

Gorbunovite $\text{CsLi}_2(\text{Ti}, \text{Fe}^{+3})(\text{Si}_4\text{O}_{10})(\text{F}, \text{OH}, \text{O})_2$ – a new mica supergroup mineral from the Darai-Pioz alkaline massif, Tajikistan

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Abstract

Gorbunovite, $\text{CsLi}_2(\text{Ti}, \text{Fe}^{+3})(\text{Si}_4\text{O}_{10})(\text{F}, \text{OH}, \text{O})_2$, a new **cesium** trioctahedral mica, was discovered in the Darai-Pioz alkaline massif (Tajikistan). The mineral is named after the Russian chemist, leader of the Tajik-Pamir Expedition Academician Nikolai Petrovich Gorbunov (1892–1938). Gorbunovite occurs as lamellar grains or flakes from 2 μm to 0.2 mm in a quartz-pectolite aggregate and is associated with quartz, fluorite, pectolite, baratovite, aegirine, leucosphenite, neptunite, reedmergnerite, orlovite, sokolovaite, mendeleevite-(Ce), odigitriaite, pekovite, zeravshanite, kirchhoffite and garmite. The mineral is colourless, transparent, with vitreous luster. Mohs hardness is 2½. $D_{\text{meas.}}$ is 3.28 (2), D_{calc} is 3.302 g/cm³. Gorbunovite is optically biaxial, negative, $\alpha = 1.609$ (2), $\beta = 1.621$ (2), $\gamma = 1.623$ (2), $2V_{\text{meas.}}$ 30(5), $2V_{\text{calc.}}$ 44. Gorbunovite is monoclinic, space group $C2/m$, $C2$ or Cm (polytype 1M), $a = 5.236(2)$, $b = 9.054(4)$, $c = 10.767(4)$ Å, $\beta = 99.61(4)^\circ$, $V = 503.3(6)$ Å³ and $Z = 2$. The strongest lines in the powder X-ray diffraction pattern [d , Å, (I)] are: 4.49 (25), 3.94 (20), 3.69 (46), 3.57 (23), 3.45(34), 2.991 (42), 2.608(77), 2.581 (100), 2.240 (33), 2.188 (62), 2.020 (24), 1.722 (27), 1.511(23). Chemical composition (microprobe analysis; H₂O, Li₂O SIMS): SiO₂ 47.44, TiO₂ 9.40, Al₂O₃ 0.66, MgO 0.63, **Fe₂O₃** 3.64, ZnO 1.01, K₂O 0.39, Cs₂O 26.64, Li₂O 5.83, H₂O 0.89, F 4.48, –O=F 1.89, total **99.17**. The empirical formula is $(\text{Cs}_{0.96}\text{K}_{0.04})_{\Sigma 1.00}\text{Li}_{1.98}(\text{Ti}_{0.60}\text{Fe}^{+3}_{0.23}\text{Mg}_{0.08}\text{Al}_{0.07}\text{Zn}_{0.06})_{\Sigma 1.04}\text{Si}_{4.00}\text{O}_{10}(\text{F}_{1.19}\text{OH}_{0.50}\text{O}_{0.31})_{\Sigma 2}$

Keywords: gorbunovite, orlovite, kreiterite, sokolovaite, new mineral, trioctahedral mica, Darai-Pioz alkaline massif, Tien Shan, Tajikistan, electron-microprobe analysis, cesium.

Introduction

The new mineral gorbunovite, $\text{CsLi}_2(\text{Ti}, \text{Fe}^{+3})(\text{Si}_4\text{O}_{10})\text{F}_2$, belonging to the trioctahedral-mica subgroup, was found in the alkaline rocks of the Darai-Pioz massif [the Rasht (formerly Garm) district, Central Tajikistan]. It is named after the Russian chemist, academician Nikolai Petrovich Gorbunov (Николай Петрович Горбунов) (1892-1938), head of the Tajik-Pamir expedition, this first expedition that geologically surveyed a many remote areas of Central Asia, including the Darai-Pioz massif. Gorbunovite (Russian Cyrillic: горбуновит) is a titanium analogue of sokolovaite $\text{CsLi}_2\text{Al}(\text{Si}_4\text{O}_{10})\text{F}_2$, garmite $\text{CsLiMg}_2(\text{Si}_4\text{O}_{10})\text{F}_2$ and kreiterite $\text{CsLi}_2\text{Fe}^{+3}(\text{Si}_4\text{O}_{10})\text{F}_2$ and a cesium analogue of orlovite $\text{KLi}_2\text{Ti}(\text{Si}_4\text{O}_{10})(\text{OF})_2$. Gorbunovite was approved as a new mineral species by the IMA Commission on New Minerals, Nomenclature and Classification, IMA No. 2017-040. The holotype sample of gorbunovite is deposited in the systematic collection of the Fersman Mineralogical Museum of the Russian Academy of Sciences (Moscow) with catalogue no. 94187. The approved mineral symbol for gorbunovite is Gbv (Warr, 2021).

Occurrence and associated minerals

Gorbunovite was found in rock samples of the Upper Darai-Pioz alkaline massif (N 39°27'; E 70°43'), located on the southern slope of the Alai Range in the joint area of three sub-latitudinal ranges: the Turkestan, Alai and Zeravshan Ranges. The Darai-Pioz massif itself is difficult to access due to the mountainous terrain, and the majority of mineralogical investigations have been done on material collected from the deposits of glacial moraine associated with the massif.

The first data on the Darai-Pioz massif were obtained by the Tajik-Pamir Expedition in headed by N.P. Gorbunov, in 1932-1936 (Moskvina, 1937). Under the leadership of Yu.A. Arapov the Alai and Turkestan ranges, including the Darai-Pioz massif, were prospected for rare metals during 1946-1947. The most complete work on the massif was done in the 1960s - 1990s by V.D. Dusmatov, as a result of which a 1:10000 scale geological map was compiled. Extensive data on petrography and rock geochemistry were obtained, and in collaboration with E.I. Semenov, A.F. Efimov and A.P. Khomyakov, a unique mineralization of lithium, boron, zirconium and rare-earth elements was revealed. Many publications are devoted to the

mineralogy of the Darai-Pioz massif (Dusmatov, 1968; 1970; 1971; 1993; Semenov, Dusmatov, 1975; Ganzeev et al., 1976; Belakovskiy, 1991; Grew et al., 1993; Vladykin et al., 1995; Vladykin, Dusmatov, 1996; Pautov et al., 1996; Pautov, Agakhanov, 1997; Reguir et al., 1999; Agakhanov et al., 2011, etc.). One of the most interesting features of the Darai-Pioz massif is the variety of **cesium** minerals (Agakhanov, 2010). To date, 13 distinct caesium minerals have been discovered in the rocks of the massif, **cesium** kupletskite (Efimov et al., 1971) later renamed kupletskite-(Cs) $\text{Cs}_2\text{NaMn}^{2+}_7\text{Ti}_2(\text{Si}_4\text{O}_{12})_2\text{O}_2(\text{OH})\text{F}$ (Bayliss, 2007), telushenkoite $\text{CsNa}_6[\text{Be}_2(\text{Si},\text{Al},\text{Zn})_{18}\text{O}_{39}]\text{F}_2$ (Agakhanov et al., 2003), zeravshanite $\text{Na}_2\text{Cs}_4\text{Zr}_3[\text{Si}_{18}\text{O}_{45}]\cdot 2\text{H}_2\text{O}$ (Pautov et al., 2004), senkevichite $\text{CsKNaCa}_2\text{TiO}[\text{Si}_7\text{O}_{18}](\text{OH})$ (Agakhanov et al., 2005), sokolovaite $\text{CsLi}_2\text{Al}(\text{Si}_4\text{O}_{10})\text{F}_2$ (Pautov et al., 2006), kirchhoffite, CsBSi_2O_6 , (Agakhanov et al., 2012), mendeleevite-(Ce) $\text{Cs}_6[\text{Ce}_{22}\text{Ca}_6](\text{Si}_{70}\text{O}_{175})(\text{OH},\text{F})_{14}(\text{H}_2\text{O})_{21}$ (Pautov et al., 2013), odigitriite $\text{CsNa}_5\text{Ca}_5[\text{Si}_{14}\text{B}_2\text{O}_{38}]\text{F}_2$ (Agakhanov et al., 2016), mendeleevite-(Nd) $\text{Cs}_6[\text{Nd}_{23}\text{Ca}_7](\text{Si}_{70}\text{O}_{175})(\text{OH},\text{F})_{19}(\text{H}_2\text{O})_{16}$ (Agakhanov et al., 2017), fluorapophyllite-(Cs) $\text{CsCa}_4(\text{Si}_8\text{O}_{20})\text{F}\cdot 8\text{H}_2\text{O}$ (Agakhanov et al., 2019a), kreiterite $\text{CsLi}_2\text{Fe}^{3+}\text{Si}_4\text{O}_{10}\text{F}_2$ (Agakhanov et al., 2019b), garmite $\text{CsLiMg}_2(\text{Si}_4\text{O}_{10})\text{F}_2$ (Pautov et al., 2022a) and gorbunovite $\text{CsLi}_2(\text{Ti},\text{Fe})\text{Si}_4\text{O}_{10}(\text{F},\text{OH},\text{O})_2$ described here.

Gorbunovite was found in non-rounded or slightly rounded boulders (up to 2 m in size) of a rock composed mainly of granular quartz, which were described in detail by Pautov et al. (2004; 2022b and references therein). Unfortunately, neither we nor previous geologists have found it in bedrock outcrop. Moreover, no contacts of these quartz boulders with any other rock has been ever observed, which makes it even more difficult to establish their origin. **For this reason, we will call them simply "quartz lumps," as has already been done in many publications on Darai-Pioz mineralogy.**

Gorbunovite occurs in polymineralic quartz-pectolite aggregates from 1 to 15 cm in the largest dimension, sometimes embedded in "quartz lumps." They are composed of brown or greyish-brown fine- to medium-grained polymineralic aggregates, consisting of Mn-bearing pectolite (up to 3.5 wt% MnO), quartz, Sr-rich fluorite (up to 21 wt% SrO), aegirine (with chemical composition close to the end-member), polyolithionite, datolite and a range of rare minerals. Within these pectolite aggregates, the distribution of gorbunovite is extremely uneven. Most commonly, gorbunovite is confined to the boundaries of aegirine with quartz or, sporadically, pectolite. Small gorbunovite individuals form ingrowths in aegirine crystals (Fig. 1). In general, this mica is very rare: it is found only in a few samples.

Gorbunovite forms lamellar grains from 2 μm to 0.1 mm, rarely up to 0.2 mm in the largest dimension. The thickness of its grains varies from fractions of a micron to 20 μm . Fan-

shaped intergrowths of lamellar crystals are common. For the most part, the grains of gorbunovite are deformed.

Physical properties

Grains of gorbunovite are colorless, in aggregates the mineral is white, and visually is indistinguishable from other micas of the association. Luster is vitreous, the streak is white. Cleavage is perfect on {001}, lamellae are flexible. Mohs hardness $2\frac{1}{2}$; the average micro-indentation hardness VHN is 87 kgf/mm^2 (with a range from 82 to 111 kgf/mm^2 from 10 measurements), measured using a PMT-3 instrument at a loading of 20 g, calibrated on NaCl. The density of the mineral was determined by floatation of the grains in Clerici solution. The measured density, D_{meas} is $3.28 (2) \text{ g/cm}^3$, and the calculated one D_{calc} is 3.302 g/cm^3 . Gorbunovite fluoresces pale yellow in shortwave ultraviolet light. Gorbunovite is optically negative, biaxial. The $2V$ angle measured on a Fedorov stage is $= -30(5)^\circ$, $2V_{\text{calc.}} = -44^\circ$. The small size of the mineral individuals, low birefringence and deformation of the grains did not allow better measurement. The optical axes plane is almost perpendicular to the cleavage plane {001}. The mineral is colourless in transmitted light. Pleochroism is not observed. Gorbunovite is biaxial (–) with $\alpha = 1.609(2)$, $\beta = 1.621(2)$, $\gamma = 1.623(2)$. Measurements were done at $\lambda = 589 \text{ nm}$ using a rotating needle. Dispersion is weak, $r > v$.

Chemical composition

The chemical composition of gorbunovite was analysed using a JCXA-733 JEOL electron-microprobe analyser in the laboratory of the Fersman Mineralogical Museum and a Cameca IMS-4F ion-mass spectrometer at the Institute of Microelectronics and Information Mathematics of the Russian Academy of Sciences (Yaroslavl', Russia) (SIMS). All elements except fluorine, lithium and hydrogen were determined using an Si(Li) energy-dispersive detector and the INCA Energy 350 analysis system of Oxford Instruments. The analyses were done at 20 kV accelerating voltage, 2 nA probe current, 5 μm probe diameter; 100 sec of spectrum set time (excluding dead time). Fluorine concentration was measured using a wave-dispersion spectrometer with an LDE1 crystal analyzer at 10 kV accelerating voltage, 30 nA probe current and a 10 μm defocused electron beam.

Hydrogen and lithium in gorbunovite were determined using SIMS according to the methods reported by Smirnov et al. (1995). A primary $^{16}\text{O}^{2-}$ ion beam focused to a 10–15 μm diameter spot was used. The current intensity of the bombardment ions was 3–8 nA. Element

concentrations were calculated from *element*/³⁰Si⁺ ion currencies intensity ratio, using calibration constants obtained on reference samples.

For a more correct estimation of the lithium content in gorbunovite, an internal laboratory reference sample of polyolithionite from the Darai-Pioz alkaline massif with a known Li content, was used. Both the standard sample and gorbunovite were placed in a same polished section and were analyzed under the same conditions and this made it possible to correct the obtained lithium data.

The valence of iron in gorbunovite was not determined. Yet, it was determined in kreiterite CsLi₂Fe³⁺Si₄O₁₀(F,OH)₂ (which is Fe analogue of gorbunovite) by measuring of oxygen directly using WDS –EPMA. Although the relative error in oxygen determination was too large, it was shown unambiguously that iron is present as Fe³⁺ in kreiterite. It was not possible to find out the valence of iron in gorbunovite by the same method of oxygen measuring, since there is 4 times less iron than in kreiterite. It seems probable that there is an isomorphic series between kreiterite and gorbunovite, and that the valence of Fe (in full or partly) in gorbunovite is the same as in kreiterite.

Chemical composition of gorbunovite is given in Table 1.

Table 1. Chemical composition for gorbunovite (wt%).

Constituent	Average on 10 analyses	Range	S.D.	Reference samples
SiO ₂	47.44	46.49 – 47.98	0.21	microcline USNM 143966
TiO ₂	9.40	7.84 – 10.07	0.49	ilmenite USNM 96189
Al ₂ O ₃	0.66	0.29 – 0.92	0.61	microcline USNM 143966
Fe ₂ O ₃	3.68	3.32 – 4.02	0.25	ilmenite USNM 96189
MgO	0.63	0.25 – 1.11	0.29	diopside USNM 11773
ZnO	1.01	0.55 – 1.59	0.32	ZnS
K ₂ O	0.39	0.17 – 0.83	0.19	microcline USNM 143966
Cs ₂ O	26.64	26.03 – 27.06	0.33	CsTbP ₄ O ₁₂
Li ₂ O*	5.83	6.11 – 5.42	0.29	polyolithionite
H ₂ O*	0.89	1.22 – 0.45	0.30	
F	4.49	3.98 – 4.62	0.25	MgF ₂
-O=F	-1.89			
Total	99.17			

* SIMS analysis data.

The empirical formula of gorbunovite, calculated on the basis of 12 (O + F + OH), is:

$(\text{Cs}_{0.95}\text{K}_{0.04})_{\Sigma 0.99}\text{Li}_{1.96}(\text{Ti}_{0.59}\text{Fe}^{+3}_{0.23}\text{Mg}_{0.08}\text{Al}_{0.06}\text{Zn}_{0.06})_{\Sigma 1.02}\text{Si}_{3.96}\text{O}_{10}(\text{F}_{1.19}\text{OH}_{0.50}\text{O}_{0.31})_{\Sigma 2}$ and the simplified formula is $\text{CsLi}(\text{Ti},\text{Fe}^{+3})(\text{Si}_4\text{O}_{10})(\text{F},\text{OH},\text{O})_2$. The Gladstone-Dale compatibility index value (for $D_{\text{meas.}} = 3.28 \text{ g/cm}^3$) is $(1-\text{Kp/Kc}) = 0.073$ (fair) (Mandarino, 1981). Probably the value of the compatibility index is strongly influenced by the variable **degree of distortion** of Ti-O polyhedra in different minerals. For example, such a problem exists when calculating the compatibility index for layered titanosilicates of the lamprophyllite group, as well as in orlovite, titanium member of mica group, in which $(1-\text{Kp/Kc})$ is even larger (Agakhanov et al., 2011).

X-ray diffraction data

Single-crystal X-ray diffraction studies were done using a Bruker APEX II DUO diffractometer equipped with a CCD detector (MoK α radiation) at 50 kV and 0.6 mA. The following parameters of the monoclinic unit cell (space group **C2/m, C2 or Cm**) corresponding to the *1M* polytype were obtained: $a = 5.25$ (15), $b = 9.1$ (1), $c = 10.7$ (7) Å, $\beta = 99$ (3)°, $V = 505$ (3) Å³ and $Z = 2$. Single-crystal X-ray diffraction showed gorbunovite to be a *1M* polytype. The low quality of all tested crystals is due to deformation and splitting prevented single-crystal structure refinement and the paucity of material prevented the Rietveld refinement.

The powder X-ray diffraction pattern of gorbunovite was obtained using a Rigaku R-Axis Rapid II single-crystal diffractometer equipped with a cylindrical detector using Debye-Scherrer geometry ($d = 127.4 \text{ mm}$) at CoK α radiation. The results of calculation of the powder X-ray diffraction pattern are shown in Table 2. The unit-cell parameters, refined on the basis of powder data, are as follows: $a = 5.236$ (2), $b = 9.054$ (4), $c = 10.767$ (4) Å, $\beta = 99.61$ (4)° and $V = 503.3$ (6) Å³.

Raman spectroscopy

Raman spectra were obtained from a polished section of a randomly oriented crystal of gorbunovite, and from cleavage plates of chemically characterized orlovite and polyolithionite (Fig. 2). Spectra were obtained at room temperature using a Thermo DXR2xi Raman imaging confocal microscope in the range 3400 cm^{-1} to 50 cm^{-1} with 2 cm^{-1} resolution, a $25 \text{ }\mu\text{m}$ aperture, and a grating of 400 lines/mm. The excitation source was a laser with a wavelength of 785 nm, and the output power of the laser beam was 30 mW (excitation with 532 nm laser beam caused intensive sample fluorescence). The backscattered Raman signal was collected with a 100x objective; the signal acquisition time for a single scan was from 0.25 to 2 s and the signal was averaged from 5 to 30 scans. The spectra were processed using OMNIC software.

Figure 2 shows the Raman spectrum of gorbunovite, polyolithionite and orlovite. Bands from 1150 to 800 cm^{-1} , similar to other layered silicates, generally are stretching modes of the SiO_4 tetrahedra (McKeown *et al.*, 1999; Wang *et al.*, 2007). The intense band at 878 cm^{-1} is possibly diagnostic for this group of trioctahedral mica. Another intense line at 712 cm^{-1} is common in sheet silicates and corresponds to both Si-O stretching and O-Si-O bending deformations (Wang *et al.*, 2015).

Raman lines below 600 cm^{-1} correspond to deformations of octahedra and interlayer complexes (Tlili *et al.*, 1989; Wang *et al.*, 2015). Note that the 388 cm^{-1} band is also present in orlovite, possibly associated deformations of the TiO_6 octahedra as this band is absent in polyolithionite and other Ti-free trioctahedral Li-micas. Differences in the intensities of the Raman bands in the range 80-200 cm^{-1} for gorbunovite, compared to those of orlovite and polyolithionite, may be the result of different orientation: the spectra for polyolithionite and orlovite were collected on cleavage planes whereas the spectrum of gorbunovite was collected on a randomly oriented grain.

Discussion

The formation of such unusual and rare trioctahedral micas as sokolovaite, orlovite, garmitite, kreiterite and gorbunovite is directly connected to the genesis of both the quartz-pectolite aggregate itself and the significantly quartz rocks or "quartz lumps" in which it was found. It can be assumed that the "quartz lumps" of Darai-Pioz are fragments of quartz cores of specific peralkaline and supersaturated with silica highly agpaitic pegmatites. Unfortunately, we have not yet found any pegmatites with quartz cores at the Darai-Pioz, which would be completely similar to "quartz lumps," and therefore it is unclear whether such pegmatites exist at all. We are most inclined that the formation of "quartz lumps" occurred from a water-silicate liquid (WSL) that arose during the interaction of an alkaline fluid, **derived from carbonatites**, which caused extensive fenitization of the Darai-Pioz massif rocks, with quartz-containing rocks of the massif, which are granites and their pegmatites.

The mechanism of the formation of "quartz lumps", as well as the formation of quartz-pectolite aggregates in them, is discussed in details in the work of L.A. Pautov *et al.* (2022b). Several ways of the formation of pectolite aggregates with cesium mineralization can be assumed: (1) the separation of an aqueous silicate liquid into two liquids, one of which, significantly enriched in Na, Ca and F, just gave rise to pectolite aggregates; (2) formation of pectolite aggregates from extruding residues from crystallization of the quartz aggregate; (3) contamination of carbonate melt clumps with WSL.

The origin of cesium minerals, including gorbunovite, is associated with the ability of WSL to "extract" Cs and Li from a coexisting fluid (Smirnov, 2015; Smirnov et al., 2017). A very high Si/Al ratio and the presence of Li promotes the crystallization of trioctahedral mica which contributes to the crystallization of both K- and Cs-dominant tetra-silicate micas), the species diversity of which depends on the amount of cations in the surrounding fluid.

The following heterovalent isomorphism schemes maintain electroneutrality where the octahedral sheets are occupied by tri- and tetra-valent ions we assume:



Gorbunovite is a cesium analogue of orlovite $\text{KLi}_2\text{TiSi}_4\text{O}_{11}\text{F}$ (Agakhanov et al., 2011; Sokolova et al., 2018) and a titanium analogue of as many as three Cs-Li-micas, including sokolovaite $\text{CsLi}_2\text{AlSi}_4\text{O}_{10}\text{F}_2$ (Pautov et al., 2006), garmite $\text{CsLiMg}_2\text{Si}_4\text{O}_{10}\text{F}_2$ (Pautov et al., 2022a) and kreiterite $\text{CsLi}_2\text{Fe}^{3+}\text{Si}_4\text{O}_{10}(\text{F, OH})_2$ (IMA2019-041).

A comparison of gorbunovite with related minerals is given in Table 3. As can be seen from the table, all cesium micas are expectedly characterized by a significantly larger unit cell dimensions compared to that of potassium analogues. This is due to the significantly larger ionic radius of the $^{12}\text{Cs} = 2.011 \text{ \AA}$ interlayer cation compared to $^{12}\text{K} = 1.729 \text{ \AA}$ (Hawthorne, Gagné, 2024). For the same reason, there are no significant isomorphic series between cesium and potassium mica in nature. The unit-cell dimensions of gorbunovite are close to those of kreiterite as their ionic radii are reasonably similar ($^{6}\text{Ti}^{4+} = 0.605 \text{ \AA}$ and $^{6}\text{Fe}^{3+} = 0.649 \text{ \AA}$). This is probably due to the fact gorbunovite includes Fe^{3+} as a secondary component (3.3-4.0 wt% Fe_2O_3), and, on the other hand, Ti is a minor component in kreiterite (0.6 – 1.6 wt.% TiO_2). Whether there is a continuous series between gorbunovite and kreiterite can only be shown by new findings and further study of these, so far rare, minerals.

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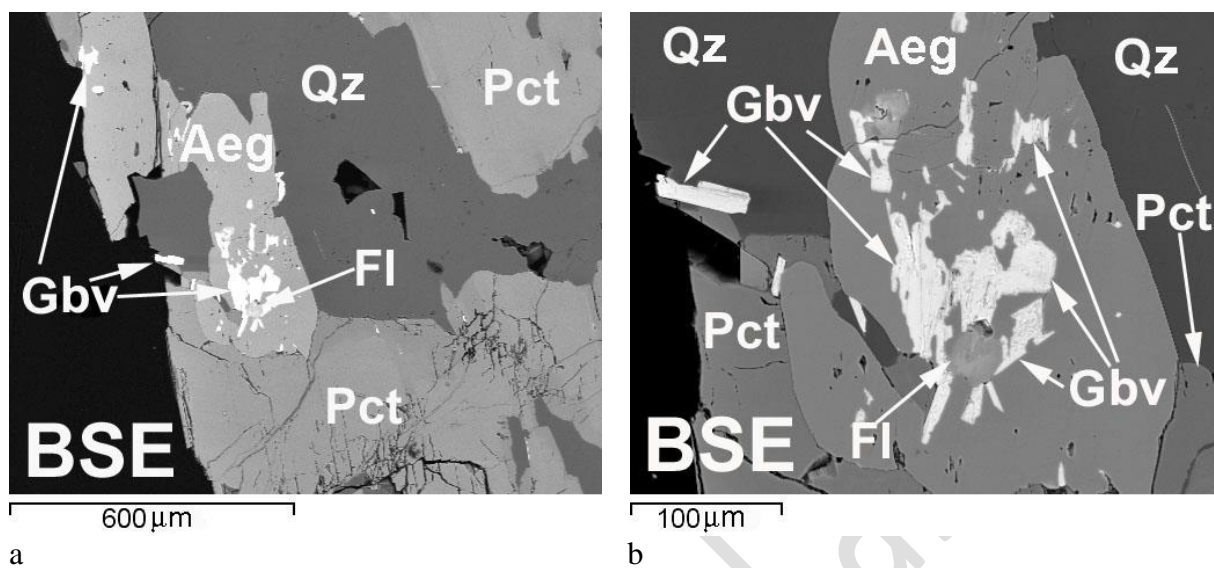
Table 2. Powder X-ray powder diffraction data for gorbunovite.

<i>I</i>	$d_{\text{meas.}}(\text{\AA})$	$d_{\text{calc.}}(\text{\AA})$	<i>hkl</i>
8	10.63	10.616	0 0 1
6	5.32	5.308	0 0 2
25	4.49	4.485	1 1 0
6	4.36	4.364	-1 1 1
10	4.17	4.164	0 2 1
20	3.94	3.932	1 1 1
46	3.69	3.700	-1 1 2
23	3.57	3.539	0 0 3
34	3.45	3.444	0 2 2
12	3.21	3.204	1 1 2
42	2.991	2.997	-1 1 3
6	2.789	2.788	0 2 3
15	2.656	2.654	0 0 4
77	2.608	2.605	1 3 0
100	2.581	2.581	2 0 0
			-1 3 1
8	2.491	2.491	-2 0 2
14	2.419	2.421	-1 3 2
33	2.240	2.242	2 2 0
62	2.188	2.188	-1 3 3
17	2.124	2.123	0 0 5
24	2.020	2.018	1 3 3
11	1.786	1.784	1 3 4
27	1.722	1.722	0 4 4
		1.718	-1 3 5
12	1.589	1.588	-2 0 6
23	1.511	1.511	-3 3 1
10	1.308	1.308	-4 0 1
9	1.273	1.273	0 2 8
6	1.228	1.229	3 3 4
		1.228	3 1 5

Table 3. Comparative data for gorbunovite, orlovite and trioctahedral caesium micas.

Mineral	Gorbunovite	Orlovite	Garmite	Sokolovaite	Kreiterite
Formula	CsLi ₂ (Ti,Fe ⁺³) Si ₄ O ₁₀ (F,OH,O) ₂	KLi ₂ Ti Si ₄ O ₁₀ (OF) ₂	CsLiMg ₂ (Si ₄ O ₁₀)F ₂	CsLi ₂ Al (Si ₄ O ₁₀)F ₂	CsLi ₂ Fe ³⁺ Si ₄ O ₁₀ (F,OH) ₂
Space group	<i>C2/m</i> , <i>C2</i> or <i>Cm</i>	<i>C2/m</i>	<i>C2/m</i> , <i>C2</i> or <i>Cm</i>	<i>C2/m</i> , <i>C2</i> or <i>Cm</i>	<i>C2/m</i> , <i>C2</i> or <i>Cm</i>
<i>a</i> , Å	5.236	5.198	5.234	5.189	5.240
<i>b</i> , Å	9.054	9.046	9.042	9.005	9.054
<i>c</i> , Å	10.767	10.093	10.780	10.692	10.761
β, °	99.61	99.53	99.73	99.82	99.58
<i>V</i> , Å ³	503.3(6)	468.1(1.1)	502.8(6)	491.6(7)	503.4(6)
<i>Z</i>	2	2	2	2	2
Polytype	1 <i>M</i>	1 <i>M</i>	1 <i>M</i>	1 <i>M</i>	1 <i>M</i>
Strongest X-Ray powder lines, <i>d</i> , Å(<i>I</i>)	4.49(25) 3.94(20) 3.69(46) 3.57 (23) 3.45(34) 2.991(42) 2.608(77) 2.581(100) 2.240(33) 2.188(62) 2.020(24) 1.722(27) 1.511(23)	9.92(40) 4.48(67) 3.87(40) 3.33(100) 2.86 (35) 2.60(28) 2.57(30) 2.50(16) 2.40(31) 2.136(16) 1.993(16) 1.654(17) 1.507(20)	4.48(35) 3.94(27) 3.70(70) 3.45(44) 3.20(20) 3.00(28) 2.658(24) 2.608(70) 2.580(100) 2.241(45) 2.187(80) 2.126(25) 1.721(20) 1.510(27)	4.15(28) 3.897(49) 3.682(80) 3.418(65) 3.174(100) 2.980(41) 2.767(32) 2.634(79) 2.582(66) 2.249(24) 2.107(94) 2.001(22)	4.49(31) 3.94(31) 3.70(70) 3.53(22) 3.45(36) 3.00(34) 2.610(72) 2.583(100) 2.241(38) 2.190(67) 2.122(21) 2.722(24) 2.512(25)
<i>D</i> , g/cm ³ (meas- ured/calcul ated)	3.28/3.302	2.91/2.914	3.34/3.336	3.25/3.23	3.33/3.351
Optical properties	Biaxial (-)	Biaxial (-)	Biaxial (-)	Biaxial (-)	Biaxial (-)
α	1.609	1.600	1.582	1.554	1.596
β	1.621	1.620	1.601	1.566	1.605
γ	1.623	1.625	1.602	1.567	1.607
Source	This work	Agakhanov et al., 2011 Sokolova et al., 2018	Pautov et al., 2022a	Pautov et al., 2006	Agakhanov et al., 2019 (IMA2019- 041)

Figure 1



SEM (BSE) image) general view of lamellar aggregations of gorbunovite (Gbv) in aegirine (Aeg) with fluorite (Fl) from the quartz (Qz) - pectolite (Pct) aggregate; **b)** enlarged area

Figure 2

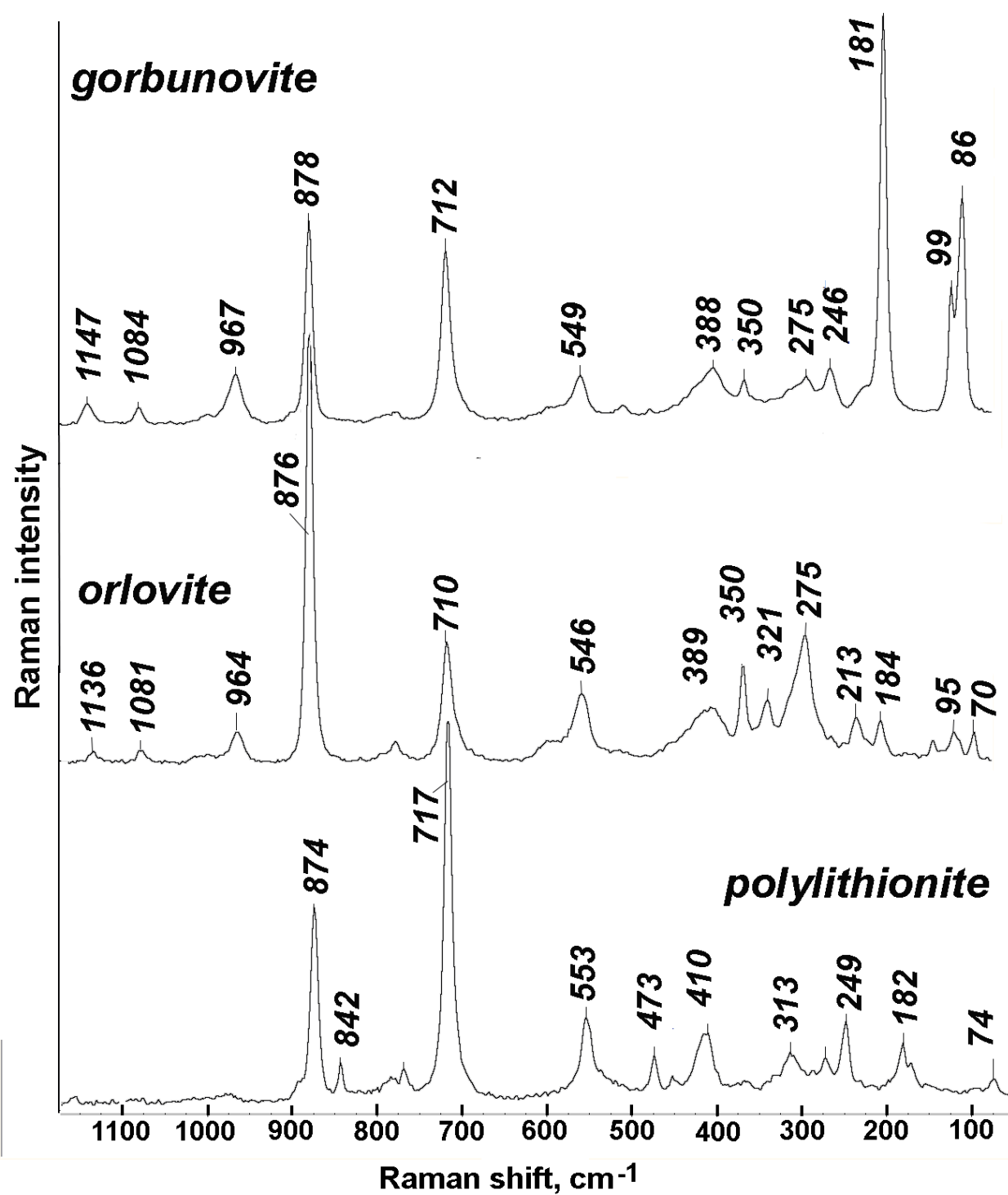


Fig. 2. Raman spectra of gorbunovite, orlovite and polyolithionite.

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