

FAIZIEVITE, $K_2Na(Ca_6Na)Ti_4Li_6Si_{24}O_{66}F_2$ – A NEW MINERAL SPECIES*

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Faizievite, a new sodium-potassium-calcium-lithium titanosilicate, was found in a quartz boulder in association with pectolite, baratovite, aegirine, polyolithionite, leucosphenite, fluorite, etc. on a moraine of the Darai-Pioz glacier, Tadjikistan. It is colourless with a strong vitreous lustre, forms tabular plates without vicinal forms, and up to 0.3 cm in maximum dimension. Mohs hardness is 4–4.5, measured density is 2.83(2) g/cm³, calculated density is 2.819 g/cm³. Faizievite is optically positive, biaxial, $n_g = 1.651(2)$, $n_m = 1.655(2)$, $n_g = 1.657(2)$, $2V_{mms} = -72(2)^\circ$, $2V_{calc.} = -70.4^\circ$. The crystal structure was refined to an R index of 7.5%. Faizievite is triclinic, space group $P-1$, cell dimensions: $a = 9.8156(9)\text{\AA}$; $b = 9.8249(9)\text{\AA}$; $c = 17.3087(16)\text{\AA}$; $\alpha = 99.209(2)^\circ$, $\beta = 94.670(2)^\circ$, $\gamma = 119.839(1)^\circ$, $V = 1403.7(4)\text{\AA}^3$, $Z = 1$. The strongest lines of the X-ray powder diffraction pattern are as follows: [d , \AA , (h , k , l), (hkl)]: 5.60 (9) (0 0 3), 4.25 (60) (0 -2 1), 3.35 (100) (0 0 5), 3.14 (20) (1 -3 2), 3.06 (90) (-1 -2 3), 2.885 (55) (-2 1 5), 2.870 (10) (-2 3 2), 1.868 (17) (-1 4 4). The strongest lines of the IR absorption spectra are as follows: 1211, 1178, 1130, 1022, 940, 783, 683, 651, 557, 534, 460 cm⁻¹. The chemical composition (microprobe, excepting data for Li₂O, Rb₂O, BaO, SrO – which was obtained by ICP OES, wt.%): SiO₂ – 60.65, CaO – 14.52, TiO₂ – 13.44, Nb₂O₅ – 0.11, SrO – 0.72, BaO – 0.24, K₂O – 3.93, Na₂O – 1.99, Li₂O – 3.76, Rb₂O – 0.13, F – 1.30, -O = F₂ – -0.55, total – 100.24. The empirical formula of faizievite is $(K_{1.98}Rb_{0.03})_{2.01}(Na_{0.90}\square_{0.10})_{1.00}(Ca_{6.16}Na_{0.63}Sr_{0.17}Ba_{0.04})_{7.00}(Ti_{4.00}Nb_{0.02})_{4.02}Li_{5.98}Si_{24}O_{66.00}(F_{1.63}O_{0.36})_{1.99}$. The ideal formula is $K_2Na(Ca_6Na)Ti_4Li_6Si_{24}O_{66}F_2$. The name honors Faiziev Abdulkhak Radzhabovitch (born 1938) of Dushanbe, Tadjikistan, professor and member-correspondent of the Academy of Sciences of the Republic of Tadjikistan. He is a well-known mineralogist, and author of numerous works on the mineralogy and geochemistry of Central Asia. The sample with faizievite is stored in Fersman Mineralogical Museum, Russian Academy of Science (Moscow).
2 tables, 4 figures, 8 references

Type Locality and Association

Faizievite was discovered in rocks collected on a moraine of the Darai-Pioz glacier, Tadjikistan. The glacier is located in the upper reaches of the Darai-Pioz river and crosses the Darai-Pioz alkaline massif, which is widely known for its unique mineralization. Many publications are devoted to the mineralogy and geology of this alkaline massif (Dusmatov, 1968, 1971, Belakovskiy, 1991, etc.). As is the case for many other alkaline massifs, there is an important role for elements substituting for aluminium in minerals: titanium, zirconium,

niobium, beryllium and boron. In particular, there is major enrichment in boron. The wide variety of titanium minerals is also a characteristic geochemical feature of the massif. Titanium is a dominant element in one-fifth of all Darai-Pioz mineral species. Ring titanosilicates are of special interest here. Together with zirconosilicates, this group at Darai-Pioz has unusual and unique features. Many of these minerals were first described from Darai-Pioz, and practically all of them are abundant here, e.g., **baratovite**, $KCa_7(Ti,Zr)_2Li_3Si_{12}O_{36}F_2$ and **sogdianite** $K(\square,Na)_2(Zr,Ti,Fe^{3+})_2Li_3Si_{12}O_{30}$, are often rock-forming

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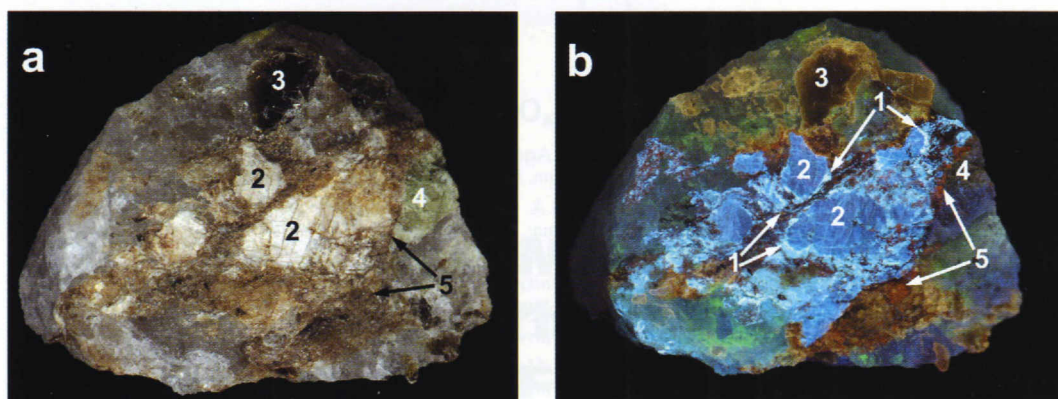


Fig. 1. A general view of the quartz boulder in which faizievite was found (a) in normal light, and (b) in short-wave ultraviolet light.
 1 – faizievite,
 2 – baratovite,
 3 – polyolithionite,
 4 – leucosphenite,
 5 – pectolite.

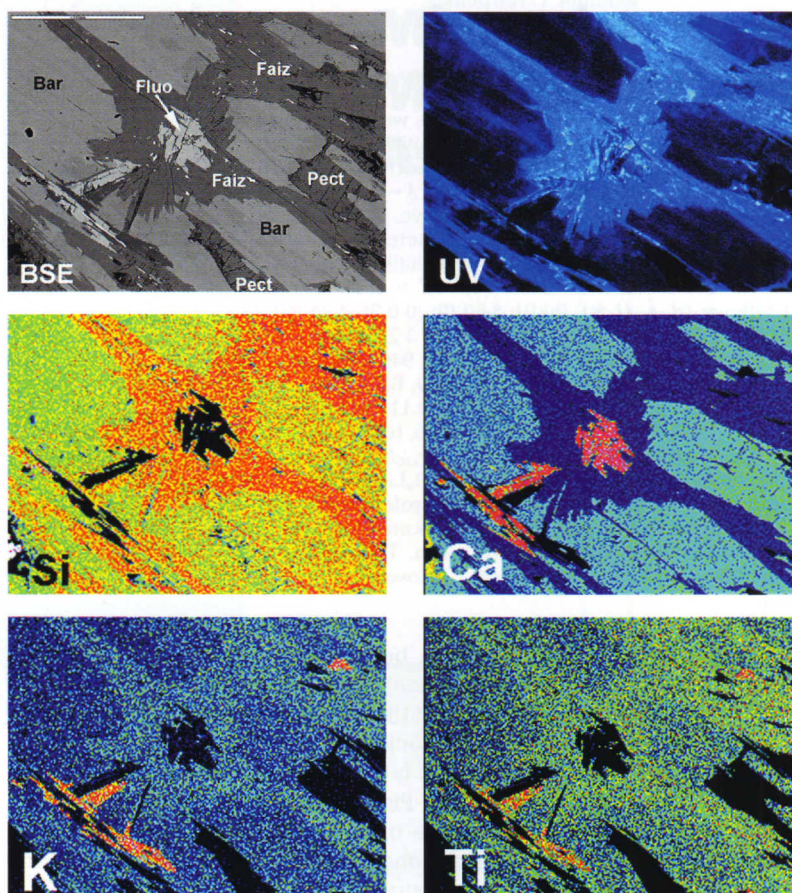


Fig. 2. Intergrowth of faizievite (Faiz) and baratovite (Bar), fluorite (Fluo), pectolite (Pect) imaged in BSE mode, short-wave ultraviolet and characteristic X-rays. Scale bar is 200 μ m.

minerals. Many ring tinosilicates are also present, e.g., **baotite**, **berezanskite**, **tienshanite**, **titantaramellite** and **faizievite**. As will be shown below, the structure of faizievite is derived from the structures of baratovite and berezanskite. (Minerals first described at Darai-Pioz are noted in bold above).

The Darai-Pioz massif is difficult to access because of the complex mountain relief, including sheer walls of a trough-shaped glacial valley. Glacial sediments consists of massive transported material and outcrop. Some boulders in the moraine one can correlate with rocks observed in outcrop. Some of

the transported rocks can be seen in outcrop, but some of the rocks in the moraine could not be established authentically until now. The quartz rocks contain rich rare-earth and rare-metal mineralization where faizievite has been found. The boulder in which faizievite was found consists dominantly of granulose and middle-large-grainy clear quartz, and contains large plates of polyolithionite (up to 20 cm), microcline (crystals up to 3 cm), reedmergnerite pockets (up to 12 cm), idiomorphic crystals of aegirine (up to 5 cm), rare red-brown lenticular crystals of stillwellite-(Ce) (up to 2 cm), grass-green crystals of leucosphenite (up to 3 cm), violet-red plates of sodgianite and sugilite (up to 20 cm), dark green prismatic crystals of hydrated turkestanite with high U-content (up to 2 cm), pockets of polymineral aggregates consisting mainly of pectolite (up to 20 cm). Less common in this rock are baratovite, galena, calcite, kapitzaite-(Y), neptunite, pyrochlore, eudialite-group minerals, hyalotekite, tadhikite, bismuth, sphalerite, fluorite, fluorapatite and fluorapophillite, sokolovaite, pekovite and senkevichite. These rocks occur on a moraine as boulders of different roundness and sizes from 0.2 up to 2 m in diameter. They have not been seen in outcrop and, unfortunately, no contact with any other rock was encountered. As has already been noted, the genesis of these boulders lacks a satisfactory explanation. In order to avoid genetically inappropriate rock names, we call these "quartz boulders".

Faizievite occurs in quartz boulders (fig. 1) as platy grains with no vicinal faces, up to 3 mm across and up to 0.2 mm thick, closely

intergrown with baratovite and fluorite in quartz-pectolite aggregates (Fig. 2). More commonly, faizievite overgrows baratovite, forming a thin rind between quartz and baratovite.

Physical Properties

Faizievite is colourless, transparent, with a strong vitreous lustre. In short-wave ultraviolet light, it has a bright white luminescence; in long-wave ultraviolet light, it does not luminesce. The Mohs hardness is 4–4.5. Micro-indentation VHN was determined with a 50 g load on a PMT-3 instrument, graduating on NaCl; the mean value is 445 kg/mm² (average of 20 measurements in the range 424–474 kg/mm²).

Faizievite is brittle. Density was determined in Clerici solution. The measured density is 2.83(2) g/cm³, calculated density is 2.819 g/cm³. Faizievite is biaxial positive, $2V = -72(2)^\circ$ measured on a Fedorov stage, calculated $2V = -70.4^\circ$. Indices of refraction were measured by immersion at 589 nm: $n_p = 1.651(2)$, $n_m = 1.655(2)$, $n_g = 1.657(2)$. Dispersion is medium, $r < v$. Faizievite does not dissolve in water or HCl (1:1). The infra-red spectrum of faizievite was recorded on an Avatar IR-Fourier spectrometer (Thermo Nicolet), and is characterized by the following absorption bands: 1211, 1178, 1130, 1022, 940, 783, 683, 651, 557, 534, 460 cm⁻¹. The spectrum of faizievite is individual, does not correspond to that of any known mineral (Fig. 3).

Chemical Data

The chemical composition of faizievite was determined on a JCSA-50A JEOL electron microprobe and by ICP OES (Table 1). EMP analyses were done at 20 kV accelerating voltage and 2 nA probe current (for energy-dispersive analysis) and at 15 kV and 25 nA (for wavelength-dispersive analysis). Si, K, Na, Ca, Ti and Nb were analysed by EDS, and F was measured by WDS. Microcline USNM143966 (Si, K), omphacite USNM 110607 (Na), anorthite USNM 137041 (Ca), ilmenite USMN 96189 (Ti), synthetic LiNbO₃ (Nb), MgF₂ (F) were used as standards. Grains of the new mineral are homogeneous and free from inclusions of other minerals. The raw data were processed

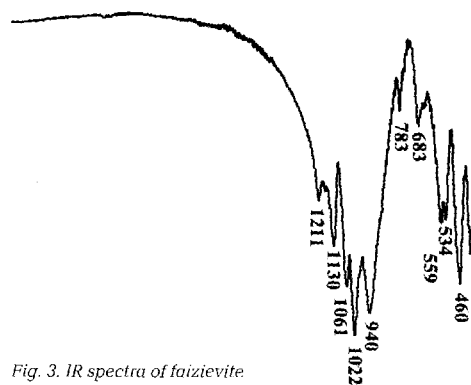


Fig. 3. IR spectra of faizievite prepared in a KBr tablet (analyt A.A. Agakhanov).

Table 1. Chemical data for faizievite (wt%)

Constituent	Content from 20 points in 6 grains	
	Average	Limits of contents
SiO ₂	60.65	58.77–62.15
CaO	14.52	13.58–15.39
TiO ₂	13.44	12.94–13.84
Nb ₂ O ₅	0.11	0.00–0.34
SrO*	0.72	
BaO*	0.24	
K ₂ O	3.93	3.68–3.97
Na ₂ O	1.99	1.81–2.07
Li ₂ O*	3.76	
Rb ₂ O*	0.13	
F	1.30	1.20–1.39
-O=F ₂	-0.55	
Total	100.24	

Note: The data was done by the ICP OES method. Analysts: A.A. Agakhnov, L.A. Pautov.

by a ZAF-correction program. Li, Ba, Sr and Ba concentrations were determined by ICP OES. Mineral grains were digested in a polypropylene tube in concentrated HF with the addition of HNO₃, and the resulting solution was evaporated to wet salts. Further HNO₃ was added to the sample and was evaporated to dryness in order to remove all fluorides. The precipitate was diluted in 2 % HNO₃ and then the solution was analysed with VISTA Pro ICP OES of Varian. The average composition of the analysed grains (table 1) is recalculated for Si = 24 atoms per formula unit to give the empirical formula (K_{1.98}Rb_{0.53})_{2.01}(Na_{0.90}□_{0.10})_{1.00}(Ca_{6.16}Na_{0.63}Sr_{0.17}Ba_{0.04})_{7.00}(Ti_{4.70}Nb_{0.02})_{4.02}Li_{3.96}Si₂₄O_{65.03}(F_{1.63}O_{0.36})_{1.99}. The ideal formula of faizievite is K₂Na(Ca₆Na)Ti₄Li₃Si₂₄O₆₆F₂. The compatibility index (1-K_p/K_c) is 0.005, superior.

X-Ray Crystallography

X-ray powder diffraction data for faizievite was obtained (Table 2) with a DRON-2 instrument. To avoid preferred orientation, the X-ray powder pattern was also obtained with a RKU-114M chamber. The powder-diffraction pattern of faizievite does not correspond to any known mineral or synthetic compound. Quartz was used as an internal standard.

The crystal structure of faizievite, ideally, K₂Na(Ca₆Na)Ti₄Li₃Si₂₄O₆₆F₂, triclinic, $a = 9.8156(9)$,

Table 2. Diffraction data of faizievite

Debaegram		Diffractogram		Theoretical		hkl	
I	D	I	D	I	D		
			6	8.47	4	8.488	-1 1 0
					8	8.390	0 0 2
			9	5.60	10	5.594	0 0 3
7	4.27	60	4.25	50	4.261	0 -2 1	
				42	4.249	-2 2 0	
				50	4.244	0 0 4	
		4	4.16	13	4.181	2 0 0	
				22	4.162	-1 -1 3	
1	4.06	5	4.08	29	4.080	2 -1 2	
				34	3.998	1 -2 3	
				5	3.72	1 -2 2	
				3	3.699	-2 0 3	
				3	3.59	-1 -1 4	
				4	3.46	2 -2 3	
10	3.36	100	3.35	100	3.356	0 0 5	
5h	3.14	20	3.14	12	3.164	1 -3 2	
				13	3.157	-1 3 0	
				15	3.136	2 1 0	
				14	3.131	3 -2 1	
				36	3.123	-1 -1 5	
9	3.08	90	3.06	48	3.066	-1 -2 3	
				51	3.064	-2 3 1	
				52	3.063	3 -1 1	
				43	3.061	2 -1 4	
2	3.01	9	3.00	23	2.999	-1 3 1	
				42	2.996	1 -2 5	
8h	2.886	55	2.885	35	2.881	-2 1 5	
		10	2.870	39	2.865	-2 3 2	
				39	2.865	-1 -2 4	
		9	2.803	41	2.864	3 -1 2	
1	2.722	8	2.721	17	2.716	-1 -1 6	
				10	2.708	-3 1 4	
		5	2.400	13	2.398	3 -1 4	
		1	2.298	2	2.297	-3 3 4	
		2	2.178	8	2.179	3 -1 5	
				7	2.177	-1 -2 7	
		1	2.120	2	2.119	1 -4 5	
				3	2.119	-1 4 2	
		1	2.062	6	2.062	-4 1 5	
		1	2.014	1	2.015	4 -4 3	
		2	1.983	7	1.983	3 1 3	
				5	1.983	-1 -2 8	
				4	1.983	3 -1 6	
		17	1.868	5	1.868	-1 4 4	

Note: Photographic method – RKU 114 M, Fe – anode, Mn-filter, URS-50IM. Diffractometer DRON-2, Fe – anode, graphite monochromator, speed of counter 1 degree /min., internal standard – quartz. Analyst: A.A. Agakhnov

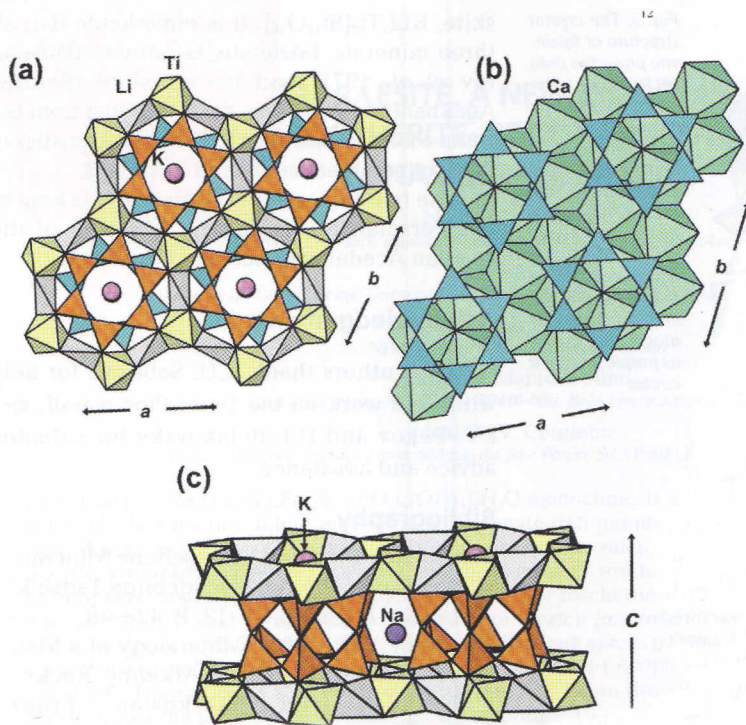


Fig. 4. The crystal structure of faizievite: (a) a fragment of the structure showing $[Si_{12}O_{30}]$ double milarite rings, $[Si_6O_{18}]$ single beryl rings, $[LiO_4]$ tetrahedra and $[TiO_6]$ octahedra viewed down $[001]$; (b) a linkage of $[Si_6O_{18}]$ single rings and Ca-dominant $M(1,2,3,4)$ octahedra viewed down $[001]$; (c) a linkage of $[Si_{12}O_{30}]$ rings and $[LiO_4]$ tetrahedra and $[TiO_6]$ octahedra viewed down $[100]$. $[SiO_4]$ tetrahedra constituting milarite and beryl rings are orange and blue, $[LiO_4]$ tetrahedra are grey, $[TiO_6]$ octahedra are honey yellow; $M(1,2,3,4)$ octahedra are green, $A(1)$ (=Na) and $A(2)$ (=K) atoms are shown as purple and pink circles.

$b = 9.8249(9)$, $c = 17.3087(16)\text{\AA}$, $\alpha = 99.209(2)$, $\beta = 94.670(2)$, $\gamma = 119.839(1)^\circ$, $V = 1403.7(4)\text{\AA}^3$, space group $P-1$, $Z = 1$, was refined to an R_1 index of 7.5% unique reflections measured with MoK X-radiation on a Bruker P4 diffractometer equipped with a Smart 4K CCD detector (Uvarova *et al.*, 2008). There are fifteen tetrahedrally coordinated T sites, twelve of them are occupied solely by Si, with a grand $\langle Si-O \rangle$ of 1.613\AA , and three other tetrahedrally coordinated sites that are occupied solely by Li, with a grand $\langle Li-O \rangle$ of distance 1.928\AA . There are six octahedrally coordinated sites. Two of them are occupied by Ti and four of them are occupied by Ca with minor Na and Sr. The $D(1)$ site is occupied by $Ti_{2.00}$ with $\langle D(1)-O \rangle = 1.937\text{\AA}$, and the $D(2)$ site is occupied by $Ti_{2.00}$ with $\langle D(2)-O \rangle = 1.934\text{\AA}$. The $M(1)$ site is occupied solely by $Ca_{2.00}$ with $\langle M(1)-O \rangle = 2.441\text{\AA}$. The $M(2)$ site is occupied by $(Ca_{1.87}Sr_{0.13})$, with $\langle M(2)-O \rangle = 2.424\text{\AA}$. The $M(3)$ site is occupied by $(Ca_{1.55}Na_{0.37}Sr_{0.04}Ba_{0.04})$, with $\langle M(3)-O \rangle = 2.415\text{\AA}$. The $M(4)$ site is occupied by $(Ca_{0.74}Na_{0.26})$, with $\langle M(4)-O \rangle = 2.418\text{\AA}$. There are two interstitial A sites: the $A(1)$ site is

$[12]$ -coordinated and is occupied by $(K_{1.98}Rb_{0.03})$ with $\langle A(1)-O \rangle = 3.092\text{\AA}$; the $A(2)$ site is $[9]$ -coordinated and is occupied by $(Na_{0.90}K_{0.10})$ with $\langle A(2)-O \rangle = 2.718\text{\AA}$.

In the structure of faizievite, Si tetrahedra share common vertices and form $[6]$ -membered rings. Some of the rings are single, $[Si_6O_{18}]$, and some of them are double, $[Si_{12}O_{30}]$. Both types of $[6]$ -membered rings share common vertices with $[LiO_4]$ tetrahedra and $[TiO_6]$ octahedra (Fig. 4a) and form heteropolyhedral sheets perpendicular to the c axis. $M(1,2,3,4)$ octahedra share common vertices and form octahedral sheets perpendicular to the c axis (Fig. 4b). Heteropolyhedral sheets of $[SiO_4]$, $[LiO_4]$ tetrahedra and $[TiO_6]$ octahedra alternate with octahedral sheets of $M(1,2,3,4)$ octahedra (Fig. 2). $[6]$ -membered double- and single rings occlude interstices. K atoms are located in these interstices (Figs. 4a,c). Na atoms are located in between double $[6]$ -membered rings (Fig. 4c)

The faizievite structure (Uvarova *et al.*, 2008) includes an interleaving of sheets of baratovite, $KLi_3Ca_7Ti_2[Si_6O_{18}](OH,F)$ (Sandorskii *et al.*, 1976, Menchetti, Sabelli 1979) and berezan-

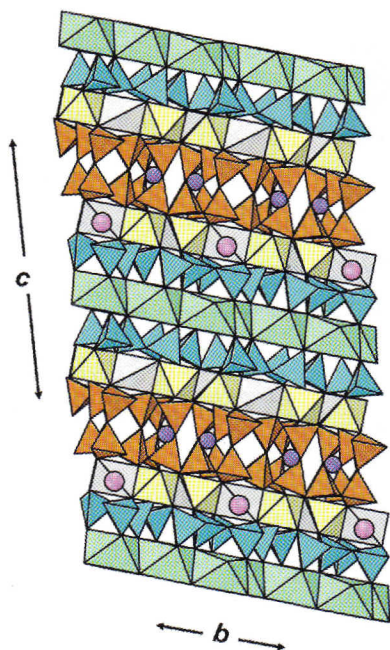


Fig. 5. The crystal structure of faizievite projected onto (011): $[SiO_4]$ tetrahedra constituting milarite and beryl rings are orange and blue, $[LiO_4]$ tetrahedra are grey, $[TiO_6]$ octahedra are honey yellow; $M(1,2,3,4)$ octahedra are green, $A(1)$ ($=Na$) and $A(2)$ ($=K$) atoms are shown as purple and pink circles

Table 3. Comparative characteristic of faizievite, baratovite and berezanskite

	faizievite	baratovite	berezanskite
Chemical formula	$K_2Na(Ca_5Na)Ti_4Li_6Si_{24}O_{66}F_7$	$KCa_7(Ti,Zr)_2Li_3Si_{12}O_{30}F_2$	$KLi_3Ti_2Si_{12}O_{30}$
Space group	Triclinic	Monoclinic	Hexagonal
	<i>P</i> -1	<i>C</i> 2/ <i>c</i> or <i>C</i> <i>c</i>	<i>P</i> 6/ <i>mcc</i>
<i>a</i> , Å	9.8156(9)	16.941(3)	9.903 (1)
<i>b</i> , Å	9.8249(9)	9.746(2)	14.276(2)
<i>c</i> , Å	17.3087(16)	20.907(3)	
α , °	99.209(2)		
β , °	94.670(2)	112.5(1)	
γ , °	119.839(1)		
<i>V</i> , Å ³	1403.7(4)	3189.1	1212.4(4)
<i>Z</i>	1	4	2
Strong lines in X-ray diffraction pattern d_{meas} (Å)			
	5.60 (9)	4.18(3)	7.15(40)
	4.25 (60)	3.54(4)	5.81(12)
	3.35 (100)	3.22(100)	4.29(50)
	3.14(20)	3.02(5)	4.07(85)
	3.06(90)	2.41(20)	3.57(80)
	2.885(55)	1.92(17)	3.16(100)
	2.870(10)	1.83(3)	2.952(50)
	1.868(17)		2.895(95)
			2.742(30)
Density, g/cm ³ (meas.)			
	2.83	2.89	2.66
	Biaxial(+)	Biaxial(+)	Monoaxial(-)
n_p	1.651	1.672	1.630
n_m	1.655	1.672	
n_g	1.657	1.673	1.635
Angle $2V$, °	-72	+60	

skite, $KLi_3Ti_2[Si_{12}O_{30}]$. It is remarkable that all three minerals, faizievite, baratovite (Dusmatov *et al.* 1975) and berezanskite (Pautov, Agakhanov, 1997), were described first from the Darai-Pioz alkaline massif. The characteristics of these minerals are compared in Table 3.

The holotype sample of faizievite is kept at the Fersman Mineralogical Museum of the Russian Academy of Science (Moscow).

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