

Eirikite, a new mineral species of the leifite group from the Langesundsfjord district, Norway

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Abstract: Eirikite, ideally, $\text{KNa}_6[\text{Be}_2(\text{Si}_{15}\text{Al}_3)_{\Sigma=18}\text{O}_{39}\text{F}_2]$, is a new mineral species from the Vesle Arøya island in the Langesundsfjord district, Larvik, Vestfold, Norway. It is the potassium analogue of leifite, $\text{NaNa}_6[\text{Be}_2(\text{Si}_{15}\text{Al}_3)_{\Sigma=18}\text{O}_{39}\text{F}_2]$, and telyushenkoite, $\text{CsNa}_6[\text{Be}_2(\text{Si}_{15}\text{Al}_3)_{\Sigma=18}\text{O}_{39}\text{F}_2]$. An average of five electron microprobe analyses gave Na_2O 13.38, K_2O 3.13, Al_2O_3 11.08, SiO_2 66.03, F 2.70, BeO 3.65 (calc.), $\text{O} = \text{F} - 1.14$, total 98.83 wt. %, resulting in the empirical formula $\text{K}_{0.91}\text{Na}_{5.92}[\text{Be}_2(\text{Si}_{15.07}\text{Al}_{2.98})_{\Sigma=18.05}\text{O}_{39}(\text{F}_{1.95}\text{O}_{0.05})]$; infrared spectroscopy indicates the absence of OH and H_2O .

Eirikite occurs as both finely or coarsely fibrous, monomineralic aggregates and bundles up to 3 cm across, wholly or partly filling voids between larger microcline crystals. Individual acicular-prismatic crystals show the forms $\{10\bar{1}0\}$ and $\{0001\}$. Eirikite also occurs as aggregates up to 100 cm^3 in volume, built of interlocking, radiating fibrous groups, each up to 5 mm across, intergrown with large amounts of small zircon crystals and penetrated by aegirine crystals. Polyolithionite, albite, eudialyte, catapleite and pyrochlore can be found within these aggregates. Eirikite is white to colourless with a white streak, a vitreous to silky lustre, Mohs hardness of 6; it is brittle with an uneven to conchoidal fracture, and with a good $\{10\bar{1}0\}$ cleavage. The mineral is uniaxial positive, $\omega = 1.517(1)$ and $\varepsilon = 1.521(1)$, and nonpleochroic; $D_{\text{meas}} = 2.59(1)\text{ g/cm}^3$, $D_{\text{calc}} = 2.577\text{ g/cm}^3$ (from the empirical chemical formula) and 2.584 g/cm^3 (from the crystal structure determination).

Eirikite is trigonal, $P\bar{3}m1$ (no. 164), with $a = 14.3865(9)\text{ \AA}$, $c = 4.8733(4)\text{ \AA}$, $V = 873.5(1)\text{ \AA}^3$, and $Z = 1$, refined from X-ray powder diffraction data. The five strongest lines in the X-ray powder pattern are $[d$ (in Å) $(I/I_0)(hkl)]$: $4.710(29)(120)$, $4.153(21)(030)$, $3.386(70)(211)$, $3.161(100)(031)$, and $2.466(31)(231)$. The crystal structure, which was determined from single-crystal X-ray intensity data and refined to $R1(F) = 1.99\%$, is a framework of corner-sharing $(\text{Si},\text{Al})\text{O}_4$ and BeO_3F tetrahedra ($\langle\text{Be}-(\text{O},\text{F})\rangle = 1.610\text{ \AA}$), leading to chain and ring units. Voids in the framework are occupied by K ($\langle\text{K}-\text{O}\rangle = 3.105\text{ \AA}$), and seven-coordinated Na atoms ($\langle\text{Na}-(\text{O},\text{F})\rangle = 2.542\text{ \AA}$). The B site, which is vacant in telyushenkoite and partly occupied by water molecules in leifite, is nearly vacant in eirikite.

Key-words: eirikite, new mineral species, chemical composition, crystal structure, leifite group, Vesle Arøya, Norway.

1. Introduction

Twenty-one beryllium minerals have been identified in the alkaline pegmatites within the Larvik plutonic complex of the Oslo Region, Norway (Brøgger, 1890; Andersen *et al.*, 1996; Larsen, 2010), a diversity rarely attained in most geological environments. Most of the Be minerals resulted from hydrothermal alteration of leucophanite and meliphanite, which are, together with gadolinite-(Ce) and chrysoberyl, the only Be-bearing magmatic minerals in the pegmatites. Gadolinite-(Ce) and chrysoberyl, however, are of very restricted occurrence.

The two leifite-group minerals hitherto described have the general formula $\text{ANa}_6\text{Be}_2\text{Al}_3\text{Si}_{15}\text{O}_{39}\text{F}_2$, where A can be Na >0.5 apfu (leifite *sensu stricto*) or Cs >0.5 apfu

(telyushenkoite). From the description of telyushenkoite, Sokolova *et al.* (2002) and Agakhanov *et al.* (2003) pointed out that the chemical compositions of leifite (*sensu lato*) given in the literature include several examples with a high content of potassium (>0.5 apfu), *i. e.* the potassium analogue of leifite and telyushenkoite (assuming that K is invariably ordered at the A site). Among them was the leifite from Vesle Arøya in the Langesundsfjord district described by Larsen & Åsheim (1995). The description of telyushenkoite resolved the ambiguities within the leifite group, and gave us the opportunity to re-describe the Vesle Arøya mineral as the new species eirikite. The mineral is named after the Viking Eirik Raude (Eric the Red, born in about the year 950, died in about the year 1003), emigrant from Norway and the discoverer of Greenland in the year 982, and father of Leif (Leif)

Eirikson, after whom leifite was named and described by Bøggild (1915). Thus we have the appropriate combination of the names of both father and son for two closely related species within the same mineral group. Eirikite, with reference to the same Viking person (using the Danish spelling Erik), was described by Bøggild (1903). The mineral was, however, discredited by Pekov *et al.* (1997) as being a pseudomorph after vitusite, composed of monazite and rhabdophane.

The new mineral species and its name have been approved by the Commission on New Minerals, Nomenclature and Classification, International Mineralogical Association (CNMNC no. 2007-017). The holotype specimen of eirikite is housed in the collection of the Department of Geology, Natural History Museum, University of Oslo (catalogue no. 41773).

2. Occurrence

The eirikite-bearing nepheline syenite pegmatite dike is situated on the south-eastern part of the Vesle Arøya island in the Langesundsfjord district (coordinates N59°00.617', E9°47.746') (Larsen & Åsheim, 1995). Most of the dike was blasted more than 100 years ago in search of minerals. Therefore, all samples of eirikite and its associated minerals for the present study were collected on the dump. The main minerals of the pegmatite are grey microcline, biotite, nepheline, ferro-edenite, aegirine, eudialyte *s. l.*, and small amounts of arfvedsonite, sodalite, magnetite, astrophyllite, catapleiite and leucophanite. They all belong to the magmatic stage of the pegmatite formation. In parts of the pegmatite most of the magmatic minerals have been subject to intensive hydrothermal alteration resulting in the following late-stage minerals occurring in small vugs or as replacements of the primary minerals: löllingite, sphalerite, galena, molybdenite, fluorite, pyrochlore, pyrophanite, böhmite, calcite, monazite-(Ce), bastnäsite-(Ce), parisite-(Ce), aegirine (second generation), albite, zircon, eudidymite, epididymite, eirikite, sérandite, astrophyllite (second generation), polyolithionite, chlorite, chiavennite, apophyllite-(KF), analcime and natrolite. Pharmacosiderite has been observed as a supergene alteration product of löllingite. From the studies of the mineral paragenesis in hand specimens containing eirikite the following relative order of crystallization has been determined (oldest first): zircon, pyrophanite, aegirine (second generation), polyolithionite, eirikite, albite, eudidymite/epididymite (always epitaxially intergrown), analcime, apophyllite-(KF), and chiavennite. Hydrothermal alteration of leucophanite is considered as the origin of the late-stage Be-minerals in the pegmatite. K and Al in eirikite may originate from the hydrothermal decomposition of nepheline, which, in the Langesundsfjord district, typically contains up to 5 wt% K₂O.

3. Physical and optical properties

Eirikite occurs as either finely or coarsely fibrous, monomineralic aggregates up to several centimetres across, wholly or

partly filling voids between larger microcline crystals. Individual acicular-prismatic crystals show the forms {10 $\bar{1}$ 0} and {0001}. Bundles of radiating fibres reach 3 cm in length. Eirikite also occurs as aggregates up to 100 cm³ in volume, built of interlocking, radiating fibrous groups, each up to 5 mm across, intergrown with large amounts of small zircon crystals and penetrated by aegirine crystals. Polyolithionite, albite, eudialyte, catapleiite and pyrochlore can be found within these aggregates.

Eirikite is white to colourless with a white streak and a vitreous to silky lustre. Mohs hardness = 6, brittle with an uneven to conchoidal fracture, and with a good {10 $\bar{1}$ 0} cleavage. The mineral is uniaxial positive, $\omega = 1.517(1)$ and $\varepsilon = 1.521(1)$ ($\lambda = 589$ nm) and nonpleochroic. The measured density of eirikite is 2.59(1) g/cm³, determined by the sink-float method using diodomethane diluted with acetone. This agrees well with the calculated density of 2.577 g/cm³ (from the empirical chemical formula) and 2.584 g/cm³ (from the crystal structure determination). The Gladstone-Dale relationship gives a compatibility index $1 - (K_p/K_c) = 0.0035$, which is regarded as "superior" (Mandarino, 1981).

Eirikite is insoluble in warm 6 M HCl, melts relatively easily using a gas torch, leaving a white, vesicular globule, and shows no fluorescence in either short- or long-wave UV light.

4. Chemical composition

Chemical analyses were performed in wavelength-dispersive spectroscopic (WDS) mode on a JEOL 733 electron microprobe using the Geller Microanalytical system and programs. The instrument is housed at the Canadian Museum of Nature in Ottawa, Canada. Data reduction was done with a PAP routine in XMAQNT (personal communication, C. Davidson, CSIRO). The operating voltage was 15 kV and the beam current was 20 nA. The beam was defocused to 30 μ m to minimize Na migration and general burn-up of the sample. The following standards and analyzing crystals were used: NaK α (albite, TAP), KK α (sanidine, PET), RbL α (rubidium microcline, TAP), CsL α (pollucite, LIF), AlK α (sanidine, TAP), SiK α (diopside, TAP) and FK α (fluorite, TAP). Zinc was specifically sought but not detected. Energy-dispersive spectroscopic (EDS) scans of 100 s indicated no other elements with $Z > 8$. Data for the major elements in the sample were collected for 25 s or 0.5 % precision, whichever was attained first. Cesium and rubidium were collected for 100 s. Five samples were analyzed, however only the sample chosen as the holotype is reported here. An average of 5 analyses (with ranges) on the holotype sample gave: Na₂O 13.38 (13.24–13.57), K₂O 3.13 (3.07–3.18), Al₂O₃ 11.08 (11.04–11.12), SiO₂ 66.03 (65.91–66.22), F 2.70 (2.40–3.12), BeO 3.65, O = F –1.14, total 98.83 wt% resulting in the empirical formula K_{0.91}Na_{5.92}[Be₂(Si_{15.07}Al_{2.98}) $\Sigma=18.05$]O₃₉(F_{1.95}O_{0.05}). BeO was calculated by stoichiometry from the crystal structure analysis. The formula was calculated on the basis of 41 anions. A series of

scans over the fluorine peaks of the sample and of the standard confirmed the accuracy of the fluorine analysis. Rubidium was detected in the holotype specimen only in trace amounts, while cesium was below the detection limit. Analyses of the other four samples were similar except that rubidium and cesium concentrations up to 1.25 wt% Rb₂O and 2.09 wt% Cs₂O were determined. These two minor elements substitute for K at the A site as discussed in the structure portion of this paper. Ranges for all five samples are as follows (in wt%): Na₂O (12.83–13.53), K₂O (2.01–3.25), Rb₂O (0–1.25), Cs₂O (0–2.09), Al₂O₃ (10.60–11.06), SiO₂ (63.49–66.74), F (1.64–3.13).

For analysis by Fourier-transform infrared spectroscopy (FTIR), a single grain of the holotype sample was positioned on a Spectra-Tech low-pressure diamond microsample cell and analyzed using a Bruker Optics Hyperion 2000 microscope interfaced to a Tensor 27 spectrometer. These instruments are housed at the Canadian Conservation Institute in Ottawa, Canada. The spectra were acquired in the 4000 to 430 cm⁻¹ range by co-adding 200 scans. The spectrum (Fig. 1) shows the absence of bands in the regions 1645 and 3535 cm⁻¹ clearly indicating the absence of (OH) and H₂O. The spectrum shows several strong absorption bands in the regions 442–505, 708–795 and 977–1174 cm⁻¹, which can be attributed to Si–O and Be–O stretching and bending vibrations. The spectrum is nearly identical to that of telyushenkoite, the cesium analogue of eirikite (Agakhanov *et al.*, 2003).

5. X-ray crystallography

X-ray powder diffraction data on eirikite were obtained using a Philips X'pert diffractometer (housed at Statoil Research Centre, Porsgrunn) equipped with automatic divergence slits and diffracted-beam graphite monochromator (CuK α ₁ radiation, $\lambda = 1.54056$ Å). Data were collected from 5° to 85° 2 θ in steps of 0.01° 2 θ and 5 s counting time per step. Si (NBS 640a) was used as internal standard. The X-ray powder diffraction data are given in Table 1. Indexing and least-squares refinement were done

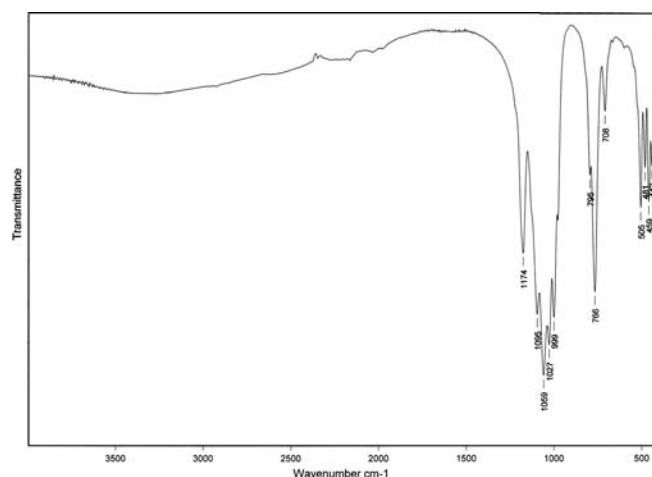


Fig. 1. Infrared spectrum of eirikite.

Table 1. X-ray powder diffraction data for eirikite.

I_{meas}	d_{meas} (Å)	d_{calc} (Å)	hkl	I_{meas}	d_{meas} (Å)	d_{calc} (Å)	hkl
4	12.463	12.459	0 1 0	2	1.570	1.570	3 6 0
5	7.196	7.193	1 1 0	2	1.557	1.557	0 8 0
10	6.229	6.229	0 2 0	4	1.544	1.544	2 5 2
29	4.710	4.709	1 2 0	4	1.516	1.516	4 5 1
8	4.540	4.538	1 0 1	1	1.513	1.513	0 3 3
21	4.153	4.153	0 3 0	9	1.494	1.494	3 6 1
4	4.035	4.034	1 1 1	2	1.483	1.483	8 0 1
6	3.839	3.838	2 0 1	4	1.440	1.440	4 0 3
15	3.597	3.597	2 2 0	4	1.439	1.439	5 5 0
12	3.456	3.455	1 3 0	1	1.402	1.402	3 7 0
70	3.386	3.386	2 1 1	2	1.397	1.397	1 8 1
100	3.161	3.161	0 3 1	7	1.384	1.384	0 9 0
17	3.115	3.115	0 4 0	2	1.380	1.380	5 5 1
1	2.893	2.894	2 2 1	1	1.371	1.371	4 6 1
5	2.819	2.819	1 3 1	7	1.345	1.345	3 3 3
2	2.719	2.719	1 4 0	3	1.335	1.335	4 5 2
6	2.624	2.624	4 0 1	2	1.332	1.332	9 0 1
31	2.466	2.465	2 3 1	7	1.319	1.320	6 3 2
1	2.437	2.437	0 0 2	1	1.312	1.312	0 8 2
19	2.398	2.398	3 3 0	2	1.291	1.291	2 7 2
7	2.374	2.374	1 4 1	1	1.279	1.279	0 6 3
3	2.237	2.238	1 5 0	1	1.265	1.265	3 8 0
20	2.217	2.219	0 5 1	3	1.261	1.261	1 9 1
3	2.164	2.164	1 2 2	2	1.251	1.251	1 8 2
6	2.152	2.151	3 3 1	2	1.249	1.249	7 4 1
7	2.120	2.120	4 2 1	1	1.235	1.235	1 6 3
7	2.102	2.102	3 0 2	3	1.227	1.228	2 9 0
5	1.991	1.991	1 3 2	3	1.224	1.224	3 8 1
2	1.919	1.919	4 0 2	1	1.218	1.218	0 0 4
13	1.910	1.910	6 0 1	1	1.215	1.215	3 7 2
2	1.900	1.900	1 6 0	1	1.212	1.213	0 1 4
2	1.888	1.888	4 3 1	3	1.207	1.207	10 0 1
2	1.854	1.854	3 2 2	2	1.204	1.204	0 9 2
2	1.815	1.815	1 4 2	4	1.200	1.200	7 0 3
7	1.798	1.798	4 4 0	1	1.193	1.193	5 7 0
3	1.780	1.780	0 7 0	1	1.191	1.190	2 9 1
4	1.770	1.770	1 6 1	1	1.187	1.187	2 8 2
17	1.742	1.742	5 0 2	1	1.179	1.179	1 2 4
5	1.693	1.693	2 4 2	1	1.177	1.177	4 8 0
1	1.687	1.687	4 4 1	2	1.169	1.169	0 3 4
1	1.672	1.672	3 5 1	2	1.159	1.159	7 5 1
3	1.650	1.650	1 7 0	1	1.151	1.151	5 6 2
5	1.629	1.628	6 2 1	1	1.141	1.141	4 7 2
1	1.611	1.611	0 1 3				
10	1.580	1.580	0 6 2				

by the program CELREF (Laugier & Bochu, 1999). The unit-cell dimensions found are $a = 14.3865(9)$ Å, $c = 4.8733(4)$ Å, and $V = 873.5(1)$ Å³.

The crystal structure was determined from single-crystal X-ray intensity data collected with a Nonius KappaCCD diffractometer (housed at Institut für Mineralogie und Kristallographie, Universität Wien) on a crystal fragment of excellent quality (see Table 2 for details). The structure was solved and refined in space group $P\bar{3}m1$ (no. 164) to $R1(F) = 1.99\%$ using SHELX97 (Sheldrick, 1997a and b). The refined structure model is basically identical with that given for isotypic leifite and telyushenkoite (Sokolova *et al.*, 2002). The atomic arrangement is characterized by

Table 2. Crystal data, data collection information and refinement details for eirikite.

Crystal data:	
Formula	$\text{KNa}_6[\text{Be}_2(\text{Si}_{15}\text{Al}_3)_{\Sigma=18}\text{O}_{39}\text{F}_2]$
Space group, Z	$P\bar{3}m1$ (no. 164), 1
a, c (Å)	14.386(2), 4.873(1)
V (Å ³)	873.4(2)
$F(000)$, ρ_{calc} (g·cm ⁻³)	672, 2.584
μ (mm ⁻¹)	0.969
Absorption correction	multi-scan (Otwinowski <i>et al.</i> , 2003)
Crystal dimensions (mm)	0.22 × 0.25 × 0.28
Data collection:	
Diffractometer	Nonius KappaCCD system
λ (Mo- $K\alpha$) (Å), T (K)	0.71073, 293
Detector distance (mm)	30
Rotation axis, width (°)	$\varphi, \omega, 2$
Total no. of frames	549
Collect. time per degree (s)	8
Collection mode, $2\theta_{\text{max}}$ (°)	sphere, 70
h, k, l ranges	-23 → 23, -19 → 19, -7 → 7
Total reflections measured	5088
Unique reflections	1399 (R_{int} 1.06 %)
Refinement:	
Refinement on	F^2
$R1(F)$, $wR2_{\text{all}}(F^2)$	1.99 %, 6.22 %
“Observed” reflections	1326 [$F_o > 4\sigma(F_o)$]
Extinct. coefficient	0.0093(17)
No. of refined parameters	69
Goof	1.111
$(\Delta/\sigma)_{\text{max}}$	0.000
$\Delta\rho_{\text{min}}, \Delta\rho_{\text{max}}$ (e/Å ³)	-0.46, 0.40

Note: Unit-cell parameters were refined from 2544 recorded reflections. Scattering factors for neutral atoms were employed in the refinement.

a framework of corner-sharing (Si,Al)O₄ and BeO₃F tetrahedra, leading to chain and ring units. Voids in the framework are occupied by K and Na atoms. Details of the topology are discussed in Sokolova *et al.* (2002) and will not be repeated here. Atomic coordinates and displacement parameters are listed in Table 3. Relevant bond-length data are given in Table 4.

The occupancy of the *A* site is 1.02, if modelled as a K atom ($\langle A-O \rangle = 3.105$ Å); therefore, the very minor Rb contents revealed by EPMA are attributable to this site. The *B* site, which is vacant in telyushenkoite and partly occupied by water molecules in leifite (occupancy: 0.63 Ow), is nearly vacant in eirikite. The very low electron density on the *B* site was modelled as a Na atom (refined occupancy about 0.02), since the distance to the nearest O ligand is 2.55 Å, a distance typical for Na–O bonds (as written earlier, infrared spectroscopy indicates the absence of OH and H₂O). Since the distance between the *B* site and the neighbouring *A* site is 2.44 Å, both sites can not be simultaneously occupied, thus necessitating the very minor presence of vacancies on the *A* site.

Concerning the *A*-site occupancy, we point out that it would at first sight seem surprising that the reported unit-cell volume of type material of the Cs member telyushenkoite [873.2(1) Å³, Agakhanov *et al.*, 2003] is very slightly smaller

than that of the K member eirikite [873.5(1) Å³]. Note that, although type telyushenkoite contains considerable Na and K on the *A* site (empirical occupancy: Cs_{0.69}Na_{0.31}K_{0.14}Rb_{0.02}), thus reducing the average ionic radius of the *A*-site cations, the (Cs,Na,K,Rb)-O bond length [3.158(3) Å × 6] is still distinctly longer than that in eirikite [3.1046(10) Å × 6] and therefore cannot cause the smaller-than-expected unit-cell volume of type telyushenkoite. However, the measured Si:Al ratio in type telyushenkoite (15.46:2.06; the 0.30 apfu Zn is neglected here) is larger than that in eirikite (15.07:2.98), and, accordingly, the average (Si,Al)-O bond lengths are smaller (1.667 / 1.609 / 1.617 Å in telyushenkoite vs 1.677 / 1.618 / 1.618 Å in eirikite for the *T*(1) / *T*(2) / *T*(3) sites, respectively), resulting in a reduced cell volume.

The seven-coordinated Na site is fully occupied by Na ($\langle Na-(O,F) \rangle = 2.542$ Å). Tentative refinements of the Si occupancies on the three *T* sites (occupied by Si + minor Al) suggest that Al shows a slight preference for *T*(1) and *T*(2), in agreement with the situation in leifite and telyushenkoite (Sokolova *et al.*, 2002); for the refinement the occupancy was fixed according to the measured Si:Al ratio ($\approx 15:3$). The average Be-(O,F) bond length in the BeO₃F tetrahedron, 1.610 Å, is very close to the values in the other two members of the leifite group. The tetrahedrally coordinated F atom is bonded to one Be atom and three Na atoms. Consequently, space requirements rule out any substitution of OH for F at this site.

6. Other occurrences of eirikite

Sokolova *et al.* (2002) and Agakhanov *et al.* (2003) first mentioned that specimens of leifite (*s. l.*) from a number of localities contain sufficient K to constitute a new species, which we have called eirikite. In addition to the Vesle Arøya type locality described in the present paper, eirikite occurs in a late albitite vein in naujaite at Tugtup Agtakorfiá, Ilimaussaq, South Greenland (Petersen *et al.*, 1994). Eirikite has also been identified as a late-stage mineral from hyperagpaic pegmatites in the Sodovyi crosscut, Kukisvumchorr, Khibiny and at Alluaiv Mountain, Lovozero (Pekov & Podlesnyi, 2004; Pekov, 2005). Eirikite samples from the above mentioned localities in Greenland and the Kola Peninsula are identified on the basis of chemical composition only. It is assumed that K is invariably ordered at the *A* site, but this has to be proven by single-crystal structure refinement.

The chemical composition of potassium-rich leifites (*s. l.*) from Mont Saint-Hilaire, Quebec, Canada, was published already by Semenov (1972) and Sokolova *et al.* (2002). As part of an ongoing project to update the mineralogy of Mont Saint-Hilaire, Quebec, Canada, a set of electron microprobe analyses (G. Poirier, analyst) were performed on 14 samples of leifite-group minerals from the collections of the Canadian Museum of Nature and the private László and Elsa Horváth collection. Of the 14 samples analyzed, 6 have eirikite compositions, and in 3 cases leifite and eirikite compositions are found in the same specimen. A few single crystals show

Table 3a. Fractional atomic coordinates for eirikite.

Atom	<i>x</i>	<i>y</i>	<i>z</i>	<i>U</i> _{eq}	Occupancy
T(1)	0.0	0.21580(2)	0.5	0.00921(8)	(Si,Al)*
T(2)	0.0	0.34389(2)	0.0	0.00717(8)	(Si,Al)*
T(3)	0.447403(11)	-0.447403(11)	0.30818(6)	0.00624(8)	(Si,Al) ^a
T(4)	0.3333	0.6667	0.3685(5)	0.0080(3)	Be
Na	0.75075(2)	-0.75075(2)	0.20243(12)	0.01861(12)	Na
A	0.0	0.0	0.0	0.0438(3)	K _{1.018(5)} ^b
B	0.0	0.0	0.5	0.04(4)	Na _{0.017(9)}
O(1)	0.09980(4)	-0.09980(4)	0.38138(19)	0.01764(17)	O
O(2)	0.30843(5)	0.25990(5)	0.24793(12)	0.01445(12)	O
O(3)	0.35937(5)	0.45859(5)	0.10578(12)	0.01207(11)	O
O(4)	0.5	0.0	0.5	0.0139(2)	O
O(5)	0.39429(3)	-0.39429(3)	0.48464(16)	0.01058(14)	O
F	0.33333	0.66667	0.0448(2)	0.0136(2)	F

^aT-site occupancy fixed to measured Si:Al ratio (15:3); see text for tentative Al site preferences.

^bRefined A-site occupancy indicates presence of very minor Rb (see text for discussion).

Table 3b. Atomic displacement parameters (in Å²) for eirikite.

Atom	<i>U</i> ₁₁	<i>U</i> ₂₂	<i>U</i> ₃₃	<i>U</i> ₂₃	<i>U</i> ₁₃	<i>U</i> ₁₂
T(1)	0.00949(13)	0.00935(11)	0.00883(13)	-0.00058(4)	-0.00116(9)	0.00475(7)
T(2)	0.00752(13)	0.00675(10)	0.00750(13)	0.00020(4)	0.00040(8)	0.00376(6)
T(3)	0.00725(11)	0.00725(11)	0.00607(12)	-0.00005(4)	0.00005(4)	0.00501(10)
T(4)	0.0079(5)	0.0079(5)	0.0080(8)	0.0	0.0	0.0040(3)
Na	0.01746(18)	0.01746(18)	0.0164(2)	-0.00316(10)	0.00316(10)	0.0054(2)
A	0.0460(5)	0.0460(5)	0.0394(6)	0.000	0.000	0.0230(2)
O(1)	0.0164(3)	0.0164(3)	0.0154(4)	0.00408(16)	-0.00408(16)	0.0047(3)
O(2)	0.0157(3)	0.0131(3)	0.0152(3)	0.00539(19)	0.0054(2)	0.0077(2)
O(3)	0.0132(2)	0.0094(2)	0.0147(2)	-0.00318(18)	-0.00411(19)	0.00642(18)
O(4)	0.0175(4)	0.0078(4)	0.0134(5)	-0.0049(4)	-0.00247(18)	0.0039(2)
O(5)	0.0143(3)	0.0143(3)	0.0087(3)	-0.00051(11)	0.00051(11)	0.0113(3)
F	0.0168(3)	0.0168(3)	0.0073(4)	0.0	0.0	0.00839(17)

Table 4. Selected bond distances (Å) for the coordination polyhedra in eirikite.

T(1)–O(1) × 2	1.6686(4)	T(2)–O(2) × 2	1.6011(7)
–O(2) × 2	1.6857(7)	–O(3) × 2	1.6343(6)
<T(1)–O>	1.677	<T(2)–O>	1.618
T(3)–O(5)	1.5783(8)	T(4)–O(5) × 3	1.6209(11)
–O(4)	1.6098(3)	–F	1.577(3)
–O(3) × 2	1.6410(6)	<T(4)–O>	1.610
<T(3)–O>	1.618		
Na–O(5) × 2	2.4165(7)	A–O(1) × 6	3.1046(10)
–F	2.4168(9)		
–O(3) × 2	2.4504(7)	A–B × 2	2.4365(5)
–O(2) × 2	2.8228(9)		
<Na–O>	2.542	B–O(1) × 6	2.5532(12)

strong Na-K zoning. It should be pointed out that no single-crystal X-ray diffraction data have been collected from this material to verify the ordering of K at the A site. At Mont Saint-Hilaire leifite-group minerals are found exclusively as

late-stage minerals in open cavities of the alkaline pegmatites of this complex (Horváth & Gault, 1990).

As shown by Sokolova *et al.* (2002), Agakhanov *et al.* (2003) and the present work, eirikite is relatively widespread in its occurrence. A comparison of leifite, eirikite and telyushenkoite data in Table 5 shows that quantitative chemical analyses will be necessary to distinguish between these three species, although comparatively low values of the unit-cell parameters *a*, *c* and *V* may indicate a Na-dominant sample, *i.e.* leifite. A Rb analogue of eirikite may exist in Rb-rich pegmatitic environments.

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Table 5. Comparison of leifite, eirikite and telyushenkoite.

Mineral	Leifite	Eirikite	Telyushenkoite
Idealized formula	$\text{NaNa}_6[\text{Be}_2(\text{Si}_{15}\text{Al}_3)_{\Sigma=18}\text{O}_{39}\text{F}_2]$	$\text{KNa}_6[\text{Be}_2(\text{Si}_{15}\text{Al}_3)_{\Sigma=18}\text{O}_{39}\text{F}_2]$	$\text{CsNa}_6[\text{Be}_2(\text{Si}_{15}\text{Al}_3)_{\Sigma=18}\text{O}_{39}\text{F}_2]$
<i>a</i> (Å)	14.361(1)	14.3865(9)	14.3770(8)
<i>c</i> (Å)	4.8570(5)	4.8733(4)	4.8786(3)
<i>V</i> (Å ³)	867.5(2)	873.5(1)	873.2(1)
Space group	<i>P</i> $\bar{3}m1$	<i>P</i> $\bar{3}m1$	<i>P</i> $\bar{3}m1$
Z	1	1	1
Strongest lines in the powder pattern	3.15 (100), 3.38 (100), 2.46 (90), 4.69 (70), 2.21 (70), 2.39 (70), 4.14 (70)	3.161 (100), 3.386 (70), 2.466 (31), 4.710 (29), 4.153 (21)	3.161 (100), 3.387 (75), 4.149 (50), 3.456 (40), 6.226 (35), 2.456 (30)
D(meas.); (calc.)	2.57–2.58; 2.624	2.59(1); 2.577 ^a	2.73(1); 2.73
Mohs hardness	6	6	6
ϵ	1.520(1)	1.521(1)	1.531(2)
ω	1.516(1)	1.517(1)	1.526(2)
Birefringence	0.004	0.004	0.005
Opt. character	(+)	(+)	(+)
Habit	Acicular-prismatic	Acicular-prismatic	Acicular-prismatic
Cleavage	{10 $\bar{1}$ 0}	{10 $\bar{1}$ 0}	{10 $\bar{1}$ 0}
Fracture	Uneven	Uneven	Uneven
References	1, 2, 3	4	2, 3

^aFrom the empirical chemical formula (2.584 g/cm³ from crystal structure determination).

References: 1, Micheelsen & Petersen (1970); 2, Sokolova *et al.* (2002); 3, Agakhanov *et al.* (2003); 4, this work.

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