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NORMANDITE, THE Ti-ANALOGUE OF LÅVENITE FROM MONT SAINT-HILAIRE, QUEBEC

GEORGE Y. CHAO *

Ottawa–Carleton Geoscience Centre, Department of Earth Sciences, Carleton University, Ottawa, Ontario K1S 5B6

ROBERT A. GAULT †

Research Division, Canadian Museum of Nature, Ottawa, Ontario K1P 6P4

Abstract

Normandite, the titanium analogue of låvenite, is a new mineral species from the Poudrette quarry, Mont Saint-Hilaire, Quebec. It is found in nepheline syenite and in miarolitic cavities in nepheline syenite, associated with nepheline, albite, microcline, aegirine, natrolite, catapleiite, kupletskite, eudialyte, cancrinite, villiaumite, rinkite and donnayite-(Y). It occurs as transparent to translucent orange-brown aggregates of subparallel acicular crystals up to 10 mm in length, and as patches of yellow, fibrous crystals. It has a white to very pale yellow streak and vitreous luster. It is brittle, with distinct {100} and {001} cleavages, and a conchoidal fracture. Normandite is biaxial negative, with indices of refraction α 1.743(2), β 1.785(2) and γ 1.810(5), $2V_{meas.}$ in the range 72–84°, $2V_{calc.}$ = 74° and a moderate dispersion $r > v$. Pleochroism is pronounced: *X* pale yellow, *Y* yellow, *Z* brownish red to deep red. The optical orientation is $Y = b$, $X \wedge c = 15°$ (in obtuse angle β). Normandite is monoclinic, space group $P2_1/a$, with *a* 10.828(7), *b* 9.790(7), *c* 7.054(2) Å, β 108.20(3)°, *V* 709.9(8) Å^3 and *Z* = 4. The strongest six lines of the X-ray powder-diffraction pattern [*d* in Å(*I*)(*hkl*)] are: 3.942(20)($\bar{1}$21), 3.234(30)(310), 2.859(100)($\bar{1}$22), 2.807(70)(320), 1.762(20)($\bar{2}$04) and 1.741(20)(242). The crystals are elongate on [001] and flattened on {010}, with the following forms, in order of predominance: {100}, {110} and {001}. Electron-microprobe analyses gave Na_2O 9.26(9.19–9.40), K_2O 0.01(0.01–0.02), CaO 15.38(15.08–15.59), MnO 9.31(9.11–9.52), FeO 6.13(5.89–6.26), TiO_2 17.51(17.09–17.83), Nb_2O_5 3.89(3.51–4.61), ZrO_2 2.62(2.29–2.73), SiO_2 31.92(31.69–32.04), F 5.11(4.82–5.31), O = F –2.15, total 98.99 wt.%. The empirical formula based on 9(O + F) is: $Na_{1.12}Ca_{1.03}(Mn_{0.49}Fe_{0.32})_{\Sigma 0.81}(Ti_{0.82}Nb_{0.11}Zr_{0.08})_{\Sigma 1.01}Si_{2.00}O_{7.99}F_{1.01}$, ideally $NaCa(Mn,Fe)(Ti,Nb,Zr)Si_2O_7OF$; $D_{meas.}$ = 3.50(1), $D_{calc.}$ = 3.48 g/cm^3. The name honors Charles Normand, who discovered the species.

Keywords: normandite, new mineral species, Ti-analogue of låvenite, Mont Saint-Hilaire, Quebec.

Sommaire

La normandite, analogue titanifère de la låvenite, est une nouvelle espèce minérale provenant de la carrière Poudrette, au mont Saint-Hilaire, Québec. On la trouve dans la syénite néphélinique et les cavités miarolitiques de celle-ci, en association avec néphéline, albite, microcline, aegyrine, natrolite, catapléiite, kupletskite, eudialyte, cancrinite, villiaumite, rinkite et donnayite-(Y). On la trouve en agrégats de cristaux orange-brun transparents à translucides atteignant jusqu'à 10 mm et en taches de cristaux jaunes fibreux. Elle possède une rayure blanche à jaune très pâle et un éclat vitreux. Elle est cassante, avec une fracture conchoïdale et des clivages {100} et {001}. Elle est biaxe négative, et ses indices de réfraction sont α 1.743(2), β 1.785(2) et γ 1.810(5); $2V_{mes.}$ est dans l'intervalle 72–84°, $2V_{calc.}$ est égal à 74°, et la dispersion $r > v$ est moyenne. Elle a un pléochroïsme prononcé: *X* jaune pâle, *Y* jaune, *Z* rouge brunâtre à rouge foncé. L'orientation optique est $Y = b$, $X \wedge c = 15°$ (dans l'angle obtus β). La normandite est monoclinique, groupe spatial $P2_1/a$, avec *a* 10.828(7), *b* 9.790(7), *c* 7.054(2) Å, β 108.20(3)°, *V* 709.9(8) Å^3 et *Z* = 4. Les six raies les plus intenses du spectre de diffraction (méthodes des poudres) [*d* en Å(*I*)(*hkl*)] sont: 3.942(20)(121), 3.234(30)(310), 2.859(100)($\bar{1}$22), 2.807(70)(320), 1.762(20)($\bar{2}$04) et 1.741(20)(242). Les cristaux sont allongés sur [001] et applatis sur {010}, avec les formes suivantes, présentées selon leur importance: {100}, {110} et {001}. Les analyses à la microsonde électronique ont donné Na_2O 9.26(9.19–9.40), K_2O 0.01(0.01–0.02), CaO 15.38(15.08–15.59), MnO 9.31(9.11–9.52), FeO 6.13(5.89–6.26), TiO_2 17.51(17.09–17.83), Nb_2O_5 3.89(3.51–4.61), ZrO_2 2.62(2.29–2.73), SiO_2 31.92(31.69–32.04), F 5.11(4.82–5.31), O = F –2.15, total 98.99% par poids. La formule empirique, calculée pour 9(O + F), est: $Na_{1.12}Ca_{1.03}(Mn_{0.49}Fe_{0.32})_{\Sigma 0.81}(Ti_{0.82}Nb_{0.11}Zr_{0.08})_{\Sigma 1.01}Si_{2.00}O_{7.99}F_{1.01}$ ou, de façon idéale, $NaCa(Mn,Fe)(Ti,Nb,Zr)Si_2O_7OF$; $D_{mes.}$ = 3.50(1), $D_{calc.}$ = 3.48 g/cm^3. Le nom honore M. Charles Normand, qui en a fait la découverte.

Mots-clés: normandite, nouvelle espèce minérale, analogue titanifère de la låvenite, mont Saint-Hilaire, Québec.

* Present address: 2031 Delmar Drive, Ottawa, Ontario K1H 5P6
† *E-mail address*: rgault@mus-nature.ca

Introduction

Normandite, ideally $NaCa(Mn,Fe)(Ti,Nb,Zr)Si_2O_7OF$ and formerly designated as UK 59 (Chao *et al.* 1990), occurs in the Poudrette quarry, Mont Saint-Hilaire, Rouville County, Quebec. The alkaline rocks of Mont Saint-Hilaire are well known for the diversity of rare-element minerals they contain (Horváth & Gault 1990), and normandite is yet another example of this diversity. The data presented herein establish this species as a new member of the låvenite group of minerals (Table 1). These chemically and structurally related minerals are commonly found in alkaline igneous environments. Merlino & Perchiazzi (1988) suggested the general formula $X_{16}(Si_2O_7)_4(O,OH,F)_8$, where X represents cations of various possible charges and radii, and characterized by octahedral and roughly octahedral coordination. As well, they derived ten structure-types for the group, and suggested a classification scheme useful to understand the structural relationships among the known members of the group and to predict unknown members. Besides normandite, other members of the group found at Mont Saint-Hilaire are låvenite, wöhlerite, hiortdahlite and rosenbuschite. Normandite (pronounced NAWRMANDITE) recognizes Mr. Charles Normand (b. 1963), of Montreal, Quebec, who discovered the mineral and brought it to the attention of one of the authors (GYC). The new mineral and the name have been approved by the Commission on New Minerals and Mineral Names, IMA. Cotype material is housed in the collections of the Canadian Museum of Nature, Ottawa, under catalogue numbers CMNMI 81540 and CMNMI 81541, and the Royal Ontario Museum, Toronto, under catalogue numbers M44520 and M44521.

TABLE 1. MINERALS CHEMICALLY AND STRUCTURALLY RELATED TO NORMANDITE

Mineral	Chemical Formula	Space Group
Seidozerite	$(Na,Ca)_2(Zr,Ti,Mn)_2Si_2O_7(O,F)_2$	$P2/c$
Burpalite	$Na_2CaZrSi_2O_7F_2$	$P2_1/a$
Wöhlerite	$NaCa_2(Zr,Nb)Si_2O_7(O,OH,F)_2$	$P2_1$
Rosenbuschite	$(Ca,Na)_3(Zr,Ti)Si_2O_8F$	$P\bar{1}$
Hiortdahlite	$(Ca,Na)_3(Zr,Ti)Si_2O_7(O,F)_2$	$P\bar{1}$
Götzenite	$Na_2Ca_5Ti(Si_2O_7)_2F_4$	$P\bar{1}$
Hainite	$Na_4Ca_8(Ti,Zr,Mn^{2+})_3Si_8O_{28}F_8$	$P\bar{1}$
Baghdadite	$Ca_3(Zr,Ti)Si_2O_9$	$P2_1/a$
Cuspidine	$Ca_4Si_2O_7(F,OH)_2$	$P2_1/a$
Niocalite	$Ca_{14}Nb_2(Si_2O_7)_4O_6F_2$	$P2_1$
Janhaugite	$Na_3Mn^{2+}{}_3Ti_2Si_4O_{15}(OH,F,O)_3$	$P2_1/n$
Normandite	$NaCa(Mn,Fe)(Ti,Nb,Zr)Si_2O_7OF$	$P2_1/a$
Låvenite	$(Na,Ca)_2(Mn^{2+},Fe^{2+})(Zr,Ti)Si_2O_7(O,OH,F)_2$	$P2_1/a$

Occurrence

Normandite was discovered in 1980 in miarolitic cavities in nepheline syenite at the Poudrette quarry, Mont Saint-Hilaire, Quebec, associated with albite, kupletskite, natrolite and donnayite-(Y). The mineral was found again in 1986 in the same quarry as an abundant accessory associated with nepheline and albite in a large block of nepheline syenite. Since that time, normandite has been found frequently, but in minor quantities, leading us to believe that the mineral is often overlooked and is more abundant than it at first appeared. It is commonly associated with nepheline, microcline, aegirine, catapleiite, eudialyte, cancrinite, villiaumite and rinkite. A mineral with similar physical properties and chemical composition as normandite has been found in Russia at Partachorr, Khibina massif, Kola Peninsula and near the Koklukhtiuai and Muruai Rivers, Lovozero massif, Kola Peninsula (Vlasov 1966), at Tamazeght, Haut Atlas, Morocco (Kadar & Fontan 1988, Khadem Allah 1993), and at Tenerife, Canary Islands (Ferguson 1978).

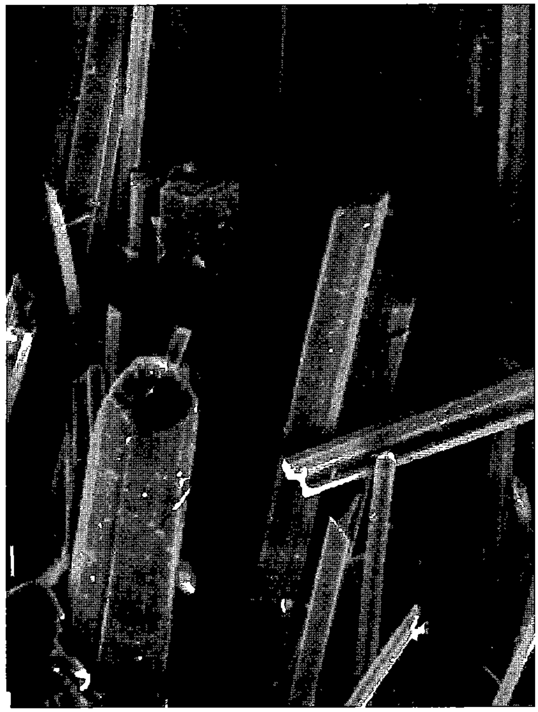

FIG. 1. Scanning electron micrograph of acicular normandite from Mont Saint-Hilaire, Quebec. Scale bar corresponds to 10 μm.

Physical and Optical Properties

Normandite is generally orange to orange-brown; very fine fibers are yellow. The streak is white to very pale yellow. The mineral is translucent to transparent, with a vitreous luster. It is brittle, with a Mohs hardness of 5 to 6. The mineral has distinct {100} and {001} cleavages and a conchoidal fracture. In the miarolitic cavities, normandite occurs as groups of fine acicular crystals up to 2 mm in length and as irregular fibrous patches; in the

TABLE 2. COMPOSITION OF NORMANDITE AND RELATED MINERALS

	(1) Normandite		(2) Låvenite		(3) Wöhlerite		(4) «Titano-låvenite»	
	wt%	apfu	wt%	apfu	wt%	apfu	wt%	apfu
Na_2O	9.26	2.25	11.20	2.97	7.55	1.92	10.70	2.88
K_2O	0.01		0.04	0.01	0.03	0.01		
MgO			0.15	0.03	0.35	0.07		
CaO	15.38	2.06	6.94	1.02	25.90	3.63	10.92	1.54
MnO	9.31	0.99	10.38	1.20	3.39	0.38	10.34	1.15
FeO	6.13	0.64	2.39	0.27	1.54	0.17	4.89	0.54
Fe_2O_3							0.12	0.01
Al_2O_3			0.04	0.01	0.05	0.01		
SiO_2	31.92	4.00	29.05	3.97	30.92	4.05	30.92	4.06
TiO_2	17.51	1.65	1.81	0.19	2.05	0.20	11.30	1.12
ZrO_2	2.62	0.16	26.18	1.74	15.01	0.96	16.72	1.07
Nb_2O_5	3.89	0.22	7.63	0.47	9.21	0.55	3.01	0.20
F	5.11	2.02	3.71	1.60	4.18	1.73	1.55	0.64
H_2O			(0.44)	(0.40)	(0.32)	(0.27)		
SUM	101.14		99.96		100.50		100.47	
O = F	-2.15		-1.56		-1.76		-0.65	
TOTAL	98.99		98.40		98.74		99.82	

(1) Mont Saint-Hilaire, Quebec. Average result of five electron-microprobe analyses. Formula calculation on the basis of 18(O+F).
(2) Mont Saint-Hilaire, Quebec. Average result of five electron-microprobe analyses. Formula calculation on the basis of 16(O) + 2(F,OH). Proportion of H_2O calculated by stoichiometry.
(3) Mont Saint-Hilaire, Quebec. Average result of three electron-microprobe analyses. Formula calculation on the basis of 16(O) + 2(F,OH). Proportion of H_2O calculated by stoichiometry.
(4) Lovozero, Kola Peninsula, Russia (Kutukova 1940).
apfu: atoms per formula unit.

nepheline syenite, normandite commonly occurs as euhedral prismatic crystals up to 10 mm in length as well as in groups of subparallel acicular crystals or fine fibers. The crystals are elongate on [001] and flattened on {100}, with the following forms being observed, in order of predominance: {100}, {110} and {001}.The (100) and (110) faces are commonly striated longitudinally. Normandite is nonfluorescent in ultraviolet light. The density of the mineral, measured with a Berman balance at room temperature, is 3.50(1) g/cm³, which compares well with the calculated density of 3.48 g/cm³. The mineral is not attacked by 1:1 HCl or HNO_3.

Optically, normandite is biaxial negative, with indices of refraction α 1.743(2), β 1.785(2) and γ 1.810(5) (λ = 589 nm); the angle $2V$ was measured on two crystals: 72(1)° and 84(1)°; $2V_{calc.}$ is equal to 74. There is moderate dispersion, $r > v$. Pleochroism is pronounced: X pale yellow, Y yellow and Z brownish red to deep red. The optical orientation is $Y = b$, $X \wedge c$ = 15° (in obtuse angle β).

Chemistry

Normandite was analyzed using wavelength dispersion on a Cambridge Microscan MK5 electron microprobe with an operating voltage of 15 kV and a beam current of 0.30 µA. The following standards were employed: albite (Na), anorthite (Ca), hornblende (K,Fe,Ti,Si), manganoan ilmenite (Mn), $NaNbO_3$ (Nb), zircon (Zr) and biotite (F). Mg and Al were sought, but not detected. Rhodochrosite (Mn) and LiF (F) were used as standards in the analysis of the låvenite. The average result of five analyses of normandite is presented in Table 2, along with compositions of låvenite, wöhlerite and "titano-låvenite" for comparison. The empirical formula of normandite derived from the analysis and based on 9(O + F) is: $Na_{1.12}Ca_{1.03}(Mn_{0.49}Fe_{0.32})_{\Sigma 0.81}(Ti_{0.82}Nb_{0.11}Zr_{0.08})_{\Sigma 1.01}Si_{2.00}O_{7.99}F_{1.01}$ or, ideally, $NaCa(Mn,Fe)(Ti,Nb,Zr)Si_2O_7OF$. A structural study would be useful to test the ordering of the Na, Ca, O and F sites suggested in the ideal formula.

The compatibility index derived from the Gladstone–Dale calculations $1-(K_p/K_c) = 0.033$, is regarded as excellent (Mandarino 1981).

X-Ray Crystallography

Single-crystal X-ray precession photographs show normandite to be monoclinic, space group $P2_1/a$. The initial unit-cell parameters measured from the precession photographs were refined by a least- squares method, using Gandolfi X-ray-diffraction data (Table 3). The indexing of the Gandolfi diffraction lines was based on the calculated d-values, using precession photographs as a guide. It was assumed that only the strong reflections on the precession photographs were recorded on the Gandolfi diffraction pattern. The refined unit-cell parameters are: a 10.828(7), b 9.790(7), c 7.054(2) Å, β 108.20(3)°.

TABLE 3. NORMANDITE: X-RAY POWDER-DIFFRACTION DATA

I	d_{obs}	d_{calc}	hkl	I	d_{obs}	d_{calc}	hkl
10	6.70	6.701	001	10	2.165	2.1630	$\bar{3}32$
5	5.50	5.496	$\bar{1}11$	10	2.011	2.0132	510
10	5.13	5.143	200	10	1.974	1.9756	042
20	3.942	3.9395	$\bar{1}21$			1.9719	232
5	3.350	3.3505	002	10	1.876	1.8772	142
30	3.234	3.2358	310	20	1.762	1.7634	$\bar{2}04$
100	2.859	2.8609	$\bar{1}22$	20	1.741	1.7400	242
70	2.807	2.8078	320	20	1.727	1.7280	$\bar{4}42$
5	2.749	2.7483	$\bar{2}22$	20	1.688	1.6886	610
10	2.477	2.4757	$\bar{3}22$	20	1.627	1.6269	152
10	2.441	2.4415	$\bar{4}02$	5	1.554	1.5532	$\bar{6}32$
10	2.337	2.3371	032	5	1.532	1.5312	512
10	2.276	2.2762	420	5	1.486	1.4857	$\bar{5}24$
10	2.187	2.1844	$\bar{4}22$				

Gandolfi camera, 114.6 mm in diameter, Co$K\alpha$ radiation, λ = 1.7902 Å, intensities visually estimated.

Discussion

The crystal structures of cuspidine (Saburi *et al.* 1977), låvenite (Mellini 1981), niocalite (Mellini 1982), wöhlerite (Mellini & Merlino 1979), hiortdahlite (Merlino & Perchiazzi 1985, 1987) and burpalite (Merlino *et al.* 1990), and the description of janhaugite, show a close structural relationship among all these minerals. Walls of octahedra, consisting of various cations, are interconnected by corner sharing to create a framework strengthened by the Si_2O_7 units (Merlino & Perchiazzi 1988). The cell parameters and the X-ray powder-diffraction pattern of normandite are very close to those of the låvenite-group minerals, particularly låvenite and janhaugite (Raade &

TABLE 4. SELECTED PROPERTIES OF NORMANDITE AND RELATED MINERALS

	(1) Normandite	(2) "Titano låvenite"	(3) Låvenite	(4) Låvenite	(5) Wöhlerite	(6) Wöhlerite	(7) Janhaugite
Space group	$P2_1/a$	$P2_1/a$	$P2_1/a$	$P2_1/a$	$P2_1$	$P2_1$	$P2_1/n$
a (Å)	10.828(6)		10.83(1)	10.825(5)	10.823(3)	10.863(8)	10.668(2)
b	9.790(6)		9.98(1)	9.979(5)	10.244(3)	10.255(9)	9.787(4)
c	7.054(2)		7.174(5)	7.173(2)	7.290(2)	7.290(3)	13.931(3)
β (°)	108.20(3)		108.1(1)	108.20(2)	109.00(4)	109.19(4)	107.82(2)
R.I. α	1.743(2)	1.720	1.67	1.720(1)	1.700	1.701(2)	1.770(4)
β	1.785(2)	1.746	1.69	1.751(2)	1.716	1.715(2)	1.828(4)
γ	1.810(5)	1.760	1.72	1.774(2)	1.726	1.726(2)	1.910(calc.)
2*V* (°)	(-)72	(-)73-74	(-)40-70	(-)78(1)	(-)71-79	(-)72(3)	(+)80
Dispersion	Moderate $r > v$		Weak	Strong $r < v$	Distinct $r < v$	Indistinct	
Orientation	$Y = b$ $X \wedge c = 15°$ in obtuse β		$Y = b$ $X \wedge c = 20°$ in acute β	$Y = b$ $X \wedge a = 21°$	$Z = b$ $X \wedge c = 45°$ in acute β	$Z = b$ $X \wedge c = 48°$ in acute β	$Z = b$ $X \wedge c = +15(3)°$
H_{mohs}	5-6	6	6	~6	5.5-6	~6	5
$D_{meas.}$ g/cm^3	3.50(1)	3.556	3.51-3.54		3.42		3.60(5)

(1) Mont Saint-Hilaire, Québec, this study.
(2) Koklukhtiuai River, Lovozero massif, Russia (Kutukova 1940).
(3) Langesundfjord district, Norway (Roberts *et al* 1990); cell parameters from Mellini (1981).
(4) Mont Saint-Hilaire, Québec, this study.
(5) Brevik, Norway (Winchell & Winchell 1961); space group and cell parameters from Mellini and Merlino (1979).
(6) Mont Saint-Hilaire, Québec, this study.
(7) Gjerdingen, Nordmarka, northern Oslo region, Norway (Raade & Mladeck 1983).

Mladeck 1983), suggesting an isostructural relationship (Table 4). Titanium-for-zirconium substitution in låvenite was proposed by Simonov & Belov (1960) and by Mellini (1981). The wide range of Ti–Zr variation in låvenite, as reported in Vlasov (1966), Mellini (1981) and this study, indicates that a complete solid-solution exists between låvenite and normandite.

All four members of the låvenite group found at Mont Saint-Hilaire occur in similar environments, most commonly in miarolitic cavities within the nepheline syenite and in the nepheline syenite itself: one specimen was found to contain rosenbuschite, wöhlerite and hiortdahlite in a single cavity. Although not definitive, color and morphology are useful in visually distinguishing these minerals at Mont Saint-Hilaire. Hiortdahlite is generally pale yellow and thick acicular, rosenbuschite is pale yellow and fibrous, wöhlerite is yellow and tabular, normandite is orange to yellow, acicular to fibrous, and låvenite is brownish yellow, acicular to fibrous, and occurs most commonly in xenoliths and pegmatites.

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