	6.9	7.8	9.62
CaO	0.26	—	—	0.02
MnO	0.31	0.4	0.4	0.31
FeO	14.68	17.4(4)	16.0(4)	11.49
Al_2O_3	25.51	26.7	27.0	26.07
Fe_2O_3	3.82	—	—	2.65
P_2O_5	37.23	38.4	38.5	37.70
H_2O	11.45	n.d.	n.d.	12.04
SnO	—	—	—	0.04
TiO_2	—	—	—	0.07
total	99.91			100.01
		Number of ions		
	(5)	(6)	(6)	(5)
Mg	1.26	1.27	1.42	1.78
Ca	0.04	—	—	0.00
Mn	0.03	0.04	0.04	0.03
Fe^{2+}	1.56	1.69	1.53	1.19
Al	3.82	3.88	3.90	3.82
Fe^{3+}	0.36	0.11	0.11	0.25
P	4.00	4.01	3.99	3.96
H	9.69	9.93	10.03	9.97
O	24.00	23.98	24.01	24.00

(1) Analyst: Dr. E. J. Brooker, X-ray Assay Laboratories, Toronto (See text for details)
(2) Analyst: Pete J. Dunn; accuracy of data ± 3% of the amount present
(3) Pecora & Fahey (1949)
(4) Total Fe expressed as FeO
(5) Calculated on the basis of O = 24
(6) Calculated on the basis of Mg + Mn + Fe + Al + P = 11. Fe partitioned between Fe^{2+} and Fe^{3+} to make Mg + Mn + Fe^{2+} = 3. H calculated to give $2H_2O$ and enough OH to balance charges.

0.028, indicating excellent compatibility of the data. The results for souzalite are $K_C = 0.211$, $K_P = 0.207$ and $1-(K_P/K_C) = 0.019$, which indicates superior compatibility of the data.

CHEMICAL COMPOSITION

A chemical analysis was made of material from ROM specimen *M*35123, and electron-microprobe analyses of material from this specimen and from ROM specimen *M*35124 (Table 5). The chemical analysis of *M*35123 has been corrected for 7.0 wt. % SiO_2, which was present as admixed quartz. Magnesium, calcium and aluminum were determined by atomic absorption, manganese, total iron and phosphorus by X-ray fluorescence, ferrous and ferric iron by titration with potassium permanganate, and H_2O by thermogravimetric analysis. The other samples were analyzed by means of an ARL–SEMQ electron microprobe, using an operating voltage of 15 kV and a beam current of 0.15 μA. The samples for microprobe examination were mounted in epoxy and examined in polished thin sections. Unmounted samples also were examined to check on possible dehydration during the sample preparation. No evidence of dehydration was observed. Microprobe standards used were montgomeryite for Al and P, and arrojadite for Mn, Ca, Mg and Fe. Compositions were verified using different standards for additional analyses not given here. The data were corrected for absorption, backscatter, fluorescence and background effects using several different computer programs, with similar results. The analytical results given in Table 5 were obtained using the standard Bence–Albee correction factors. Wavelength scans on the microprobe failed to indicate the presence of other cations.

The formula derived from the chemical analysis of *M*35123 is $(\mathrm{Fe}^{2+}{}_{1.56}\mathrm{Mg}_{1.26}\mathrm{Ca}_{0.04}\mathrm{Mn}_{0.03})_{\Sigma 2.89}(\mathrm{Al}_{3.82}\mathrm{Fe}^{3+}{}_{0.36})_{\Sigma 4.18}(\mathrm{PO}_4)_{4.00}(\mathrm{OH})_{6.32}\cdot 1.69\ \mathrm{H_2O}$. From the electron-microprobe analysis of *M*35123, the cation portion of the formula may be written $(\mathrm{Fe}^{2+}{}_{1.69}\mathrm{Mg}_{1.27}\mathrm{Mn}_{0.04})_{\Sigma 3.00}(\mathrm{Al}_{3.88}\mathrm{Fe}^{3+}{}_{0.11})_{\Sigma 3.99}$ if Fe is partitioned between the two valence states to make the summation of the divalent ions equal to three and that of the trivalent ions equal to four. Similarly, the cation portion of the formula derived from the electron-microprobe analysis of *M*35124 may be written $(\mathrm{Fe}^{2+}{}_{1.54}\mathrm{Mg}_{1.42}\mathrm{Mn}_{0.04})_{\Sigma 3.00}(\mathrm{Al}_{3.90}\mathrm{Fe}^{3+}{}_{0.10})_{\Sigma 4.00}$. We have derived the following formula from the souzalite chemical analysis given by Pecora & Fahey (1949) based on 24 oxygen atoms: $(\mathrm{Mg}_{1.78}\mathrm{Fe}^{2+}{}_{1.19}\mathrm{Mn}_{0.03})_{\Sigma 3.00}(\mathrm{Al}_{3.82}\mathrm{Fe}^{3+}{}_{0.25})_{\Sigma 4.07}(\mathrm{PO}_4)_{3.96}(\mathrm{OH})_{6.33}\cdot 1.82\ \mathrm{H_2O}$. It is evident that the general formula for the souzalite–gormanite series is $R^{2+}{}_3R^{3+}{}_4(\mathrm{PO}_4)_4(\mathrm{OH})_6\cdot 2\mathrm{H_2O}$ where R^{2+} is mainly Mg (souzalite) or Fe^{2+} (gormanite), and R^{3+} is mainly Al with some Fe^{3+}.

In the electron-microprobe analytical data for *M*35123, the results from several crystals show little variation in composition. On the other hand, *M*35124 shows variation in the Mg:Fe ratio from 0.60 to 1.30. Thus, in this specimen, the composition varies from ferroan souzalite to magnesian gormanite. No relation was observed between this compositional zoning and crystallographic orientation, although many crystals were examined. Density maps of cation distribution for Mg and Fe confirmed the randomness of the chemical inhomogeneity. The zones are small, and no attempt was made to determine the indices of refraction or other physical properties of the analyzed zones. The analysis of *M*35124 in Table 5 is an average of more than 25 sample points on many crystals.

THERMAL PROPERTIES

A 350 mg sample of gormanite (*M*35123) was subjected to simultaneous differential thermal and thermogravimetric analyses in a Mettler Thermal-Analyzer using a nitrogen atmosphere and heating rate of 8°C/min. The DTA showed a strong endothermic peak at 510°C, a broad exothermic peak at 720°C and a small exothermic peak at 850°C. The TGA showed weight loss beginning at 390°C and continuing to 700°C.

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