

ADDITIONAL DATA ON LOVERINGITE (Ca, REE) (Ti, Fe, Cr)₂₁O₃₈ AND MOHSITE DISCREDITED

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ABSTRACT

Loveringite, (Ca,REE)(Ti,Fe,Cr)₂₁O₃₈, is a recently defined member of the crichtonite group of minerals; it differs from the other members of that group in having Ca as the dominant large cation. It was found in the bronzite cumulate layers of the Jimberlana Intrusion, Western Australia. Loveringite is black with a submetallic to metallic lustre; it has a density of 4.42 g/cm³. It is opaque and in reflected light is white to greyish-white with a reflectivity of 17% in air and 5.9% in oil. The Vickers micro-indentation hardness is 421–464 kg/mm² and the streak is iron-grey. The mineral is partially metamict but may be reconstituted by heating to 800°C for 1 hour. The reconstituted grain has space group R $\bar{3}$ with a_{rh} 9.117(4) Å, a_{rh} 69.07(1)°, $Z = 1$. The strongest lines in the X-ray powder pattern, calculated from single-crystal data, are 3.384(87)(022), 3.037(93)(113), 2.867(114)(132,231), 2.831(84)(130,103), 2.465(75)($\bar{1}22,2\bar{1}2$), 2.238(72)($\bar{1}32,1\bar{2}3$), 2.129(82)(104,140), 1.791(71)(215), 1.589(92)(145), 1.433(106)($\bar{3}14,1\bar{3}4$). Mohsite is classified by Strunz (1970) as a member of the crichtonite group. With a formula given as (Fe²⁺,Ca,Mg)₂Ti₅O₁₂, it could be the member of that group with Ca as the dominant large cation. However, recent analysis of Lacroix's neotype specimen showed that it contains Sr and Pb but no Ca. Thus, mohsite is part of the senaite–crichtonite series and not a distinct mineral.

SOMMAIRE

La loveringite (Ca,REE)(Ti,Fe,Cr)₂₁O₃₈ est un membre de la famille des crichtonites récemment

décrit qui se distingue par la présence de Ca comme gros cation dominant. On la trouve dans les cumulats à bronzite de l'intrusion Jimberlana, Australie occidentale. La loveringite est noire, d'éclat submétallique à métallique et de densité 4.42. C'est un minéral opaque, blanc à gris-blanc en lumière réfléchiée; sa réflectivité est de 17% dans l'air et de 5.9% dans l'huile. La microdureté Vickers est de 421–464 kg/mm²; la poussière est gris métallique. Le minéral est partiellement métamict; on peut le reconstituer en le chauffant une heure à 800°C. Sa structure appartient au groupe spatial R $\bar{3}$, avec a_{rh} 9.117(4) Å a_{rh} 69.07(1)°, $Z = 1$. Les dix raies les plus intenses du cliché de poudre, calculées à partir des données du cristal unique, sont: 3.384(87)(022), 3.037(93)(113), 2.867(114)(132,231), 2.831(84)(130,103), 2.465(75)($\bar{1}22,2\bar{1}2$), 2.238(72)($\bar{1}32,1\bar{2}3$), 2.129(82)(104,140), 1.791(71)(215), 1.589(92)(145), 1.433(106)($\bar{3}14,1\bar{3}4$). Strunz (1970) classe la mohsite dans la famille des crichtonites. Sa formule, donnée comme (Fe²⁺,Ca,Mg)₂Ti₅O₁₂, pouvait la faire considérer comme membre calcifère de cette famille. Toutefois, une analyses récente du spécimen néotype de Lacroix montre Sr et Pb mais pas de Ca. La "mohsite" est donc membre de la série senaite–crichtonite et non espèce distincte.

(Traduit par la Rédaction)

INTRODUCTION

The incompatible elements (*e.g.*, U, Pb, Sr, REE) have, in recent years, become increasingly important in geochemistry. These elements show little tendency to enter the rock-forming minerals and are concentrated in accessory phases. Many of these accessory phases are only found in trace quantities, and their location by conventional techniques is all but impossible. Fortunately, most of them have anomalous U contents

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and can be located with confidence using the fission-track method (Kleeman & Lovering 1967). As little is known about the distribution of accessory phases in igneous rocks, a systematic study was commenced to document their distribution in the Jimberlana Intrusion of Western Australia. It was during this study that a new mineral with the formula (Ca,REE) (Ti, Fe,Cr)₂₁O₃₈ was discovered. It has been named *loveringite* after Professor J.F. Lovering, a pioneer of the fission-track method and Professor of Geology at the University of Melbourne, where the mineral was found. The type specimen is held at the National Museum of Victoria, Melbourne, Australia. The name *loveringite* has been approved by the International Mineralogical Association Commission on New Minerals and Mineral Names.

TABLE 1. LOVERINGITE: POWDER DATA CALCULATED FROM SINGLE-CRYSTAL DATA*

h	k	l	d	λ	I(obs)	I(calc)	h	k	l	d	λ	I(obs)	I(calc)
1	1	2	4.476	12	14		-3	-2	2	1.879	2	2	
-1	1	1	4.375	3	4		-1	4	0	1.879	2	3	
0	2	1	4.135	10	10		4	4	2	1.877	4	4	
0	1	2	4.135	15	15		4	3	4	1.840	1	1	
1	0	2	4.135	9	10		-1	4	2	1.839	25	24	
0	2	0	4.108	5	7		2	1	5	1.791	71	76	
0	0	2	4.108	5	7		1	1	5	1.784	1	1	
2	1	2	3.754	12	18		-2	-2	3	1.784	1	1	
2	2	2	3.446	1	2		3	2	5	1.764	13	12	
0	2	2	3.384	87	89		4	4	4	1.723	4	5	
-1	2	0	3.339	7	5		-1	4	3	1.699	18	18	
-1	2	1	3.216	4	5		0	1	5	1.699	15	16	
1	1	3	3.037	93	89		1	0	5	1.699	3	2	
-1	-1	2	2.984	40	33		4	0	4	1.692	1	1	
1	3	2	2.867	47	50		-3	-3	2	1.692	7	6	
2	3	1	2.867	67	72		0	2	5	1.686	2	2	
1	3	0	2.831	67	74		0	5	2	1.686	2	2	
1	0	3	2.831	17	18		-3	-1	3	1.686	5	4	
3	2	2	2.805	7	9		2	5	4	1.643	1	1	
-1	2	2	2.738	20	22		0	5	0	1.643	17	16	
0	0	3	2.738	18	20		5	3	4	1.635	2	2	
0	2	3	2.619	8	11		4	3	5	1.635	1	1	
0	3	2	2.619	45	44		5	0	3	1.608	1	1	
0	-2	2	2.584	11	9		-4	-2	2	1.608	5	6	
-2	0	2	2.584	10	9		-2	2	4	1.608	9	8	
-1	-2	2	2.465	3	3		-2	-1	4	1.603	2	1	
-1	-2	2	2.465	72	76		1	5	4	1.589	2	2	
-1	3	1	2.420	10	12		1	4	5	1.589	92	97	
-1	1	3	2.420	10	11		-2	-3	3	1.589	1	1	
0	-1	3	2.414	20	25		4	4	5	1.566	1	2	
3	3	3	2.297	3	4		-1	5	1	1.566	7	7	
1	1	4	2.256	1	1		-1	1	5	1.566	6	6	
-1	3	2	2.238	26	26		-1	5	2	1.541	6	6	
-1	2	3	2.238	46	46		-1	2	5	1.541	9	8	
1	4	2	2.225	2	3		-1	5	0	1.535	8	8	
2	4	1	2.225	1	2		-1	0	5	1.535	3	4	
1	2	4	2.225	1	2		2	6	2	1.519	3	3	
-1	-1	3	2.225	1	0		2	6	3	1.499	40	41	
1	4	0	2.129	14	13		-4	-2	2	1.499	3	3	
1	0	4	2.129	68	65		-2	3	4	1.499	3	3	
2	4	3	2.099	3	3		-2	-2	4	1.492	1	1	
2	3	4	2.099	4	4		2	1	6	1.488	1	1	
4	1	3	2.054	1	2		1	1	6	1.472	1	1	
3	1	4	2.054	2	2		-1	5	3	1.468	2	2	
3	3	4	2.015	3	2		-1	-1	5	1.458	4	4	
-3	-1	2	2.014	2	2		1	6	3	1.457	3	2	
-1	3	3	1.968	1	1		1	3	6	1.457	1	1	
-2	-1	3	1.954	6	7		-1	-4	3	1.457	4	4	
-1	-2	3	1.954	4	3		6	4	3	1.439	4	4	
-1	4	1	1.909	1	1		3	4	6	1.439	4	4	
-1	1	4	1.909	16	15		2	6	4	1.434	1	1	
4	0	3	1.901	19	20		-3	-1	4	1.433	100	100	
-2	-3	2	1.879	2	2		-1	-3	4	1.433	6	5	

* Indexing refers to rhombohedral axes.
Mo K α radiation. I(obs) are single-crystal reflection intensities and I(calc) are intensities calculated using model parameters given previously (Gatehouse *et al.*, 1978).

OCCURRENCE

The Jimberlana Intrusion consists of a repeated sequence of olivine and bronzite cumulate layers overlain by a thick plagioclase-augite-hypersthene cumulate layer (Campbell 1977). *Loveringite* is most abundant in bronzite cumulates, but even in these layers it rarely exceeds 5 grains per thin section. The mineral is also found in trace amounts in the lower half of the plagioclase-augite-hypersthene cumulate layer but has not been recorded in the olivine cumulates. It is closely associated with quartz-potassium feldspar intergrowths or phlogopite and is thought to be amongst the last phases to crystallize from the residual intercumulus liquid.

PHYSICAL PROPERTIES

Loveringite occurs as isolated crystals which are usually anhedral but occasionally it forms needles. The grain size rarely exceeds 100 μm x 50 μm . It is black with a submetallic to metallic lustre and has a calculated density of 4.42 g/cm³. *Loveringite* is opaque and white to greyish-white in reflected light. Reflectances measured in white light are 17% in air and 5.9% in oil ($n = 1.518$). The Vickers micro-indentation hardness is 421–464 kg/mm² (load 10 g), the streak is iron-grey, and polishing cleavage is absent.

CRYSTALLOGRAPHY

Loveringite is partly metamict. In an initial study of individual grains, precession and Weissenberg photographs showed diffraction patterns consisting of sharp spots which could be indexed with a hexagonal cell $a = 2.87$, $c = 20.67 \text{ \AA}$. These subcell parameters correspond to those of the anion lattice of *dauidite*, *senaita* and *crichtonite*. Heating the grain to 800°C for one hour in air produced single-crystal X-ray diffraction patterns similar to those of *senaita* and *crichtonite*. The unit-cell data obtained using a Phillips PW1100 4-circle automatic diffractometer are $a_{\text{rh}} 9.117(4) \text{ \AA}$, $a_{\text{rh}} 69.07(1)^\circ$, with $Z = 1$ [$a_{\text{hex}} 10.337(6) \text{ \AA}$ and $c_{\text{hex}} 20.677(12) \text{ \AA}$ with $Z = 3$]. A successful refinement of the structure was obtained in space group $R\bar{3}$ using the coordinates for *senaita* as starting values. The conventional final R -factor was 0.043 for 398 observed reflections. Attempts to obtain a powder pattern by extracting grains from thin sections were unsuccessful due to the

rarity and small grain-size of the crystals. Powder data were therefore calculated from single-crystal data and are presented in Table 1.

Loveringite is isostructural with crichtonite (Grey *et al.* 1976) and senaite (Grey & Lloyd 1976), having a structure based on a close-packed array of anions with a (*hhc---*) stacking sequence and with Ca (plus REE and minor large cations) occupying one anion site per unit cell (the M_0 site; Table 2). The small cations are distributed over 19 octahedral and 2 tetrahedral sites per unit cell, and there is considerable ordering of the cations in different sites (Table 2). The detailed structure is discussed by Gatehouse *et al.* (1978).

CHEMISTRY

The mineral was analyzed on a JEOL electron microprobe, using a sample current between 12 and 14 μ A with a beam focused to approximately 5 μ m. Most of the elements were measured at 15 kV, but Pb, Hf, Zr, Th, Ce, La, Nd, Y, Sr and V were determined at 20 kV. The sample was analyzed before and after heat treatment but no detectable change in the chemistry was observed. All of the Fe is assumed present as Fe_2O_3 after heating in air but the $FeO:Fe_2O_3$ ratio in the natural sample is unknown. The analytical results are given in Table 3. The formula, normalized to 38 oxygen atoms, is: $Ca_{0.72}REE_{0.33}(Y,Pb,Th,U)_{0.05}Ti_{12.48}Fe_{3.38}Cr_{2.24}Mg_{0.92}Zr_{0.58}V_{0.21}Al_{0.35}Mn_{0.04}O_{38}$. Loveringite is a titanium-iron-chromium oxide with significant amounts of Zr, Ca, Mg and REE. The REE pattern is characterized by a strong depletion trend between La and Eu, a sharp reversal between Eu and Ho and a second depletion pattern from Ho to Lu. The detailed chemistry is discussed by Campbell & Kelly (1978).

RELATIONSHIP TO MOHSITE

Gatehouse *et al.* (1978) have proposed that the crichtonite group of minerals be named after the dominant large cation in the M_0 site. Thus, the dominant cation in the M_0 site is Sr for crichtonite, Pb for senaite, REE for davidite, Na for landauite and Ca for loveringite. This proposal has been endorsed by the International Mineralogical Association Commission on New Minerals and Mineral Names.

Strunz (1970) has listed mohsite with the formula $(Fe^{3+},Ca,Mg)_2Ti_5O_{12}$ and has classified it with the crichtonite group of minerals.

TABLE 2. LOVERINGITE SITE OCCUPANCY

Atomic site	Occupancy
M(0) *	0.72 Ca + 0.23 REE + 0.05 (Y,Th,U,Pb)
M(1)	0.58 Zr + 0.1 REE + 0.32 Mg
M(2)	0.60 Mg + 1.23 Fe
M(3)	2.24 Cr + 2.19 Fe + 0.86 Ti + 0.21 V
M(4)	5.81 Ti + 0.19 Al
M(5)	5.81 Ti + 0.19 Al

*For details see Gatehouse *et al.* (1978).

TABLE 3. ELECTRON MICROPROBE ANALYSES OF RECONSTITUTED LOVERINGITE AND MOHSITE

Loveringite		Mohsite	Loveringite		Mohsite
TiO ₂	58.3	58.2	ZnO	-	0.9
ZrO ₂	4.2	0.2	MnO	0.2	2.1
HfO ₂	0.4	-	Fe ₂ O ₃ *	15.8	26.1
SiO ₂	-	-	La ₂ O ₃	1.2	0.7
UO ₂	0.2	0.2	Ce ₂ O ₃	1.3	0.5
ThO ₂	0.1	-	Y ₂ O ₃	0.1	2.6
MgO	2.2	-	Cr ₂ O ₃	9.9	0.1
NiO	0.1	-	Al ₂ O ₃	1.2	0.1
CaO	2.4	0.2	Nd ₂ O ₃	0.2	0.1
SrO	-	2.7	V ₂ O ₅	1.1	0.2
PbO	0.2	5.3	REE**	0.3	0.2
			Total	99.4	100.4

* Total Fe as Fe_2O_3 . ** Other REE contributions estimated from chondrite normalized REE pattern.

Thus, the possibility existed that mohsite was the Ca-rich member of the crichtonite group. Mohsite, first described by Lévy (1827), was probably found near Dauphiné. Its chemistry was unknown and his description is almost wholly morphological. He did note that it might be united with crichtonite but added that "a rhomboid as acute as that of crichtonite may be derived by simple laws from many rhomboids", including hematite and ilmenite as well as mohsite. Lévy's material cannot be traced. In 1901 Lacroix found material at Plate Muratouse, La Grave, Hautes Alpes (part of Dauphiné), which he described as mohsite, agreeing exactly with Lévy's description. There was not enough material for a chemical analysis but, in the absence of Lévy's specimen, Lacroix's became the neotype. Colomba (1902) described material morphologically similar to mohsite from Dora Riparia, Neaume, Oulx, Italian Alps. Qualitative analysis showed that this sample contains TiO₂, FeO with a little CaO and MgO but no Fe_2O_3 .

We were able to obtain a sample of Lacroix's original specimen, kindly supplied by Dr. Schubnel of the Muséum National d'Histoire Naturelle, Paris. The sample was analyzed and

found to contain significant amounts of Sr and Pb but negligible Ca (Table 3). Mohsite is therefore a member of the crichtonite-senaite series and not a distinct mineral species. As the name crichtonite (De Bournon 1813) has priority, it is proposed that *the name mohsite be discarded*. This proposition has been accepted by the I.M.A.

Although Colomba's "mohsite" has not been re-examined it may also be identical with crichtonite, Colomba having mistaken Sr for Ca. Alternatively, it may prove to be the Ca-dominant member of the series, lovingite. It is perhaps worth noting that the crichtonite locality, St-Christophe, Bourg d'Oisans, Isère (44°52'N, 6°11'E), is only 12.9 km from the mohsite locality, La Grave (45°2', 6°50'E), whereas Oulx on the Italian side of the Alps is about 40 km away.

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