

# Leifite from a nepheline syenite pegmatite on Vesle Arøya in the Langesundsfjord district, Oslo Region, Norway

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Leifite has been found in a nepheline syenite pegmatite on the southeastern part of the island Vesle Arøya in the Langesundsfjord district, Norway. The mineral occurs as white to colourless fibrous masses and radiating bundles. The unit-cell dimensions are  $a = 14.387(1)$  Å,  $c = 4.8734(7)$  Å and  $V = 873.6(1)$  Å<sup>3</sup>. The mineral is uniaxial positive,  $\varepsilon = 1.521(1)$  and  $\omega = 1.517(1)$ .

$D_{\text{meas.}} = 2.59(1)$  g/cm<sup>3</sup>.  $D_{\text{calc.}} = 2.60$  g/cm<sup>3</sup>. IR spectroscopic analysis shows that leifite contains (OH) groups, but no water of crystallization as previously assumed. Wet chemical analysis gives the following empirical formula:

$(\text{Na}_{6.14}\text{K}_{0.92}\text{Rb}_{0.12}\text{Cs}_{0.04}\text{Mg}_{0.03}\text{Ca}_{0.01})_{\Sigma 7.26}\text{Be}_{2.07}\text{Al}_{3.04}\text{Si}_{14.61}\text{O}_{37.99}(\text{OH})_{0.97}\text{F}_{2.04}$ . The optical, physical and chemical data are in good agreement with previous results for the mineral. New chemical data have also been obtained for leifite from Narssârssuk, South Greenland.

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Leifite was described by Bøggild (1915) as a new mineral from the Narssârssuk pegmatite at Tunugdliarfik fiord, South Greenland. He was, however, unaware of the fact that the mineral contained a significant amount of beryllium. The mineral was therefore revised by Micheelsen & Petersen (1970), who in the same article discredited 'karpinskyite' (Shilin 1956) from Mount Karnasurt, Lovozero massif, the Kola Peninsula, Russia, which was shown to be a mixture of leifite, montmorillonite and sauconite. Leifite from Mount Karnasurt was also briefly described by Semenov (1972). Other leifite localities on the Kola Peninsula include Mount Eveslogchorr, Khibina massif (Kostyleva-Labuntsova et al. 1978) and Allu-aiv, Lovozero massif (Khomyakov et al. 1979). Leifite has been found at Mont Saint-Hilaire, Quebec, Canada. Boissonnault (1966) gave a brief description of this leifite. Further data were given by Mandarino & Anderson (1989), and exceptional crystal aggregates were described by Horváth & Gault (1990). Petersen et al. (1994) described leifite from the Ilimaussaq alkaline complex, South Greenland, and reported microprobe analysis for other leifite samples. The crystal structure of leifite was solved by Coda et al. (1974) based on the chemical formula  $\text{Na}_6[\text{Si}_{16}\text{Al}_2(\text{BeOH})_2\text{O}_{39}] \cdot 1.5\text{H}_2\text{O}$ . The mineral has an open-branched *zweier* framework, which gives rise to several chains and rings. According to Liebau (1985), there are only a few minerals, namely leifite, wenkite, roggianite and ussingite, which have interrupted frameworks, *i.e.* atomic ratio T:O < 1:2. Leifite with the tetrahedrally coordinated cations  $[(\text{Al}_2\text{Si}_{16})\text{O}_{39}]$  has a T:O ratio of ideally 1:2.167. As shown by Petersen et al. (1994), leifite has one cation in excess compared to the chemical formula proposed by Coda et al. (1974).

Leifite was found on Vesle Arøya in the Langesundsfjord district by T. Engvoldsen in 1983, and identified at the Mineralogisk-Geologisk Museum in Oslo. A brief description was given by Engvoldsen et al. (1991). It is a new mineral for the nepheline syenite pegmatites in the Oslo Region. The monograph by Brøgger (1890) contributed in making these pegmatites famous for their variety of rare minerals. A mineral list was drawn up by Raade et al. (1980), and brief descriptions of minerals new to the area and an updated mineral list were presented by Engvoldsen et al. (1991). The present article reports new chemical, physical and X-ray crystallographic data for the very rare mineral, leifite.

## Occurrence

Leifite has been found in a nepheline syenite pegmatite dike in the southeastern part of the island Vesle Arøya in the Langesundsfjord. The pegmatite was blasted in the 1890s during a search for thorite. A comprehensive description of the morphology of eudidymite and epididymite from the locality was given by Flink (1899).

The pegmatite dike starts at the sea shore and strikes approximately east–west for a distance of 30 m, narrowing to a decimetre in thickness at both ends. The central part of the pegmatite dike is of considerable thickness, although actual data are inaccessible because of the blasting activity and refilling of the site. Information on the mineralogy is therefore mostly obtained from material collected on the dumps.

The main minerals of the pegmatite dike are grey microcline, biotite, nepheline, ferro-edenitic hornblende

('barkevikite') and small amounts of sodalite, magnetite, eudialyte, astrophyllite, catapleiite and leucophanite. They all belong to the magmatic stage of the pegmatite formation. The pegmatite has been subject to intensive hydrothermal alteration, resulting in the following late stage minerals occurring in small vugs or as replacements of earlier minerals: Löllingite, sphalerite, galena, molybdenite, fluorite, pyrochlore, pyrophanite, böhmite, calcite, monazite-(Ce), bastnäsite-(Ce), parisite-(Ce), aegirine, albite, zircon, eudidymite, epididymite, leifite, serandite, astrophyllite, polyolithionite, chlorite, fluorapophyllite, analcime and natrolite. Pharmacosiderite has been found as a supergene alteration product of löllingite.

### Morphology, physical and optical properties

Leifite occurs as fibrous, radiating bundles up to 3 cm long, together with analcime, in vugs between larger feldspar crystals. Leifite has also been found as aggregates built up from interlocking, radiating fibrous groups, each up to 5 mm across. These aggregates can attain 100 cm<sup>3</sup> in volume, and are intergrown with large amounts of small zircon crystals and penetrated by large aegirine crystals. Polyolithionite, albite, eudialyte, catapleiite and pyrochlore can also be found within these aggregates.

Leifite is white to colourless and has a vitreous lustre. The finely fibrous masses have a somewhat silky appearance. The mineral is optically uniaxial positive. The refractive indices for Vesle Arøya leifite  $\varepsilon = 1.521(1)$  and  $\omega = 1.517(1)$  were measured by the immersion method at 23°C using NaD-light. The density  $D = 2.59(1)$  g/cm<sup>3</sup> was measured at 22°C by the sink/float method using diiodomethane diluted with acetone. The optical and physical properties of the Vesle Arøya leifite are in good agreement with data for leifite from other localities.

### X-ray crystallographic data

Leifite is trigonal, space group  $P\bar{3}m1$  (No. 164) (Coda et al. 1974). Powder diffraction data for the Vesle Arøya leifite were obtained using a Philips APD 1700 diffractometer with graphite monochromated  $\text{CuK}\alpha_1$  radiation ( $\lambda = 1.54059$  Å) and Si (NBS 640a) as internal standard. The unit-cell dimensions found by least squares refinement (Appleman & Evans 1973; Benoit 1987) from 35 reflections are  $a = 14.387(1)$  Å,  $c = 4.8734(7)$  Å and  $V = 873.6(1)$  Å<sup>3</sup>. Leifite from different localities shows considerable variations in the unit-cell dimensions (Mandarino & Anderson 1989; Petersen et al. 1994). This is mainly due to variations in the Na-K and Si-Al substitutions. However, further investigations are needed to clarify these relations.

A Guinier-Lenné high-temperature camera was used to obtain powder diffraction data from room temperature

up to 950°C. The film shows that the leifite structure is stable up to 800°C. A gradual decomposition and final collapse of the structure take place between 800° and 850°C. This decomposition course is in good agreement with findings from the thermogravimetric investigation. Concomitant with the breakdown of the leifite structure, a leucite-like phase crystallized. This phase is stable up to at least 950°C.

### IR spectroscopy, thermogravimetry and water analysis

Pellets of the Vesle Arøya leifite mixed with anhydrous KBr were analysed in a Perkin Elmer S-2000 FT-IR spectrometer. Prior to the analysis, leifite was stored over silica gel in a desiccator. The infrared spectrum (Fig. 1) shows complex absorption bands in the region 452–1175 cm<sup>-1</sup>, which are mainly due to Si-O and Be-O stretching and bending vibrations. The absence of an absorption band at 1620–1650 cm<sup>-1</sup> indicates that there is no water of crystallization in leifite as reported by Micheelsen & Petersen (1970) and Coda et al. (1974). The broad absorption region at 3435–3526 cm<sup>-1</sup> is probably due to hydroxyl groups.

A thermogravimetric analysis using a Mettler TA-3000 instrument on 15 mg Vesle Arøya leifite at a heating rate of 10°C/min in N<sub>2</sub> atmosphere from room temperature to 1000°C gave weight losses in two major intervals (Fig. 2a). The first interval occurred between room temperature and 800°C (0.8 weight-%), corresponding mainly to liberation of (OH), but also to some absorbed water. The second interval between 800° and 950°C (0.4 weight-%) is probably due to liberation of F.

The relative water signal obtained by LECO RC-412 analyser on 98.5 mg Vesle Arøya leifite from 50°C to 1000°C with a heating rate of 100°C/min showed that H<sub>2</sub>O is liberated in two steps with maxima at 130°C and 276°C (Fig. 2b). Total water was measured as 0.95 weight-%. Deconvolution of the two peaks indicates that one-third (0.32 weight-%) of the water was lost during the first peak, corresponding to absorbed water, while two-thirds (0.63 weight-%) was lost between 200°C and 800°C. The latter value has been included in the chemical composition (Table 1). Practically no water existed in the sample above 800°C. This is in good agreement with what was found by the high-temperature X-ray diffraction camera regarding the stability of the leifite structure. Both the temperature maxima and the relative amounts of the successively liberated water are in good agreement with what was found by thermogravimetric analysis on leifite from Narssârssuk, South Greenland (Micheelsen & Petersen 1970). Their value for the absolute amount of water (3.1% H<sub>2</sub>O), however, is far above what can be incorporated in leifite. Bøggild (1915) reported 0.77% H<sub>2</sub>O in leifite, a value which is closer to ours.

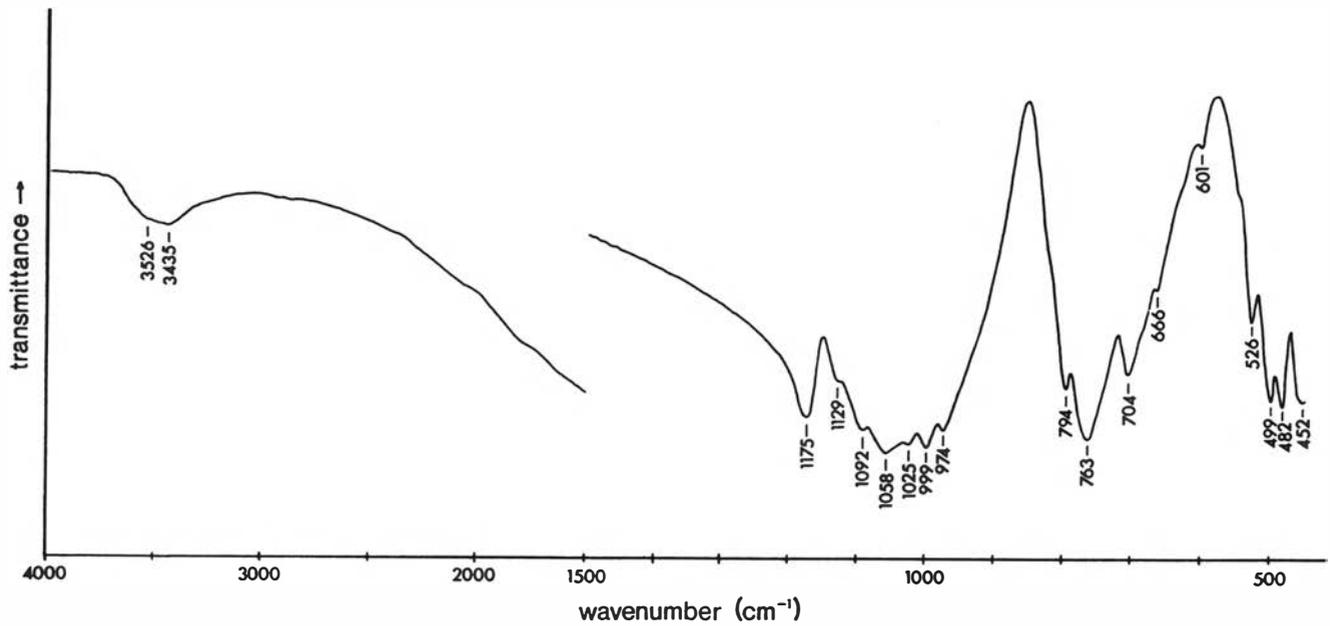


Fig. 1. Infrared spectrum of leifite from Vesle Arøya, Norway. Spectrum > 1500 cm<sup>-1</sup>: 10% leifite in KBr. Spectrum < 1500 cm<sup>-1</sup>: 2% leifite in KBr. Note scale shift at 1500 cm<sup>-1</sup>.

Table 1. Chemical composition (in weight-%) of leifite from Vesle Arøya, Norway and Narssârssuk, South Greenland, and corresponding number of atoms per formula unit based on 41(O,OH,F).

	1	2	3	4	5
SiO <sub>2</sub>	63.49	66.69	68.47	68.97	66.30
Al <sub>2</sub> O <sub>3</sub>	11.22	11.02	8.08	8.33	11.25
BeO	3.75	n.a.	4.01	n.a.	3.68
MgO	0.09	n.a.	< 0.01	n.a.	
CaO	0.02	n.a.	0.02	n.a.	
Na <sub>2</sub> O	13.77	13.70	15.59	14.30	13.68
K <sub>2</sub> O	3.12	2.72	1.49	1.36	3.47
Rb <sub>2</sub> O	0.81	n.a.	0.14	n.a.	
Cs <sub>2</sub> O	0.39	0.20	0.09	0.02	
F	2.8	2.89	2.97*	2.97	2.80
H <sub>2</sub> O	0.63	n.a.	0.77**	n.a.	
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	100.09	97.22	101.63	95.95	101.18
-O ≡ F	1.18	1.22	1.25	1.25	1.18
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	98.91	96.00	100.38	94.70	100.00
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Si	14.609		15.236		15.000
Al	3.042		2.119		3.000
Be	2.072		2.143		2.000
Mg	0.030		0.000		
Ca	0.006		0.005		
Na	6.144		6.725		6.000
K	0.915		0.422		1.000
Rb	0.119		0.019		
Cs	0.039		0.008		
F	2.038		2.090		2.000
H	0.968		1.142		

n.a. = not analysed.

\* = value from Petersen et al. (1994).

\*\* = value from Bøggild (1915).

1. Vesle Arøya, Norway (this work).
2. Vesle Arøya, Norway (Petersen et al. 1994).
3. Narssârssuk, South Greenland (this work).
4. Narssârssuk, South Greenland (Petersen et al. 1994).
5. Theoretical composition for Na<sub>6</sub>KBe<sub>2</sub>Al<sub>3</sub>Si<sub>15</sub>O<sub>39</sub>F<sub>2</sub>.

### Chemical composition

Analyses of Vesle Arøya leifite and co-type Narssârssuk leifite (Bøggild 1915) were performed on carefully hand-picked grains. Si, Al, the alkali metals and the alkaline earth metals were determined by atomic-absorption spectrometry after decomposition of the samples using a mixture of hydrofluoric acid and sulphuric acid in sealed

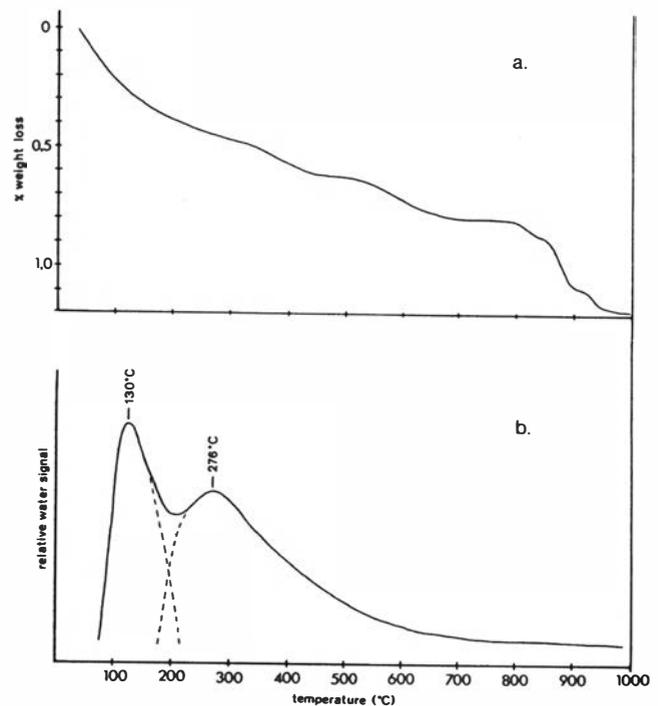


Fig. 2. Thermogravimetric curve (a) and relative water signal as given by LECO RC-412 analyzer (b) for leifite from Vesle Arøya, Norway. Hatched lines indicate deconvoluted peaks.

teflon vessels. Regarding the Vesle Arøya leifite, F was determined by Dionex ion chromatography after decomposition of the sample by  $\text{Na}_2\text{CO}_3$  and ZnO melting flux and subsequent leaching with water. The results can be found in Table 1. Li and Sr were determined as being less than 25 ppm in both samples.

The chemical composition of the two leifite samples is in good accordance with the findings by Petersen et al. (1994) (Table 1). Based on 41(O,OH,F), the empirical formulae for leifite from Vesle Arøya and Narssârssuk are:



As shown by the IR spectroscopic analysis (Fig. 1), leifite contains hydroxyl, and the chemical formulae suggest that (OH) is a substitute for O. The water content of leifite was previously assigned partly as hydroxyl, partly as water of crystallization (Coda et al. 1974). Leifite shows an Al-Si substitution in the tetrahedrally coordinated cations varying ideally from  $(\text{Be}_2\text{Al}_2\text{Si}_{16})$  to  $(\text{Be}_2\text{Al}_3\text{Si}_{15})$ .

With  $Z = 1$ , the calculated density for Vesle Arøya leifite is  $2.60 \text{ g/cm}^3$ , in good agreement with the measured value of  $2.59 \text{ g/cm}^3$ . The Gladstone–Dale relationship gives a compatibility index  $1-(K_p/K_c) = 0.006$ , which is in the 'superior' category (Mandarino 1981).

## Discussion

The present investigation confirms the results of Petersen et al. (1994): Leifite shows an Al-Si substitution in the tetrahedrally coordinated cations varying from  $(\text{Be}_2\text{Al}_2\text{Si}_{16})$  to  $(\text{Be}_2\text{Al}_3\text{Si}_{15})$ , and has seven positions for the alkalis. In addition, leifite contains no water of crystallization. These facts were not evident at the time when the crystal structure was determined (Coda et al. 1974). It is therefore timely for a new determination of the crystal structure of leifite, although it may be assumed that the main features of the structure will remain unchanged.

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leifite, and for a critical review of the manuscript. We thank S. Gajda, R. Dahl, E. Tveten and N. Morris, all at Norsk Hydro a.s., Research Centre Porsgrunn, for generously carrying out the FT-IR-spectrometric analysis, the fluorine analysis, the water analysis and the TG-analysis, respectively. The manuscript benefited from critical reviews by G. Raade, G. Juve and R. Trønnes, and the English text was corrected by A. Jenkins.

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