

FLUORAPOPHYLLITE-(Cs), CsCa₄(Si₈O₂₀)F(H₂O)₈, A NEW APOPHYLLITE-GROUP MINERAL FROM THE DARAI-PIOZ MASSIF, TIEN-SHAN, NORTHERN TAJIKISTAN

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ABSTRACT

Fluorapophyllite-(Cs) (IMA 2018-108a), ideally CsCa₄(Si₈O₂₀)F(H₂O)₈, is an apophyllite-group mineral from the moraine of the Darai-Pioz glacier, Tien-Shan, Northern Tajikistan. Associated minerals are quartz, pectolite, baratovite, agerine, leucosphenite, pyrochlore, neptunite, fluorapophyllite-(K), and reedmergnerite. Fluorapophyllite-(Cs) is a hydrothermal mineral. It is colorless and has a vitreous luster and a white streak. Cleavage is perfect; it is brittle and has a stepped fracture. Mohs hardness is 4.5–5. $D_{\text{meas.}} = 2.54(2) \text{ g/cm}^3$, $D_{\text{calc.}} = 2.513 \text{ g/cm}^3$. Fluorapophyllite-(Cs) is uniaxial (+) with refractive indices ($\lambda = 589 \text{ nm}$) $\omega = 1.540(2)$, $\varepsilon = 1.544(2)$. It is non-pleochroic. Chemical analysis by electron microprobe gave SiO₂ 48.78, Al₂O₃ 0.05, CaO 22.69, Cs₂O 10.71, K₂O 1.13, Na₂O 0.04, F 1.86, H₂O_{calc.} 14.61, $-\text{O}=\text{F}_2 -0.78$, sum 99.09 wt.%; H₂O was calculated from crystal-structure analysis. The empirical formula based on 29 (O + F) *apfu*, H₂O = 8 *pfu*, is (Cs_{0.75}K_{0.24})_{Σ0.99}(Ca_{3.99}Na_{0.01})_{Σ4}(Si_{8.01}Al_{0.01})_{Σ8.02}O_{20.03}F_{0.97}(H₂O)₈, $Z = 2$. The simplified formula is (Cs,K)(Ca,Na)₄(Si,Al)₈O₂₀F(H₂O)₈. Fluorapophyllite-(Cs) is tetragonal, space group *P4/mnc*, a 9.060(6), c 15.741(11) Å, V 1292.10(19) Å³. The crystal structure has been refined to $R_1 = 4.31\%$ based on 498 unique ($F_o > 4\sigma F$) reflections. In the crystal structure of fluorapophyllite-(Cs), there is one ^[4]*T* site occupied solely by Si, $\langle \text{T-O} \rangle = 1.615 \text{ Å}$. SiO₄ tetrahedra link to form a (Si₈O₂₀)⁸⁻ sheet perpendicular to [001]. Between the Si–O sheets, there are two cation sites: *A* and *B*. The *A* site is coordinated by eight H₂O groups [O(4) site], $\text{A-O}(4) = 3.152(4) \text{ Å}$; the *A* site contains Cs_{0.75}K_{0.24}□_{0.01}, ideally Cs *apfu*. The Cs–O bond length of 3.152 Å is definitely larger than the K–O bond length of 2.966–2.971 Å in fluorapophyllite-(K), KCa₄(Si₈O₂₀)F(H₂O)₈. The ^{[7]B} site contains Ca_{3.99}Na_{0.01}, ideally Ca₄ *apfu*; $\langle \text{B-}\phi \rangle = 2.417 \text{ Å}$ ($\phi = \text{O, F, H}_2\text{O}$). The Si–O sheets connect via *A* and *B* polyhedra and hydrogen bonding; two H atoms have been included in the refinement. Fluorapophyllite-(Cs) is isostructural with fluorapophyllite-(K). Fluorapophyllite-(Cs) is a Cs-analogue of fluorapophyllite-(K).

Keywords: fluorapophyllite-(Cs), new mineral, apophyllite group, Darai-Pioz, Tien-Shan, Northern Tajikistan, electron microprobe analysis, crystal structure.

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INTRODUCTION

Fluorapophyllite-(Cs), ideally $\text{CsCa}_4(\text{Si}_8\text{O}_{20})\text{F}(\text{H}_2\text{O})_8$, is a new mineral of the apophyllite group (Dunn & Wilson 1978, Hatert *et al.* 2013) from the moraine of the Darai-Pioz glacier, Tien-Shan, Northern Tajikistan. This locality is well-known for Cs-bearing minerals. Fluorapophyllite-(Cs) is named in accord with the current nomenclature of the apophyllite-group minerals (Hatert *et al.* 2013). The new mineral species and its name were approved by the Commission on New Minerals, Nomenclature and Classification, International Mineralogical Association (IMA 2018–108a). The holotype specimen of fluorapophyllite-(Cs) has been deposited in the collections of the Fersman Mineralogical Museum, Russian Academy of Sciences, Moscow, Russia, registration number 5280/1. Here we report the description and crystal structure of fluorapophyllite-(Cs), a new mineral.

OCCURRENCE AND MINERAL ASSOCIATION

Fluorapophyllite-(Cs) was found in the moraine of the Darai-Pioz glacier (39° 30' N and 70° 40' E), the Alai mountain range, Tien-Shan, Rashtskii district, north Tajikistan. The multiphase Darai-Pioz massif belongs to the Upper Paleozoic Alaisky (Matchaisky) intrusive complex. The area of outcrop of the massif is about 16 km². Most of the massif rocks are covered by moraine or glaciers and/or are difficult to access. In the north, the massif intrudes Silurian limestones and slates; in the south, it intrudes terrigenous slates of Late Carboniferous age. The outer zone of the massif

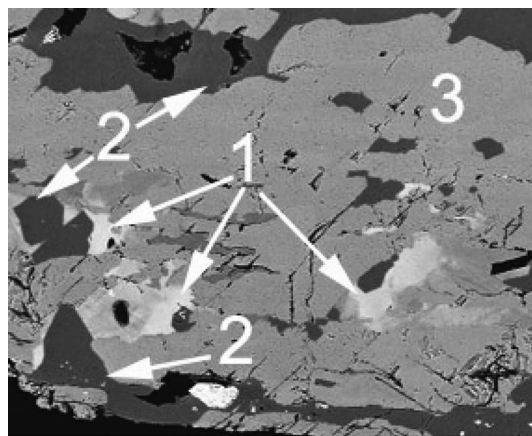


FIG. 1. Backscattered electron image of fluorapophyllite-(Cs) (1) in quartz (2) - pectolite (3) aggregate.

TABLE 1. CHEMICAL COMPOSITION AND UNIT FORMULA* FOR FLUORAPOPHYLLITE-(CS)

Constituent	wt.%	Range		<i>apfu</i>
SiO ₂	48.78	48.25–49.08	Si	8.01
Al ₂ O ₃	0.05	0.00–0.12	Al	0.01
CaO	22.69	22.32–22.83	Ca	3.99
Cs ₂ O	10.71	9.67–11.81	Cs	0.75
K ₂ O	1.13	0.72–1.46	K	0.24
Na ₂ O	0.04	0.00–0.09	Na	0.01
H ₂ O	14.61**			
F	1.86	1.65–2.18	F	0.97
F = O	–0.78		H ₂ O	8.00
Total	99.09			

* Formula unit calculated on 29 (O + F) *pfu*; ** calculated from crystal-structure analysis: H₂O = 8 *pfu*.

consists of subalkaline biotite granite, often tourmalinized (300–290 Ma), surrounding a discontinuous ring of biotite granites and granosyenites. The central part of the massif comprises quartz and aegirine syenites. In the northeast part of the massif, there is a stock of cancrinite and nepheline foyaite (247 ± 6 Ma). There are veins of syenite pegmatites and aegirine-potassium feldspar-quartz rocks containing polythionite (286 ± 7 Ma) and rare-metal and boron mineralization. Veins of calcite carbonatites and syenite carbonatites (Faiziev *et al.* 2010) are widespread. Much of the rock is fenitized to different degrees. Detailed descriptions of the petrography and mineralogy of the Darai-Pioz massif can be found in Moskvina (1937), Dusmatov (1968, 1971), Semenov & Dusmatov (1975), Belakovskiy (1991), and Reguir *et al.* (1999).

This locality is known for Cs-bearing minerals. Kupletskite-(Cs) was the first Cs-bearing mineral described from Darai-Pioz (Yefimov *et al.* 1971, Cámara *et al.* 2010). In the last five years, five Cs-bearing minerals have been described from Darai-Pioz: odigitriaite, $\text{CsNa}_5\text{Ca}_5[\text{Si}_{14}\text{B}_2\text{O}_{38}]\text{F}_2$ (IMA 2015-028, Agakhanov *et al.* 2017a); mendelevite-(Nd), $(\text{Cs}, \square)_6(\square, \text{Cs})_6(\square, \text{K})_6(\text{REE}, \text{Ca})_{30}(\text{Si}_{70}\text{O}_{175})(\text{OH}, \text{H}_2\text{O}, \text{F})_{35}$ (IMA 2015-031, Agakhanov *et al.* 2017b); two Cs-micas: garmite, $\text{CsLiMg}_2(\text{Si}_4\text{O}_{10})\text{F}_2$ (IMA 2017-008, Pautov *et al.* 2017) and gorbunovite, $\text{CsLi}_2(\text{Ti}, \text{Fe})(\text{Si}_4\text{O}_{10})(\text{F}, \text{OH}, \text{O})_2$ (IMA 2017-040, Agakhanov *et al.* 2017c); and fluorapophyllite-(Cs), $\text{CsCa}_4(\text{Si}_8\text{O}_{20})\text{F}(\text{H}_2\text{O})_8$ (IMA 2018-108a, this work).

Fluorapophyllite-(Cs) is a hydrothermal mineral. It was found in a quartz-pectolite aggregate in quartzolite boulders. Associated minerals are quartz, pectolite, baratovite, aegirine, leucosphenite, pyrochlore, nephtunite, fluorapophyllite-(K), and reedmergerite.

TABLE 2. X-RAY POWDER DIFFRACTION DATA* FOR FLUORAPOPHYLLITE-(Cs)

<i>l</i> _{est.}	<i>d</i> _{calc.} (Å)	<i>h</i>	<i>k</i>	<i>l</i>	<i>l</i> _{est.}	<i>d</i> _{calc.} (Å)	<i>h</i>	<i>k</i>	<i>l</i>
100	7.8705	0	0	2		2.0259	4	2	0
	7.8522	1	0	1	14	1.9662	2	1	7
10	6.4064	1	1	0		1.9639	3	2	5
38	4.5405	1	0	3		1.9619	4	2	2
	4.5300	2	0	0	6	1.9185	4	1	4
100	3.9352	0	0	4	25	1.8012	4	2	4
	3.9261	2	0	2		1.8001	5	0	1
	3.9239	2	1	1		1.8001	4	3	1
55	3.6024	2	1	2	25	1.7700	2	1	8
28	3.3532	1	1	4		1.7689	3	1	7
24	3.2069	2	1	3		1.7658	4	3	2
	3.2032	2	2	0	13	1.7173	1	0	9
84	2.9738	1	0	5		1.7144	4	0	6
	2.9669	2	2	2		1.7127	5	0	3
	2.9659	3	0	1		1.7127	4	3	3
12	2.8650	3	1	0	10	1.6766	2	2	8
11	2.8229	2	1	4		1.6729	5	2	1
	2.8187	3	1	1	15	1.6220	3	1	8
37	2.6922	3	1	2		1.6194	5	1	4
73	2.5146	3	1	3	20	1.6058	2	1	9
71	2.4860	2	1	5		1.6035	4	2	6
	2.4842	2	2	4		1.6021	5	2	3
19	2.4278	1	1	6		1.6016	4	4	0
25	2.1825	1	0	7	13	1.5741	0	0	10
	2.1794	3	0	5		1.5704	5	0	5
	2.1767	4	0	2	16	1.5538	5	3	0
42	2.1189	3	1	5		1.5492	3	2	8
	2.1179	3	2	4		1.5470	5	2	4
14	2.0609	3	3	2	7	1.5135	3	0	9
45	2.0296	2	2	6		1.5100	6	0	0

* Powder data were obtained by collapsing experimental single-crystal data into two dimensions. The most intense reflection (101) was covered by the beam stop. Therefore, intensity of (101) was calculated from the refined crystal structure and all intensities rescaled accordingly. Reflections with *l*_{est} < 5 are not listed.

APPEARANCE AND PHYSICAL PROPERTIES

In the quartz-pectolite aggregate, fluorapophyllite-(Cs) occurs as separate grains up to 0.08 mm across (Fig. 1) and as zones in grains of fluorapophyllite-(K) [grains of fluorapophyllite-(K) are up to 0.2 mm across]. Individual grains of fluorapophyllite-(Cs) are irregular in shape.

Fluorapophyllite-(Cs) is colorless and has a vitreous luster and a white streak. Cleavage is perfect; it is brittle and has a stepped fracture. The microhardness of fluorapophyllite-(Cs) is VHN₁₀₀ = 480 kg/mm² (with the range of 468–502), which corresponds to a Mohs hardness of 4.5–5. *D*_{meas.} = 2.54(2) g/cm³ as determined by flotation in Clerici liquid; *D*_{calc.} = 2.513

TABLE 3. MISCELLANEOUS REFINEMENT DATA FOR FLUORAPOPHYLLITE-(Cs)

<i>a</i> (Å)	9.060(6)
<i>c</i>	15.741(11)
<i>V</i> (Å ³)	1292.10(19)
Space group	<i>P4/mnc</i>
<i>Z</i>	2
Reflections (<i>I</i> > 10σ <i>I</i>)	5962
Absorption coefficient (mm ⁻¹)	2.41
<i>F</i> (000)	973.9
<i>D</i> _{calc.} (g/cm ³)	2.513
Crystal size (mm)	0.045 × 0.040 × 0.030
Radiation/monochromator	MoKα/graphite
2θ-range for data collection (°)	60.00, 47.95*
<i>h</i> *	-10 ≤ <i>h</i> ≤ 10
<i>k</i> *	-10 ≤ <i>k</i> ≤ 10
<i>l</i> *	-18 ≤ <i>l</i> ≤ 18
<i>R</i> (int)	0.0564*
Reflections collected	10527*
Independent reflections	539*
<i>F</i> _o > 4σ <i>F</i>	498*
Refinement method	Full-matrix least squares on <i>F</i> ² , fixed weights proportional to 1/σ <i>F</i> _o ²
Final <i>R</i> (obs)	
<i>R</i> ₁ (<i>F</i> _o > 4σ <i>F</i>)	0.0431
<i>R</i> ₁	0.0487
<i>wR</i> ₂	0.0851
Highest peak, deepest hole (e Å ⁻³)	0.42, -0.52
Goodness of fit on <i>F</i> ²	1.276

* Structure refinement (see text).

g/cm³ (from the empirical formula). Fluorapophyllite-(Cs) is uniaxial (+) with refractive indices (λ = 589 nm) ω = 1.540(2), ε = 1.544(2). It is non-pleochroic. The compatibility index (1 - K_p/K_c) = -0.002 (for *D*_{calc.}) and 0.010 (for *D*_{meas.}) and is rated as superior (Mandarino 1981).

CHEMICAL COMPOSITION

A grain of fluorapophyllite-(Cs) was analyzed with a JEOL 773 electron microprobe operating in wavelength-dispersive mode with an accelerating voltage of 20 kV, a specimen current of 20 nA, and a beam diameter of 3 μm. The following standards were used: Si, Al, K: microcline USNM 143966; Na: omphacite USNM 110607; Ca: anorthite USNM 110607; Cs: Cs₂Nb₄O₁₁; F: fluorophlogopite. The data were reduced and corrected by the PAP method of Pouchou & Pichoir (1985). Table 1 gives the chemical composition of fluorapophyllite-(Cs), (mean of 10 points). The empirical formula based on 29 (O + F)

TABLE 4. ATOM COORDINATES AND ANISOTROPIC DISPLACEMENT PARAMETERS (\AA^2) FOR FLUORAPOPHYLLITE-(Cs)

Atom	x	y	z	U^{11}	U^{22}	U^{33}	U^{23}	U^{13}	U^{12}	U^{21}
A	0	0	1/2	0.0196(6)	0.01960(6)	0.0814(13)	0	0	0	0.0402(6)
B	0.10274(14)	0.24597(14)	0	0.0059(7)	0.0071(7)	0.0063(7)	0	0	0.0013(5)	0.0064(4)
Si	0.22099(13)	0.09073(13)	0.19063(7)	0.0053(7)	0.0046(7)	0.0061(7)	-0.0011(5)	-0.0016(5)	-0.0001(5)	0.0053(4)
O(1)	0.3567(3)	0.1433(3)	1/2	0.0071(14)	0.0071(14)	0.009(2)	0.0010(14)	0.0010(14)	0.0011(18)	0.0078(10)
O(2)	0.0790(3)	0.1897(3)	0.2190(2)	0.0103(18)	0.0109(17)	0.0145(18)	-0.0002(14)	0.0010(14)	0.0023(13)	0.0119(8)
O(3)	0.2578(4)	0.1068(4)	0.09251(19)	0.0101(17)	0.0128(18)	0.0081(16)	-0.0027(14)	-0.0007(13)	0.0006(13)	0.0103(8)
O(4)	0.1940(5)	0.4493(4)	0.0907(2)	0.040(2)	0.0115(19)	0.0136(18)	-0.0029(15)	-0.0023(17)	0.0010(17)	0.0217(9)
F	0	0	0	0.007(2)	0.007(2)	0.028(5)	0	0	0	0.0142(18)
H(1)	0.219(5)	0.427(5)	0.1498(10)							0.02601(0)
H(2)	0.153(5)	0.549(2)	0.085(3)							0.02601(0)

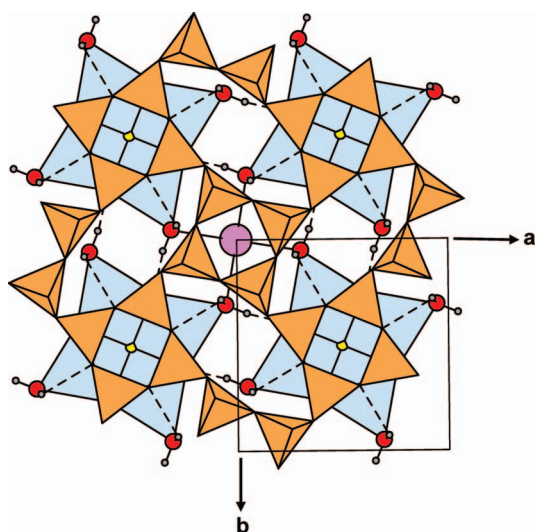


Fig. 2. General view of the crystal structure of fluorapophyllite-(Cs). SiO_4 tetrahedra and Ca-dominant polyhedra are orange and pale blue; the Cs atom (A site) is shown as a large pink sphere; the F atom is shown as a small yellow sphere; the O atom of the H_2O group at the O(4) site is shown as a medium red sphere; and H atoms are shown as small gray spheres. Bonds O(4)-H and H-acceptor are shown as black solid and dashed lines, respectively. Thin black lines show the unit cell.

apfu ($\text{H}_2\text{O} = 8 \text{ pfu}$) was calculated from crystal-structure refinement) is $(\text{Cs}_{0.75}\text{K}_{0.24})_{\Sigma 0.99}(\text{Ca}_{3.99}\text{Na}_{0.01})_{\Sigma 4}(\text{Si}_{8.01}\text{Al}_{0.01})_{\Sigma 8.02}\text{O}_{20.03}\text{F}_{0.97}(\text{H}_2\text{O})_8$, $Z = 2$. The simplified formula is $(\text{Cs},\text{K})(\text{Ca},\text{Na})_4(\text{Si},\text{Al})_8\text{O}_{20}\text{F}(\text{H}_2\text{O})_8$. The ideal formula is $\text{CsCa}_4\text{Si}_8\text{O}_{20}\text{F}(\text{H}_2\text{O})_8$, which requires SiO_2 48.03, CaO 22.41, Cs_2O 14.07, H_2O 14.40, F 1.90, $-\text{O}=\text{F}_2$ -0.80, total 100 wt.%.

TABLE 5. SELECTED INTERATOMIC DISTANCES (\AA) AND ANGLES ($^\circ$) FOR FLUORAPOPHYLLITE-(Cs)

A-O(4) _a × 8	3.152(4)	T-O(3)	1.587(3)
B-O(3) × 2	2.384(4)	T-O(1)	1.616(2)
B-O(3) _c × 2	2.395(3)	T-O(2) _b	1.626(3)
B-F	2.415(2)	T-O(2)	1.631(3)
B-O(4) × 2	2.473(4)	<T-O>	1.615
<B-φ>	2.417		
		T-O(1)-Tc	141.5(3)
		T-O(2)-Tc	140.1(2)
		<T-O-T>	140.8

* φ = O, F, H_2O . Symmetry operators: a: $-x + 1/2, y - 1/2, -z + 1/2$; b: $y, -x, z$; c: $-y, x, z$.

TABLE 6. REFINED SITE-SCATTERING VALUES AND ASSIGNED SITE-POPULATIONS FOR FLUORAPOPHYLLITE-(Cs)

Site*	Refined site-scattering (epfu)	Site population (apfu)	Calculated site-scattering (epfu)	<Ct-φ> _{obs.} (Å)*	Ideal composition (apfu)
Cations					
[8]A	45.0(3)	Cs _{0.75} K _{0.24} □ _{0.01}	45.81	3.152	Cs
[7]B	80.0	Ca _{3.99} Na _{0.01}	79.91	2.417	Ca ₄
[4]T	112.0	Si _{8.00}	112.00	1.615	Si ₈
Anions and H ₂ O groups					
[2,2,4]O(1,2,3)		O ₂₀			O ₂₀
[4]F		F _{0.97} □ _{0.03}			F
O(4)		(H ₂ O) ₈			(H ₂ O) ₈

* Ct = cation, φ = O, F, H₂O.

TABLE 7. HYDROGEN BONDING IN FLUORAPOPHYLLITE-(Cs)

D-H...A	D-H (Å)	H...A (Å)	D...A (Å)	∠DHA (°)	∠HDH (°)
O(4)-H(1)...O(2)a	0.98(1)	2.23(1)	3.186(5)	167(4)	111(4)
O(4)-H(1)...O(3)b	0.98(1)	1.81(1)	2.769(5)	167(4)	

a: $x - 1/2, -y + 1/2, z + 1/2$; b: $y, -x + 1, z$.

DATA COLLECTION AND STRUCTURE REFINEMENT

Single-crystal X-ray data for fluorapophyllite-(Cs) were collected with a Bruker D8 QUEST ECO CMOS diffractometer equipped with a fine-focus tube (MoK α) and a PHOTON 50 detector. The crystal does not diffract very well and that is why we cut the data at $2\Theta = 47.95^\circ$ (collected up to $2\Theta = 60.00^\circ$). X-ray powder diffraction data were obtained by collapsing the experimental single-crystal data into two dimensions (Table 2). Unit-cell parameters from the single-crystal data were determined by least-squares refinement of 5962 reflections with $I > 10\sigma I$ and are given in Table 3, together with miscellaneous information on data collection and structure refinement. For fluorapophyllite-(Cs), the intensities of 10,527 reflections were measured using 60 s per 0.5° frame. An absorption correction was done using the SADABS program (Sheldrick 2015). All calculations were done with the Bruker SHELXTL-2014/3 (version 3) system of programs (Sheldrick 2015).

The crystal structure of fluorapophyllite-(Cs) was refined using the atom coordinates of fluorapophyllite-

(K) (Stahl *et al.* 1987) as a starting model. The crystal structure of fluorapophyllite-(Cs) was refined to $R_1 = 4.31\%$ based on 498 unique reflections with ($F_o > 4\sigma F$). Scattering curves for neutral atoms were taken from the International Tables for Crystallography (Wilson 1992). Site-scattering values were refined for the A and B sites with the scattering curves of Cs and Ca, respectively. For the final refinement, the D(donor)-H(1,2) distances were softly constrained to 0.98 Å.

Final atom coordinates and anisotropic displacement parameters are listed in Table 4, selected interatomic distances and Si-O-Si angles are given in Table 5, refined site-scattering and assigned site-populations for selected cation and anion sites are given in Table 6, details of hydrogen bonding are given in Table 7, and bond-valence values in Table 8. A Crystallography Information File (CIF) may be obtained from The Depository of Unpublished Data on the MAC website [documents Fluorapophyllite-(Cs) CM57, 19-00038]¹.

¹ <http://mineralogicalassociation.ca>

TABLE 8. BOND-VALENCE VALUES* FOR FLUORAPOPHYLLITE-(Cs)

Atom**	A	B	T	H(1)	H(2)	Σ
O(1)			1.02 ^{x2} →			2.04
O(2)			0.99	0.09		2.06
			0.98			
O(3)		0.30 ^{x2} ↓ 0.29 ^{x2} ↓	1.10		0.19	1.88
O(4)	0.14 ^{x8} ↓	0.25 ^{x2} ↓		0.91	0.81	2.11
F		0.23 ^{x4} →				0.92
Σ	1.10	1.91	4.09	1.00	1.00	

* Bond-valence parameters (νu) are from Brown (1981), except Brown & Altermatt (1985) for H-O; ** A = Cs; B = Ca; T = Si; O(4) = O atom of an H₂O group.

STRUCTURE DESCRIPTION

In the crystal structure of fluorapophyllite-(Cs), there is one *T* site occupied solely by Si and tetrahedrally coordinated by O atoms, $\langle T-O \rangle = 1.615$ Å. SiO₄ tetrahedra link to form a (Si₈O₂₀)⁸⁻ sheet perpendicular to [001]; in a sheet, SiO₄ tetrahedra form 4- and 8-membered rings (Fig. 2). Between the Si-O sheets, there are two cation sites: *A* and *B*. The Cs-dominant *A* site is coordinated by eight H₂O groups [O(4) site], with A-O(4) = 3.152(4) Å (Table 5); the *A* site contains Cs_{0.75}K_{0.24}□_{0.01}, ideally Cs₁ *apfu* (Table 6). The Cs-O bond length of 3.152 Å is definitely larger than the K-O bond length of 2.966–

2.971 Å in fluorapophyllite-(K) (Table 9). The Ca-dominant [7]*B* site contains Ca_{3.99}Na_{0.01}, ideally Ca₄ *apfu*; the *B* site is coordinated by four O atoms, two H₂O groups, and one F atom, with $\langle B-\varphi \rangle = 2.417$ Å ($\varphi = O, F, H_2O$) (Tables 5 and 6). The Si-O sheets connect *via* *A* and *B* polyhedra and hydrogen bonding (Fig. 2). The geometry of hydrogen bonding is in accord with the geometry of hydrogen bonding in fluorapophyllite-(K) (Chao 1971, Ståhl *et al.* 1987).

We write the ideal formula of fluorapophyllite-(Cs) as the sum of cation and anion sites (Table 6), CsCa₄(Si₈O₂₀)F(H₂O)₈, *Z* = 2. Fluorapophyllite-(Cs) is isostructural with fluorapophyllite-(K) and is a Cs-analogue of fluorapophyllite-(K) (Table 9).

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TABLE 9. COMPARISON OF F-MEMBERS OF THE APOPHYLLITE GROUP

Mineral	Fluorapophyllite-(Cs)	Fluorapophyllite-(K)		Fluorapophyllite-(Na)
Endmember formula, <i>Z</i> = 2	CsCa ₄ (Si ₈ O ₂₀)F(H ₂ O) ₈	KCa ₄ (Si ₈ O ₂₀)F(H ₂ O) ₈		NaCa ₄ (Si ₈ O ₂₀)F(H ₂ O) ₈
Crystal system	Tetragonal	Tetragonal		Orthorhombic
Space group	<i>P4/mnc</i>	<i>P4/mnc</i>		<i>Pnm</i>
<i>a</i> (Å)	9.060	8.965*	8.970**	8.875
<i>b</i>	9.060	8.965*	8.970**	8.881
<i>c</i>	15.741	15.767*	15.792**	15.79
<i>V</i> (Å ³)	1292.1	1267.2*	1270.6**	1236.9
<i>A</i> -site dominant cation	Cs	K	K	Na
A-H ₂ O (Å)	3.152 × 8	2.971* × 8	2.966** × 8	2.763 × 4; 2.854 × 4
Optical data	Uniaxial (+) $\omega = 1.540$ $\epsilon = 1.544$	Uniaxial (+) $\omega = 1.530-1.536$ $\epsilon = 1.532-1.538$		Biaxial (-) $\alpha = 1.536$ $\beta = 1.538$ $\gamma = 1.544$
<i>D</i> _{meas.} (g cm ⁻³)	2.54	2.33–2.37		2.50
<i>D</i> _{calc.} (g cm ⁻³)	2.513	2.37		2.30
References	This work	* Chao (1971) ** Ståhl <i>et al.</i> (1987) Anthony <i>et al.</i> (1995)		Matsueda <i>et al.</i> (1981)

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