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MONTEREGIANITE, A NEW HYDROUS SODIUM POTASSIUM YTTRIUM SILICATE MINERAL FROM MONT ST-HILAIRE, QUÉBEC

GEORGE Y. CHAO
Department of Geology, Carleton University, Ottawa, Ontario K1S 5B6

Abstract

The new mineral monteregianite occurs as needle-shaped crystals in radiating clusters and as groups of tabular crystals in miarolitic cavities, metamorphosed inclusions and rheomorphic breccias in the nepheline syenite at Mont St-Hilaire, Québec. The mineral is orthorhombic, *Bmab* or *B2ab*, *a* 14.014(4), *b* 23.910(5), *c* 13.096(2)Å. A pronounced pseudocell with *a* and *c* halved has *Pmmb*, *P2mb* or *Pm2b* symmetry. Strongest eight lines of the X-ray powder diffraction pattern are: 12.00 (100)(020), 7.03 (100)(200), 6.55 (40)(002), 6.02 (50)(220,040), 4.42 (100)(042), 3.405 (50)(062), 3.026 (50)(034,440), 2.873 (80)(044). The minerals is colorless, white, grey or rarely mauve or pale green with white streak and vitreous to silky lustre. Crystals, varying in size from 0.05 to 3 mm, are bounded by {010}, {001} and {100}; some show additional {101}. Cleavages: {010} perfect, {001} very good and {100} fair. Hardness 3½. The mineral is readily etched by 1:1 HCl, HNO_3 and H_2SO_4. Optically, the mineral is biaxial positive, α 1.510(1) β 1.513(1), γ 1.517(1), $2V$ meas. 87°, calc. 82°, dispersion inconspicuous. Orientation: $X=c$, $Y=a$, $Z=b$. Chemical analysis gave SiO_2 60.30, Al_2O_3 0.50, Y_2O_3 (probe analysis) 11.97, CaO 0.65, MgO 0.15, BaO 0.35, MnO n.d., FeO n.d., Na_2O 9.14, K_2O 5.36, H_2O (TGA to 1000°C) 11.40, sum 99.82 wt. %, corresponding to $(Na_{4.66}K_{1.80})$ $(Y_{1.68}Ca_{0.18}Mg_{0.06}Ba_{0.04})$ $(Si_{15.87}Al_{0.16})$ $O_{38} \cdot 10.02H_2O$ or $(Na, K)_6$ $Y_2Si_{16}O_{38} \cdot 10H_2O$. $Z=4$, D(meas.) 2.42, (calc.) 2.391 g/cm³. TGA and DTG show three distinct stages of dehydration at 25–80, 80–200, and 200–400°C. Water in the mineral is zeolitic, and recoverable after heating to 650°C. Infrared spectra confirm the presence of H_2O in the mineral.

Sommaire

La montérégianite, espèce nouvelle, se présente en cristaux aciculaires formant des agrégats fibro-radiés ou en groupes de cristaux tabulaires dans les cavités miarolitiques, inclusions métamorphisées et brèches rhéomorphiques de la syénite néphélinique du mont St-Hilaire, Québec. Elle appartient au groupe *Bmab* ou *B2ab*, avec maille *a* 14.014(4), *b* 23.910(5), *c* 13.096(2)Å, et au pseudo-groupe *Pmmb*, *P2mb ou Pm2b*, avec pseudo-maille bien marquée: $a' = a/2$, $b' = b$, $c' = c/2$. Les huit raies les plus intenses du cliché de poudre sont les suivantes: 12.00(100)(020), 7.03(100)(200), 6.55(40)(002), 6.02(50)(220,040), 4.42(100)(042), 3.405(50)(062), 3.026(50)(034,440), 2.873(80)(044). Les cristaux sont d'ordinaire incolores, blancs ou gris, rarement mauves ou d'un vert pâle, à rayure blanche et éclat vitreux à soyeux. Longs de 0.05 à 3 mm, montrant la combinaison {010}, {001} et {100}, ils sont parfois tronqués par {101}. Trois clivages: {010} parfait, {001} très bon, {100} distinct. Dureté 3½. Les cristaux sont facilement attaqués par 1:1 HCl, HNO_3 et H_2SO_4. La montérégianite est optiquement positive, α 1.510(1), β 1.513(1), γ 1.517(1), $2V$ 87° (mes.), 82° (calc.); dispersion à peine observable; orientation $X=c$, $Y=a$, $Z=b$. Une analyse donne SiO_2 60.30, Al_2O_3 0.50, Y_2O_3 (par microsonde) 11.97, CaO 0.65, MgO 0.15, BaO 0.35, MnO et FeO pas décelés, Na_2O 9.14, K_2O 5.36, H_2O (par thermogravimétrie, jusqu'à 1000°C) 11.40, total 99.82% (poids), ce qui correspond à $(Na_{4.66}K_{1.80})$ $(Y_{1.68}Ca_{0.18}Mg_{0.06}$ $Ba_{0.04})$ $(Si_{15.87}Al_{0.16})$ $O_{38} \cdot 10.02H_2O$ ou $(Na,K)_6$ $Y_2Si_{16}O_{38} \cdot 10H_2O$. $Z=4$, D (mes.) 2.42, (calc.) 2.391. Trois stades de déshydratation, à 25–80, 80–200 et 200–400°C, sont décelés par ATG et TGD. L'eau est zéolitique, et récupérable après chauffage jusqu'à 650°C. Les spectres infrarouges confirment la présence de l'eau.

(Traduit par la Rédaction)

Introduction

The new mineral monteregianite, formerly known as *UK–6* (Chao *et al.* 1967) occurs in miarolitic cavities and thermally metamorphosed inclusions and rheomorphic breccias in nepheline syenite at Mont St-Hilaire, Québec. The mineral is usually associated with calcite, pectolite, microcline, albite, aegirine, arfvedsonite and minor amounts of phlogopite, fluorite, quartz, ekanite, sepiolite, ashcroftine, lorenzenite, narsarsukite, natrolite, harmotome, apophyllite, molybdenite and pyrite.

The mineral and the name, after the Monteregian Hills, have been approved by the Commission on New Minerals and Mineral Names, IMA. The type specimen is preserved in the collections at the National Museum of Natural

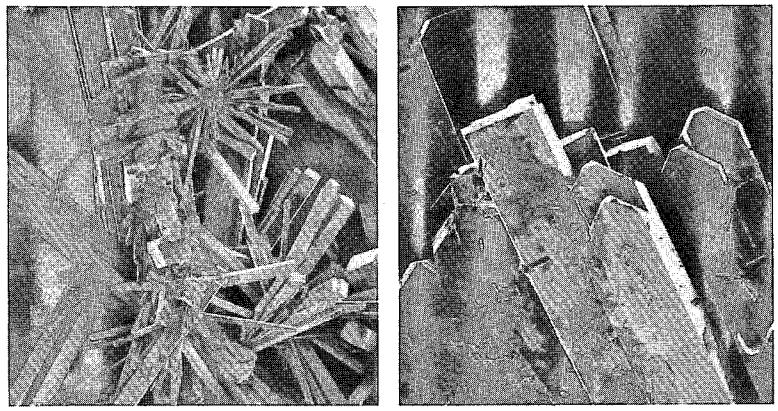

FIG. 1. SEM photomicrograph of needle-shaped monteregianite crystals in radiating clusters. Length of field = 0.5 mm.
FIG. 2. SEM photomicrograph of tabular monteregianite crystals showing {101} prism. Length of field = 1.5 mm.

Sciences, Ottawa (specimen 37130).

CRYSTALLOGRAPHIC AND PHYSICAL PROPERTIES

Monteregianite occurs as needle-shaped crystals in irregular and radiating clusters (Fig. 1), as elongate tabular crystals in parallel groups (Fig. 2), or as irregular micaceous masses. The needle-shaped crystals are elongate along the *a* axis and bounded by {010}, {001} and {100} pinacoids. The tabular crystals are elongate along *a* and flattened on *b*. Some tabular crystals show, in addition to the three pinacoids, a small but well-defined {101} prism {Fig. 2}. The crystals vary in size from 0.05 mm to 3 mm.

Weissenberg and precession photographs show that monteregianite is orthorhombic, space group *Bmab* or *B2ab*. The cell parameters, *a* 14.014(4), *b* 23.910(5) and *c* 13.096 (2)Å, were obtained from least-squares refinement using X-ray powder diffraction data (Table 1). A pronounced pseudocell with *a* and *c* halved is evident from the common absence or the very weak intensity of reflections with odd values of *h* and *l*. The space group of the pseudocell is *Pmmb, P2mb* or *Pm2b*.

The mineral is colorless, white, grey, rarely mauve or pale green, with white streak and vitreous to silky lustre. The mineral displays perfect {010}, very good {001} and good to fair {100} cleavages. Mohs hardness is about 3½. Several determinations of the density of the mineral by flotation in diluted bromoform and by use of a Berman balance give the value 2.42(2) g/cm³. The mineral is readily etched by cold 1:1 HCl, HNO_3 and H_2SO_4, along cleavage planes.

Optical data were obtained in Na light with a spindle stage using crystals previously oriented by X-ray goniometry. The immersion liquids used for refractive index measurement were checked by an Abbe 3L refractometer.

TABLE 1. X-RAY POWDER DIFFRACTION DATA FOR MONTEREGIANITE

hkl	d_{calc}(Å)	d_{obs}(Å)	I	*hkl*	d_{calc}(Å)	d_{obs}(Å)	I
020	11.955	12.00	100 P	284	2.105	2.106	5
200	7.007	7.03	100	036	2.105		
002	6.548	6.55	40 P	642	2.065	2.067	<5
012	6.316	6.32	30 P	046	2.050	2.051	5
220	6.045	6.02	50 P	236	2.016	2.014	<5
040	5.978			660	2.015		
032	5.060	5.06	30	0·12·0	1.993	1.994	<5
212	4.691	4.70	10	246	1.968	1.972	<5
042	4.415	4.42	100	2·12·0	1.917	1.914	5
113	4.106	4.11	<5 P	066	1.914		
232	4.102			4·10·2	1.891	1.891	5
060	3.985	3.985	10 P	2·10·4	1.861	1.861	10
052	3.862	3.863	5 P	2·12·2	1.839	1.841	20
242	3.735	3.731	30	076	1.839		
260	3.464	3.466	30	276	1.779		
062	3.404	3.405	50	494	1.778	1.779	<5
014	3.243	3.239	10	4·11·2	1.778		
412	3.064	3.066	30	446	1.769	1.766	<5
262	3.062			086	1.763		
072	3.028			800	1.752	1.750	20
034	3.028	3.026	50	820	1.732	1.732	5
440	3.023			4·12·0	1.732		
080	2.989	2.987	30 P	0·14·0	1.708	1.707	10
214	2.944	2.947	<5	4·10·4	1.691	1.689	5
044	2.872	2.873	80	6·10·0	1.671	1.672	10
234	2.780	2.782	5	674	1.661	1.660	5
272	2.780			008	1.637	1.637	5
442	2.744	2.748	25	028	1.622	1.622	<5 B
054	2.702	2.701	<5	6·10·2	1.619		
460	2.631	2.630	15	0·10·6	1.612	1.613	<5
064	2.530	2.531	20	486	1.575	1.575	5
092	2.462	2.466	10	2·10·6	1.571	1.570	<5
462	2.441	2.439	10	248	1.540	1.540	10
404	2.392	2.392	5	0·11·6	1.540		
264	2.379	2.374	5	068	1.514		
2·10·0	2.263	2.264	10	0·14·4	1.514	1.513	5 B
084	2.207	2.207	5	880	1.511		
602	2.200			plus many more lines			
482	2.148	2.147	20				
026	2.147						

CuKα radiation, λ = 1.5418Å, 114.6mm camera, Si standard, visual intensities, P = strong preferred orientation effect, B = broad.

TABLE 2. PROPERTIES OF MONTEREGIANITE AND RELATED MINERALS

	Monteregianite $Y_2(Na,K)_6Si_{16}O_{38}\cdot 10H_2O$	Rhodesite $Ca_4Na_2K_2Si_{16}O_{38}\cdot 12H_2O$		Macdonaldite $BaCa_4H_2Si_{16}O_{38}\cdot(8+X)H_2O$	Delhayelite $Ca_4(Na_3,Ca)K_7(Al_2Si_{14})O_{38}Cl_2F_4$	
	(1)	(2)	(3)	(4)	(5)	(6)
Cell parameters	a = 14.014(4)Å b = 23.910(5) c = 13.096(2)	c = 7.05Å a = 23.8 b = 6.54	c = 7.037(1)Å a = 23.636(4) b = 6.549(1)	a = 14.06(1)Å b = 23.52(2) c = 13.08(1)	c = 7.04(3)Å b = 24.65(2) a = 2X6.53(3)	c = 7.1Å b = 24.6-25 a = 6.69-6.75
Space group	Bmab or B2ab		Pmn2$_1$ or Pmmn	Bmmb	Pmmn	
α	1.510(1)	1.502	1.501	1.518(2)		1.529
β	1.513(1)	1.505		1.524(2)	∿1.532(2)	1.531
γ	1.517(1)	1.515	1.513	1.530(2)		1.533
Optic sign	(+)	(+)?		(±)	(-)	(±)
$2V_{meas}$	87(1)°	low		90(5)°	83(3)°	90°
$2V_{calc}$	82°			90°		
X	c	b		c	a	
Y	a	a		b	c	
Z	b	c		a	b	
Elongation	(±)	(+)				
D_{meas} (g/cm^3)	2.42(2)	2.36		2.27(2)	2.60(3)	2.571
D_{calc}	2.391			2.27		
Hardness	3½			3½-4		∿4
Cleavage						
{010}	perfect			perfect	distinct	perfect
{001}	good			good		imperfect
{100}	fair	good		poor		imperfect

(1) Monteregianite, Mont St-Hilaire, Québec: this study.
(2) Rhodesite, Kimberley, South Africa: Gard & Taylor (1957), Mountain (1957).
(3) Rhodesite, Trinity County, California: Sheppard & Gude (1969).
(4) Macdonaldite, Fresno County, California: Alfors *et al.* (1965); formula and space group from Cannillo *et al.*(1968).
(5) Delhayelite, Belgian Congo (Zaïre): Sahama & Hytönen (1959); formula and space group from Cannillo *et al.* (1970).
(6) Delhayelite, Khibiny, U.S.S.R.: Dorfman *et al.* (1961).

The mineral is biaxial positive, α 1.510(1), β 1.513(1) and γ 1.517(1). The $2V$ was measured to be 87(1)° by direct observation of the melatopes on the spindle stage, in comparison with the calculated value of 82°. The orientation is $X=c$, $Y=a$ and $Z=b$. The dispersion of the optic axes is inconspicuous.

The properties of monteregianite are summarized and compared with those of related minerals in Table 2.

Chemical Analysis

Chemical analysis was performed by D.C. Mah, on approximately one gram of hand-picked colorless material, following the procedures described by Hounslow & Moore (1966). Y_2O_3 was analyzed by use of an electron microprobe and H_2O was determined by thermogravimetric analysis (to 1000°C). The results given in Table 3 correspond to $(Na_{4.66}K_{1.80})(Y_{1.68}Ca_{0.18}Mg_{0.06}Ba_{0.01})(Si_{15.87}Al_{0.16})O_{38}\cdot 10.02H_2O$ or $(Na,K)_6Y_2Si_{16}O_{38}\cdot 10H_2O$. An electron microprobe partial analysis of a mauve variety gave 10.67% Y_2O_3, 1.38% MnO, 5.89% K_2O and 9.37% Na_2O. Assuming $Z=4$, the density calculated from the empirical formula is 2.391 g/cm^3.

TABLE 3. CHEMICAL ANALYSIS OF MONTEREGIANITE

	Wt%		Wt%
SiO_2	60.30	MnO	n.d.
Al_2O_3	0.50	FeO	n.d.
Y_2O_3	11.97	Na_2O	9.14
CaO	0.65	K_2O	5.36
MgO	0.15	H_2O	11.40
BaO	0.35	Total	99.82

Y_2O_3 by electron microprobe analysis.
H_2O by DTA to 1000°C.

Thermal Study

Simultaneous TGA and DTG (derivative thermogravimetric) analyses (Fig. 3) show that dehydration (weight loss) of monteregianite begins almost immediately on heating and is essentially complete near 400°C. The total weight loss after heating to 1000°C is 11.40%. On cooling from 650°C approximately 99% of the lost water is recovered within two hours. The material quenched from 750°C shows signs of melting and that quenched from 1000°C is amorphous to X-rays. The rehydrated material cooled to room temperature after heating to 650°C gives an X-ray powder diffraction pattern identical to that of unheated monteregianite. Water in monteregianite is, therefore, zeolitic in nature.

Both TGA and DTG curves show three distinct stages of dehydration, at 25–80°, 80–200° and 200–400°C, suggesting three major groups of structurally distinct water in monteregianite. The weight loss respectively at each of the three stages is approximately in the ratio 1:2:2.

Infrared Spectra

The infrared spectra of monteregianite are shown in Figure 4. The strong bands in the region between 350 and 550 cm^{-1} are attributable to Si–O–Si bending, the medium to weak

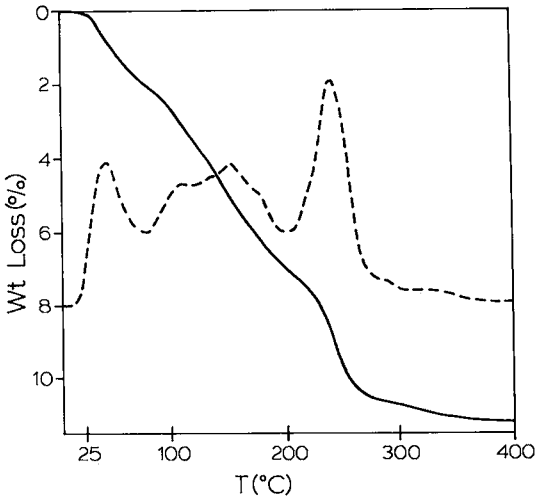

FIG. 3. DTA (solid) and DTG (dashed) curves for monteregianite. Heating rate = 10°C/min, in air. The scale for DTG rate of weigth loss is relative.

bands in the region of 550–800 cm^{-1} to Si–Si stretching and the very strong bands between 800 and 1400 cm^{-1} to Si–O stretching. The medium band at 1630 cm^{-1} is due to the H–O–H bending, confirming the presence of water in the monteregianite structure. The clearly resolved O–H stretching bands at 3460, 3510 and 3610 cm^{-1} also suggest three groups of structurally distinct water in the mineral as revealed by TGA and DTG studies.

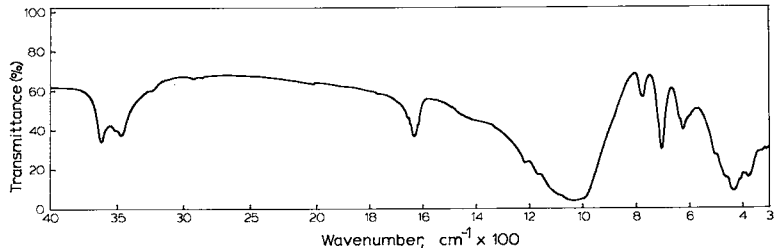

FIG. 4. Infrared spectrum of monteregianite.

DISCUSSION

On the bases of chemical formula and cell geometry (Table 2), monteregianite belongs to the macdonaldite group, which includes rhodesite and delhayelite. Cannillo *et al.* (1968, 1970) showed that the structure of macdonaldite and delhayelite is based on double layers composed of four- and eight-membered rings of SiO_4 tetrahedra. The double layers, perpendicular to the 24Å axis, are responsible for the perfect {010} cleavage in macdonaldite, delhayelite, monteregianite and the {100} cleavage in rhodesite. The structural similarities of minerals in this group are reflected in their X-ray powder diffraction patterns. However, the minor differences in the X-ray powder patterns are sufficient for the identification of the individual members.

The minerals in this group may also be distinguished from each other by their optical properties (Table 2). Monteregianite and rhodesite have significantly lower refractive indices (1.501–1.517) than macdonaldite and delhayelite (1.518–1.533). The optic plane in monteregianite and delhayelite is perpendicular to the fibre axis or the axis of elongation whereas that in macdonaldite and rhodesite is parallel to the axis of elongation. Otherwise, these minerals cannot be distinguished from each other on the basis of such properties as habit, color, lustre and cleavage.

The reported occurrence of delhayelite and rhodesite at Mont St-Hilaire in some publications (*e.g.*, Geology and Mineralogy of Mount St-Hilaire, Quebec, Worcester Mineral Club, 1973) is questionable and may be the result of misidentification of monteregianite. One specimen from Mont St-Hilaire, described as "rhodesite showing crystal form very similar to delhayelite" and sent to the author by D.W. Richerson, was shown to be monteregianite by X-ray and optical examinations and by microprobe analysis for yttrium.

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