

Fluor-ferro-leakeite, $\text{NaNa}_2(\text{Fe}_2^{2+}\text{Fe}_2^{3+}\text{Li})\text{Si}_8\text{O}_{22}\text{F}_2$, a new alkali amphibole from the Canada Pinabete pluton, Questa, New Mexico, U.S.A.

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ABSTRACT

Fluor-ferro-leakeite is a new amphibole species from the Canada Pinabete pluton, Questa, New Mexico, U.S.A.; it occurs in association with quartz, alkali feldspar, acmite, ilmenite, and zircon. It forms as anhedral bluish black crystals elongated along *c* and up to 1 mm long. It is brittle, $H = 6$, $D_{\text{meas}} = 3.37 \text{ g/cm}^3$, $D_{\text{calc}} = 3.34 \text{ g/cm}^3$. In plane-polarized light, it is strongly pleochroic, $X =$ very dark indigo blue, $Y =$ gray blue, $Z =$ yellow green; $X \wedge c = 10^\circ$ (in β obtuse), $Y = b$, $Z \wedge a = 4^\circ$ (in β obtuse), with absorption $X > Y > Z$. Fluor-ferro-leakeite is biaxial positive, $\alpha = 1.675(2)$, $\beta = 1.683(2)$, $\gamma = 1.694(1)$; $2V = 87(2)^\circ$; dispersion is not visible because of the strong absorption.

Fluor-ferro-leakeite is monoclinic, space group $C2/m$, $a = 9.792(1)$, $b = 17.938(1)$, $c = 5.3133(4) \text{ \AA}$, $\beta = 103.87(7)^\circ$, $V = 906.0(1) \text{ \AA}^3$, $Z = 2$. The ten strongest X-ray diffraction lines in the powder pattern are [$d(I, hkl)$]: 2.710(100,151), 2.536(92,202), 3.404(57,131), 4.481(54,040), 8.426(45,110), 2.985(38,241), 2.585(38,061), 3.122(29,310), 2.165(26,261), and 1.586(25,403). Analysis by a combination of electron microprobe, ion microprobe, and crystal-structure refinement (Hawthorne et al. 1993) gives SiO_2 51.12, Al_2O_3 1.13, TiO_2 0.68, Fe_2O_3 16.73, FeO 8.87, MgO 2.02, MnO 4.51, ZnO 0.57, CaO 0.15, Na_2O 9.22, K_2O 1.19, Li_2O 0.99, F 2.87, $\text{H}_2\text{O}_{\text{calc}}$ 0.60, sum 99.44 wt%. The formula unit, calculated on the basis of 23 O atoms, is $(\text{K}_{0.23}\text{Na}_{0.76})(\text{Na}_{1.97}\text{Ca}_{0.03})(\text{Mg}_{0.46}\text{Fe}_{1.14}^{2+}\text{Mn}_{0.59}^{2+}\text{Zn}_{0.07}\text{Fe}_{1.93}^{3+}\text{Ti}_{0.08}\text{Al}_{0.02}\text{Li}_{0.61})(\text{Si}_{7.81}\text{Al}_{0.19})\text{O}_{22}(\text{F}_{1.39}\text{OH}_{0.61})$. A previous crystal-structure refinement (Hawthorne et al. 1993) shows Li to be completely ordered at the M3 site. Fluor-ferro-leakeite, ideally $\text{NaNa}_2(\text{Fe}_2^{2+}\text{Fe}_2^{3+}\text{Li})\text{Si}_8\text{O}_{22}\text{F}_2$, is related to leakeite, $\text{NaNa}_2(\text{Mg}_2\text{Fe}_3^{3+}\text{Li})\text{Si}_8\text{O}_{22}(\text{OH})_2$, by the substitutions $\text{Fe}^{2+} \rightarrow \text{Mg}$ and $\text{F} \rightarrow \text{OH}$.

INTRODUCTION

Leakeite is a newly described amphibole from the Kajlidongri manganese mine, Madhya Pradesh, India (Hawthorne et al. 1992). Its ideal formula is $\text{NaNa}_2(\text{Mg}_2\text{Fe}_3^{3+}\text{Li})\text{Si}_8\text{O}_{22}(\text{OH})_2$, which may be formally derived from the end-member ferri-eckermannite, $\text{NaNa}_2(\text{Mg}_4\text{Fe}^{3+})\text{Si}_8\text{O}_{22}(\text{OH})_2$, by the substitution $\text{Fe}^{3+} + \text{Li} \rightarrow \text{Mg} + \text{Mg}$. Leakeite thus contains essential ^{69}Li . Hawthorne et al. (1993) showed that the leakeite substitution is also a feature of alkali amphiboles in peralkaline granitic rocks at Questa, New Mexico (Czamanske and Dillet 1988). During this work, a new amphibole was discovered, the "fluor-ferro-" equivalent of leakeite; a formal description of the amphibole is given here. The new species and the new name have been approved by the International Mineralogical Association Commission on New Minerals and Mineral Names. Holotype material is deposited in the Canadian Museum of Nature, Ottawa.

OCCURRENCE

Fluor-ferro-leakeite is present in light gray, mildly peralkaline porphyry (sample 82QC49, 76.0 wt% SiO_2) that occurs as a peripheral phase of the Canada Pinabete pluton, located along the west front of the Sangre de Cristo Range, north-central New Mexico (Dillet and Czamanske 1987; Czamanske and Dillet 1988), latitude $36^\circ 46.47' \text{ N}$, longitude $105^\circ 33.93' \text{ W}$. As reported by Czamanske and Dillet (1988), the peralkaline porphyry contact phase of the small, high-level Canada Pinabete ($\sim 2.5 \text{ km}^2$) and Virgin Canyon ($\sim 0.5 \text{ km}^2$) plutons typically contains the unusual mafic-mineral assemblage alkali amphibole + sodic pyroxene + tetrasilicic mica in relatively reduced rocks bearing ilmenite + titanite (Wones 1989). The bulk of each pluton is composed of hypersolvus, equigranular, metaluminous biotite granite containing 72–75 wt% SiO_2 .

Detailed analysis of alkali amphiboles in a suite of samples from the two peralkaline porphyries has shown

TABLE 1. Chemical analysis and formula unit* for fluor-ferro-leakeite

Oxide	wt%	Atom	Number
SiO ₂	51.12	Si	7.81
Al ₂ O ₃	1.13	Al	0.19
TiO ₂	0.68	Sum	8.00
Fe ₂ O ₃	16.73		
FeO	8.87	Al	0.02
MgO	2.02	Ti	0.08
MnO	4.51	Fe ³⁺	1.93
ZnO	0.57	Fe ²⁺	1.14
Li ₂ O	0.99	Mn ²⁺	0.59
CaO	0.15	Mg	0.46
Na ₂ O	9.22	Zn	0.07
K ₂ O	1.19	Li	0.61
F	2.87	Sum	4.90
H ₂ O*	0.60		
O ≡ F	-1.21	Ca	0.03
		Na	1.97
Sum	99.44	Sum	2.00
		Na	0.76
		K	0.23
		Sum	0.99
		OH	0.61
		F	1.39

* Calculated assuming OH + F = 2 in formula unit.

them to range in composition from katophoritic to arfvedsonitic, generally with high Mn and F contents; their Fe/(Fe + Mg) ratios are quite variable (Czamanski and Dillet 1988; Hawthorne et al. 1993). Fluor-ferro-leakeite occurs in sample 82QC49 as myriad, small (0.05–0.2 mm) irregular patches in the quenched, fine-grained groundmass of the rock and as sparse, larger elongate grains with irregular margins. Tetrasilicic mica is sparse in sample 82QC49, and magnetite and titanite were not found.

PHYSICAL AND OPTICAL PROPERTIES

Fluor-ferro-leakeite is bluish black to black with a vitreous luster. It has a bluish gray streak and shows no fluorescence under long-wave or short-wave ultraviolet light. When separated from a coarse crush of the rock, grains are prismatic on [001] and are bounded by {110} cleavage faces with the prism direction terminated by irregular fractures. Fluor-ferro-leakeite has a Mohs hardness of ~6 and is brittle; it has the characteristic perfect {110} cleavage of monoclinic amphiboles, intersecting at ~56°. The density, measured by flotation, is 3.37 g/cm³, compared with the calculated density of 3.34 g/cm³.

A spindle stage was used to orient a crystal for measurement of refractive indices and 2*V* by extinction curves. The optical orientation was determined by transferring the crystal from the spindle stage to a precession camera and measuring the relative axial relations by X-ray diffraction. In transmitted light, fluor-ferro-leakeite is strongly pleochroic with *X* = very dark indigo blue, *Y* = gray blue, *Z* = yellow green, *X* ∩ *c* = 10° (in β obtuse), *Y* = *b*, *Z* ∩ *a* = 4° (in β obtuse); absorption *X* > *Y* > *Z*. It is biaxial positive with indices of refraction α = 1.675(2), β = 1.683(2), γ = 1.694(1) measured with gel-filtered Na

TABLE 2. Indexed powder pattern for fluor-ferro-leakeite

<i>hkl</i>	<i>d</i> _{calc} (Å)	<i>d</i> _{obs} (Å)	<i>l</i>
020	8.969	8.998	16
110	8.400	8.426	45
111	4.881	4.882	9
040	4.484	4.481	54
111	4.031	4.033	11
131	3.868	3.867	6
221	3.658	3.660	10
131	3.402	3.404	57
240	3.262	3.262	12
310	3.120	3.122	29
241	2.988	2.985	38
151	2.929	2.929	6
330	2.800	2.800	12
151	2.710	2.710	100
061	2.587	2.585	38
202	2.536	2.536	92
170	2.474	2.472	9
350	2.375	2.376	5
351	2.322	2.322	19
171	2.287	2.287	12
312	2.268	2.268	21
331	2.268	2.268	5
242	2.208	2.207	26
261	2.165	2.165	10
202	2.069	2.068	8
351	2.024	2.024	7
402	2.003	2.003	4
242	1.878	1.878	6
512	1.735	1.734	12
133	1.695	1.695	9
0,10,1	1.695	1.695	12
550	1.680	1.680	9
282	1.680	1.680	12
461	1.654	1.654	7
481	1.634	1.634	8
480	1.631	1.632	8
1,11,0	1.607	1.607	25
153	1.586	1.586	3
403	1.586	1.586	21
402	1.570	1.570	9
263	1.515	1.515	4
0,12,0	1.495	1.495	4
443	1.495	1.495	9
2,10,2	1.464	1.465	4
642	1.442	1.442	4
572	1.442	1.442	9
661	1.430	1.430	4
533	1.420	1.419	4
711	1.394	1.394	4
590	1.376	1.376	6
313	1.376	1.376	5
710	1.354	1.354	6
553	1.354	1.354	6
263	1.345	1.345	6
333	1.344	1.345	6
1,11,2	1.340	1.340	6
204	1.328	1.327	4
681	1.317	1.317	8
114	1.317	1.317	12
552	1.288	1.288	5
2,12,2	1.288	1.288	
404	1.268	1.268	

Note: Cell: *a* = 9.792(1), *b* = 17.938(1), *c* = 5.3133(4) Å, β = 103.87(7)°.

light (λ = 589.9 nm); 2*V*_z = 87(2), 2*V*_{calc} = 81°. The dispersion is not visible because of strong absorption.

CHEMICAL COMPOSITION

Fluor-ferro-leakeite was analyzed primarily by electron microprobe using a Cameca SX-50 operating in the wavelength-dispersive mode with excitation voltage 15

kV, specimen current 20 nA, peak-count time 20 s, and background-count time 10 s. The following standards and crystals were used for $K\alpha$ X-ray lines: Si, Ca: tremolite, PET; Ti: hornblende, LiF; Fe: arfvedsonite, LiF; Mn: tephroite, LiF; Mg: tremolite, TAP; Na, Al: albite, TAP; K: orthoclase, PET; F: fluor-riebeckite, TAP; Zn: willemite, LiF. Data reduction was performed using the $\phi(\rho Z)$ procedure of Pouchou and Pichoir (1984, 1985). Li was analyzed by ion microprobe according to the procedure of Ottolini et al. (1993). The average of ten analyses on a single grain is given in Table 1.

Refinement of the crystal structure of fluor-ferro-leakeite (Hawthorne et al. 1993) showed Li to be ordered at the M3 site, showed Mn to be in the divalent state, and allowed the $\text{Fe}^{3+}/\text{Fe}^{2+}$ ratio to be derived.

X-RAY CRYSTALLOGRAPHY

X-ray precession photographs with Zr-filtered $\text{MoK}\alpha$ X-radiation are compatible with Laue symmetry $2/m$, and the condition for reflections to be present, $h + k = 2n$, indicates that the lattice is C centered. Long-exposure photographs (80 h) show no sign of any violating reflections. The possible space groups are $C2/m$, $C2$, and Cm ; crystal-structure refinement confirmed the space group $C2/m$ (Hawthorne et al. 1993).

A small amount of separate was ground to a grain size of approximately $2 \mu\text{m}$ and mounted in a standard aluminum holder. The surface of the powder was chopped with a razor blade to reduce preferred orientation. The diffraction pattern was recorded on a Philips PW 1710 diffractometer with graphite-monochromatized $\text{CuK}\alpha$ X-radiation. Peak positions were measured by fitting a five-point parabolic curve to the top of the diffraction peaks, followed by correction for α_1 - α_2 splitting; NBS Si was used as a standard. Peak intensities were estimated visually. Cell dimensions were refined from the corrected d values using the program CELREF (Appleman and Evans 1973); the indexed powder pattern and refined cell dimensions are given in Table 2.

DISCUSSION

End-member fluor-ferro-leakeite has the formula $\text{NaNa}_2(\text{Fe}_2^{2+}\text{Fe}_3^{3+}\text{Li})\text{Si}_8\text{O}_{22}\text{F}_2$. This may be derived from end-member leakeite by the homovalent substitutions $\text{Fe}^{2+} \rightarrow \text{Mg}$ and $\text{F} \rightarrow \text{OH}$ and from end-member arfved-

sonite by the substitutions $\text{Li} + \text{Fe}^{2+} \rightarrow 2\text{Fe}^{2+}$ and $\text{F} \rightarrow \text{OH}$. Hawthorne (1976) showed that C-group cation sums are anomalously low in alkali amphiboles. This and other apparent anomalies in alkali amphibole stoichiometry (Si contents > 8 apfu, low C-group cation sums, and A-site sums > 1 apfu) are probably due to incomplete chemical analyses of amphiboles that may contain significant Li (Hawthorne et al. 1993). Thus, fluor-ferro-leakeite may be a more common constituent of peralkaline granites than its recent discovery would suggest.

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