

GEOCHEMISTRY

Mendelevite-(Ce)

$(\text{Cs}, \square)_6(\square, \text{Cs})_6(\square, \text{K})_6(\text{REE}, \text{Ca}, \square)_{30}(\text{Si}_{70}\text{O}_{175})(\text{H}_2\text{O}, \text{OH}, \text{F}, \square)_{35}$: A New Mineral from the Darai-Pioz Massif, Tajikistan

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A new cesium–rare earth silicate, the composition of which may be expressed by the formula $(\text{Cs}, \square)_6(\square, \text{Cs})_6(\square, \text{K})_6(\text{REE}, \text{Ca}, \square)_{30}(\text{Si}_{70}\text{O}_{175})(\text{H}_2\text{O}, \text{OH}, \text{F}, \square)_{35}$ was discovered in rocks of the Darai-Pioz massif. The new mineral was named mendelevite-(Ce) in memory of the famous Russian physicist Dmitrii Ivanovich Mendeleev, the author of periodic table of chemical elements, a scientist of the very broad field of interest, who had a significant influence on the development of natural sciences and industry. This mineral was approved as a new mineral species by the Commission on New Minerals, Nomenclature, and Classification of Minerals, IMA on March 6, 2010 (IMA No. 2009-092). The standard sample was placed in the Fersman Mineralogical Museum, Russian Academy of Sciences, Moscow (registration no. 3921/1).

The Darai-Pioz massif, in which the new mineral was discovered, is located at the junction between the Alai, Zeravshan, and Turkestan ridges in the upper reaches of the Darai-Pioz River (left tributary of the Yarkhych River, basin of the Surkhob River). The central part of massif is cut from the north to the south by a glacier valley and is overlain by glacier and moraine deposits; it is difficult to reach most of the indigenous rock outcrops of the massif. In plan the intrusion has almost a ring structure. The outer zone of the massif is composed of medium-granular two-mica granite C₃; the intermediate zone is represented by fine- and medium-granular biotite granite C₃–P₁; the central and eastern parts of the massif are composed of aegirine syenite. There is a small stock (2 km²) of cancrinite foyaite. All rocks of the massif are cut by dykes of fine-

grained biotite and tourmaline granite T₁–T₂. Alkaline pegmatites, fenites, and carbonatites with rich rare-metal mineralization are widely abundant in the massif [1]. We should specially note that more than half of the total cesium compounds were found in the Darai-Pioz alkaline massif; most of them were discovered in rocks of this massif [2].

Mendelevite-(Ce) was found in a polymineral aggregate composed of brownish-gray fine–medium-

Table 1. Chemical composition (wt %) of mendelevite-(Ce)

Component	Average	Concentration range	Standard
SiO ₂	43.52	43.08–44.05	Microcline USNM 143966
Ce ₂ O ₃	19.24	18.56–19.92	CePO ₄
La ₂ O ₃	9.87	9.24–10.75	LaPO ₄
Nd ₂ O ₃	5.62	5.34–5.91	NdPO ₄
Pr ₂ O ₃	2.63	1.98–3.15	PrPO ₄
Sm ₂ O ₃	0.58	0.29–0.69	SmPO ₄
Gd ₂ O ₃	0.38	0.29–0.44	GdPO ₄
CaO	2.71	2.43–2.84	Anorthite USNM 137041
SrO	1.07	0.89–1.21	SrTiO ₃
Cs ₂ O	8.64	8.21–8.95	CsHo[PO ₃] ₄
K ₂ O	1.08	0.39–1.40	Microcline USNM 143966
F	1.34		Synthetic fluorapatite
H ₂ O*	4.31		
–O=F ₂	–0.56		
Total	100.43		

Note: Analyses were performed by the electron microprobe method (analyst A.A. Agakhanov). * H₂O concentration is calculated by the structural data.

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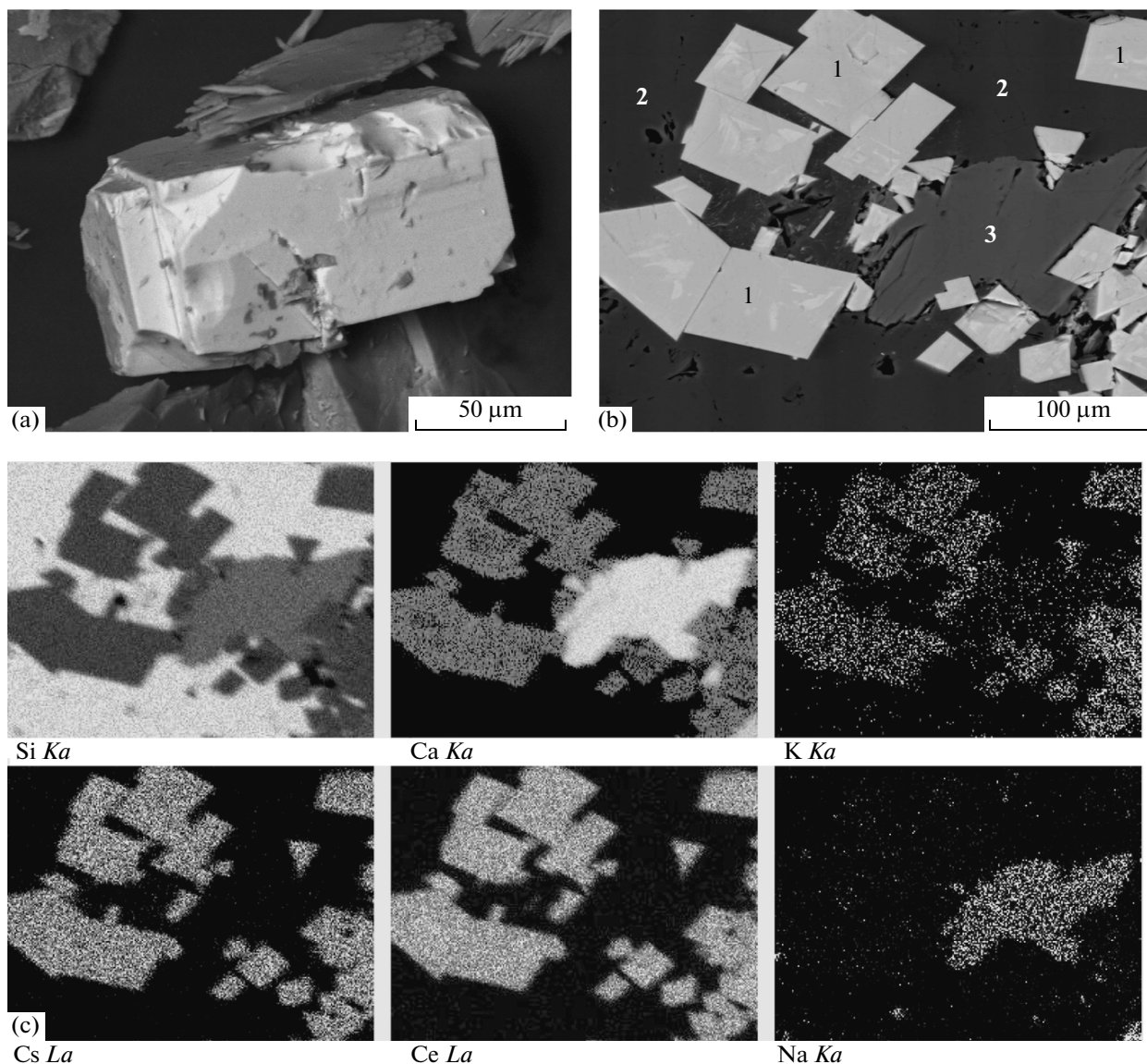


Fig. 1. Mendelevite-(Ce): (a) secondary electron image of crystal extracted from rock (damaged edges demonstrate conchoidal fracture); (b) COMPO image of mendelevite-(Ce) crystals (1) in quartz (2) with pectolite (3); (c) X-ray map of element distribution.

granular pectolite with subordinate amounts of quartz, aegirine, and fluorite forming nest-like segregations (5–30 cm in diameter) in quartz-rich rock with sogdianite, stillwellite-(Ce), reedmergnerite, leucosphenite, aegirine, polyolithionite, microcline, pyrochlore, and turkestanite. In addition to the above-mentioned minerals, mendelevite-(Ce) associates with hyalotecite, sokolovaite, kirchhoffite, pekovite, neptunite, and zeravshanite.

Mendelevite-(Ce) forms individual well-formed cubic crystals with a size of 10–30 μm (Fig. 1) and their intergrowths. Relatively large (up to 100 μm) segregations of the new mineral in association with zeravshanite and late light-green aegirine are rare.

Mendelevite-(Ce) is usually colorless, but sometimes has a clear tea color. Streak is white; lustre is vitreous; mineral is fragile with conchoidal fracture. Cleavage was not observed. The hardness is 5–5.5 on the Mohs' scale. The microhardness (average from 10 measurements) is VHN 613 in the range of VHN 508–655. Microhardness was measured on a PMT-3 instrument at a loading of 50 g graduated by NaCl. The density of minerals was determined by grain balancing in the solution of Clerici liquid. The measured density is 3.12(2) g/cm³; the calculated density is 3.07 g/cm³. The mineral is isotropic with a refractive index of $n = 1.578(2)$. The compatibility index of the composition and properties (for measured density) $(1 - K_p/K_c) = -0.038$ (excellent).

Table 2. Results of calculation of X-ray powder diffraction pattern of mendeleevite-(Ce)

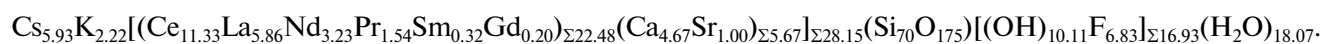
I	$d_{\text{meas}}, \text{\AA}$	$d_{\text{calcd}}, \text{\AA}$	hkl	I	$d_{\text{meas}}, \text{\AA}$	$d_{\text{calcd}}, \text{\AA}$	hkl
3	15.53	15.51	0 1 1	1	2.550	2.547	3 1 8, 5 0 7, 0 5 7
3	12.62	12.64	1 1 1	1	2.484	2.482	2 5 7, 5 2 7
10	10.95	10.96	0 0 2	1	2.432	2.434	0 0 9
3	7.76	7.748	0 2 2	1	2.374	2.375	2 0 9, 0 2 9
1	6.94	6.926	1 0 3	1	2.365	2.367	5 5 6
1	6.61	6.605	1 1 3	3	2.323	2.323	2 2 9, 6 2 7, 5 0 8
1	4.87	4.902	0 2 4	1	2.259	2.262	3 6 7
2	4.23	4.218	1 1 5	3h	2.190	2.190	0 0 10, 6 0 8
3	4.08	4.068	2 3 4, 2 0 5, 2 3 4	1	2.126	2.127	0 5 9, 5 0 9
3	3.88	3.872	0 0 4	2	2.089	2.090	3 1 10, 5 2 9, 5 6 7
1	3.75	3.757	3 3 4	2	2.027	2.028	4 1 10, 7 2 8, 2 7 8
1	3.65	3.650	2 4 4, 0 0 6	1	1.957	1.959	2 0 11
3	3.56	3.556	1 1 6, 3 2 5, 2 3 5	1	1.923	1.924	7 0 9, 0 7 9
4	3.46	3.463	2 0 6, 0 2 6	1	1.893	1.893	7 2 9, 5 3 10
2	3.341	3.342	3 3 5	1	1.820	1.821	3 6 10
1	3.304	3.305	2 2 6	1	1.793	1.795	0 7 10, 7 0 10
1	3.271	3.271	0 3 6, 3 0 6	2	1.723	1.725	5 6 10, 6 5 10, 4 8 9
5h	3.097	3.099	3 4 5, 4 3 5, 0 5 5	2	1.681	1.681	5 1 12, 1 5 12, 5 8 9, 8 5 9
4h	3.068	3.072	1 5 5	1	1.641	1.642	5 3 12, 3 5 12
2	2.983	2.982	1 2 7, 2 1 7, 3 3 6, 2 5 5	1	1.609	1.610	4 5 12
3	2.863	2.854	1 3 7, 3 5 5	1	1.547	1.549	8 6 10, 0 2 14, 0 10 10
1	2.809	2.805	3 4 6, 4 3 6	1	1.542	1.542	9 0 11, 7 3 12
2	2.714	2.716	5 2 6, 4 0 7		1.528	1.530	5 6 12
2	2.700	2.698	1 4 7, 4 1 7	1	1.185	1.186	4 6 17, 6 4 17

Note: RKU-114, Fe anode, Mn filter, URS-50IM, analyst A.A. Agakhanov.

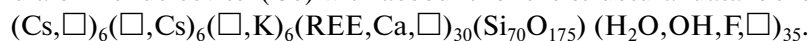
The infrared spectrum of mendeleevite-(Ce) is poorly resolved and in the area of stretching and bending vibrations of silica–oxygen anion has absorption bands at 1013, 978, 693, and 548 cm^{-1} , as well as characteristic absorption bands of molecular water: 3400 (stretching vibrations) and 1610 (bending vibrations) cm^{-1} .

The chemical composition of the new mineral was studied using Link energy-dispersive spectrometers at an accelerating voltage of 20 kV, beam current of 2 nA, and beam diameter of 2 μm on an electron microprobe JXA-50A and CamScan 4D scanning electron

microscope. The concentration of fluorine was analyzed on a wavelength spectrometer with the TAP analyzing crystal at an accelerating voltage of 15 kV, beam current of 25 nA, and beam diameter of 10 μm . Due to the small amount of material, the concentration of H₂O was not measured by the direct method. It was calculated on the basis of the structural data. Carbonate-, nitrate-, and borate-ions were not detected in the mineral by IR spectroscopy. The average composition of the new mineral (Table 1) is expressed by the following formula based on 70 Si atoms:



The idealized formula of mendeleevite-(Ce) with account for the structural data is the following:



The powder X-ray diffraction pattern of the mineral is individual (Table 2) and was obtained with the RKU-114.6 mm camera on a tube with an iron anode and manganese filter. Corrections were introduced by a separate pattern with quartz. The cell parameter and cell volume refined by the powder data are the following: $a = 21.909(1) \text{\AA}$, $V = 10516.4(9) \text{\AA}^3$, $Z = 2$.

The crystal structure of mendeleevite-(Ce) was studied in detail and described in [3]. The structure was solved and refined by direct methods and refined to $R_1 = 3.45\%$ by 2274 independent reflections with $[Fo > 4\sigma|F|]$ (Bruker *P4* diffractometer with CCD detector, $\text{MoK}\alpha$ radiation). The mineral is cubic with the space group *Pm*3; the cell parameter and cell vol-

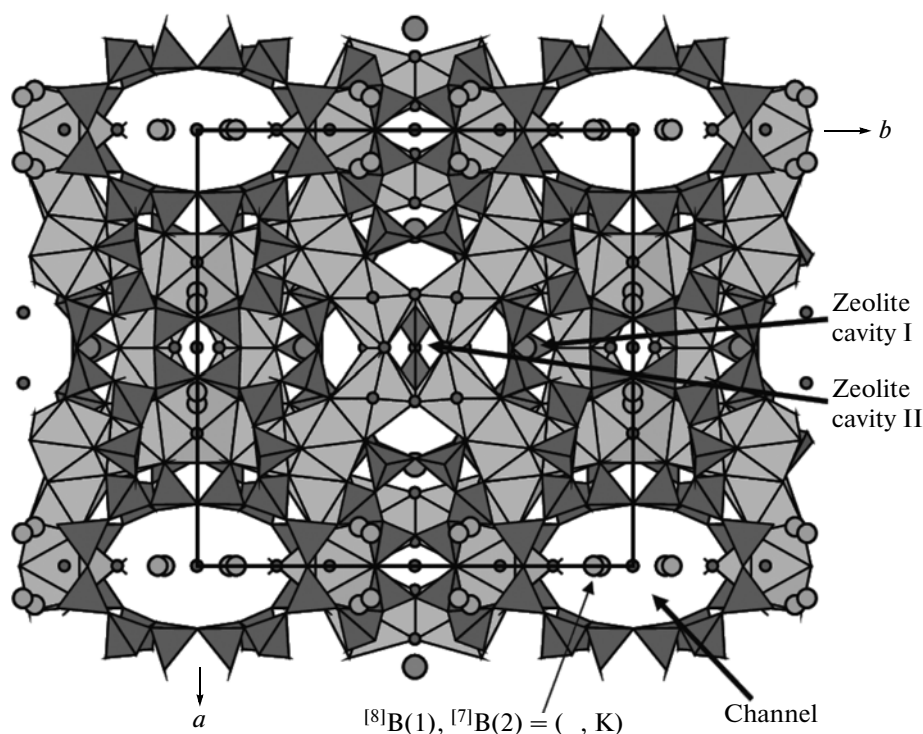


Fig. 2. General view of mendelevite-(Ce) crystal structure [3], projection on (001) plain.

ume are $a = 21.9148(4) \text{ \AA}$, $V = 10524.8(9) \text{ \AA}^3$ [3]. The crystal structure of the new mineral is a zeolite-like wide-porous heteropolyhedral structure formed by several types of units: $(Si_{104}O_{260})$ framework and $(Si_{36}O_{90})$ clusters represented by Si tetrahedrons and the framework composed of polyhedrons $[8]Ca^{2+}$, $[10](Ca^{2+}, Sr^{2+})$, and $[8]REE^{3+}$. This framework contains two types of cavities, in which Cs^+ ions and water molecules are located, and crossed by channels containing K^+ ions and H_2O (Fig. 2).

The discovery of mendelevite-(Ce) confirms the previous assumption [2] that, due to the large ionic size, cesium tends to form proper phases rather than be dispersed in rock-forming minerals at a high cesium activity in the mineral-forming environment. Mendelevite-(Ce) is a zeolite of a new structural type. Its discovery not only broadens the ideas on geochemistry and mineralogy of cesium, but may be important for

synthesis of new material for fixation of radioactive cesium isotopes.

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