

Voronkovite, $\text{Na}_{15}(\text{Na,Ca,Ce})_3(\text{Mn,Ca})_3\text{Fe}_3\text{Zr}_3\text{Si}_{26}\text{O}_{72}(\text{OH,O})_4\text{Cl} \cdot \text{H}_2\text{O}$, a New Mineral Species of the Eudialyte Group from the Lovozero Alkaline Pluton, Kola Peninsula, Russia¹

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Abstract—This paper describes a new member of the eudialyte group named in honor of Alexander Alexandrovich Voronkov (1928–1982), the prominent Russian crystallographer. The new mineral has been found in the Shkatulka hyperalkaline pegmatite body at Mt. Alluaiv, Lovozero alkaline pluton, Kola Peninsula, Russia. The mineral is associated with microcline, sodalite, nepheline, aegirine, terskite, lomonosovite, vuonnemite, shkatulkalite, manganoneptunite, and sphalerite. Voronkovite occurs as rounded, poorly faced crystals up to 2–5 mm across. The new mineral is light brown, with vitreous luster and conchoidal fracture. The streak is white. Voronkovite is transparent and brittle; the Mohs hardness is 5; cleavage or parting is not observed. $D(\text{meas}) = 2.97(2) \text{ g/cm}^3$ (volumetric method); $D(\text{calc}) = 2.95 \text{ g/cm}^3$. The new mineral is uniaxial, positive, pleochroic from lemon yellow along X to brownish pink along Y , and is not luminescent in UV light. Voronkovite easily dissolves and gels in acid at room temperature. The new mineral is trigonal, space group $R3$, $a = 14.205(7)$, $c = 30.265(15) \text{ \AA}$, $V = 5289(8) \text{ \AA}^3$, $Z = 3$. The strongest reflections in the X-ray diffraction pattern [d , Å (l)(hkl)] are 2.970(100)(315), 4.316(85)(205), 2.848(84)(404), 3.221(43)(208), 3.536(41)(027), 3.039(41)(119). The chemical composition (electron microprobe, H_2O determined with chemical analysis) is as follows, wt %: 15.84 Na_2O , 0.28 K_2O , 3.08 CaO , 1.76 SrO , 4.65 MnO , 3.53 FeO , 0.93 La_2O_3 , 1.36 Ce_2O_3 , 0.68 Nd_2O_3 , 0.15 Al_2O_3 , 49.48 SiO_2 , 0.33 TiO_2 , 14.11 ZrO_2 , 0.23 HfO_2 , 0.91 Nb_2O_5 , 0.44 Cl , 0.21 F , 1.56 H_2O , 0.19 $-\text{O} = (\text{Cl,F})_2$; total is 99.34. The empirical formula calculated on the basis of $\text{Si} + \text{Al} = 26$ ($Z = 3$) is as follows: $(\text{Na}_{13.96}\text{Sr}_{0.54}\text{K}_{0.19})_{\Sigma 14.69}(\text{Na}_{1.64}\text{Ca}_{0.92}\text{Ce}_{0.26}\text{La}_{0.18})_{\Sigma 3.00}(\text{Mn}_{2.06}\text{Ca}_{0.81}\text{Nd}_{0.13})_{\Sigma 3.00}(\text{F}_{1.54}\text{Zr}_{0.60}\text{Na}_{0.48}\text{Nb}_{0.21}\text{Ti}_{0.13}\text{Hf}_{0.04})_{\Sigma 3.00}\text{Zr}_{3.00}(\text{Si}_{1.91}\text{Al}_{0.09})_{\Sigma 2.00}(\text{Si}_{24}\text{O}_{72})[(\text{OH})_{2.98}\text{O}_{1.02}]_{\Sigma 4}(\text{Cl}_{0.39}\text{F}_{0.35})_{\Sigma 0.74} \cdot 1.23\text{H}_2\text{O}$. The simplified formula is $\text{Na}_{15}(\text{Na,Ca,Ce})_3(\text{Mn,Ca})_3\text{Fe}_3\text{Zr}_3\text{Si}_{26}\text{O}_{72}(\text{OH,O})_4\text{Cl} \cdot \text{H}_2\text{O}$. The IR spectrum of the mineral and description of its crystal structure are given. The position of voronkovite in the crystallochemical taxonomy of eudialyte group is discussed, and the relationship to other members, oneillite and raslakite, are characterized. The type material is deposited at the Fersman Mineralogical Museum, Russian Academy of Sciences, Moscow.

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INTRODUCTION

This publication describes a new zirconosilicate of the eudialyte group, which was expanded in recent years and currently includes more than 20 officially approved mineral species (Khomyakov et al., 2006a; Khomyakov, 2007; Rastsvetaeva, 2007). The new mineral, $\text{Na}_{15}(\text{Na,Ca,Ce})_3(\text{Mn,Ca})_3\text{Fe}_3\text{Zr}_3\text{Si}_{26}\text{O}_{72}(\text{OH,O})_4\text{Cl} \cdot \text{H}_2\text{O}$, was found at Mt. Alluaiv in the Lovozero alkaline pluton, Kola Peninsula, in the mineralogically unique Shkatulka pegmatite body and named *voronkovite* in honor of Alexander Alexandrovich Voronkov (1928–1982), the promi-

nent Russian crystallographer and author of numerous solved structures of new minerals and a number of monographs on the crystal chemistry of zircono- and titanosilicates (Pyatenko et al., 1976; Voronkov et al., 1978). According to the results of the study, the most remarkable features of voronkovite are substantial depletion in Ca in comparison with typical eudialyte, $\text{Na}_{15}\text{Ca}_6\text{Fe}_3\text{Zr}_3\text{Si}_{26}\text{O}_{72}(\text{O,OH,H}_2\text{O})_4(\text{Cl,OH})_2$, and $R3$ symmetry that is rather rare in minerals of this group, where the majority of members are assigned to the higher $R3m$ symmetry. This brings the new mineral together with the previously described low-Ca $R3$ analogues of eudialyte: oneillite from the Mont Saint-Hilaire alkaline complex (Johnsen et al., 1999) and raslakite from the Lovozero alkaline pluton (Chukanov et al., 2003), which are partially characterized below for comparison. The type material of voronkovite is deposited at the Fersman Mineralogical Museum, Rus-

¹ Considered and recommended by the Commission on New Minerals and Mineral Names, Russian Mineralogical Society, and Approved by the Commission on New Minerals and Mineral Names, International Mineralogical Association, November 20, 2007. Earlier, Khomyakov and Rastsvetaeva (2000) arbitrarily called this mineral an Na,Mn-ordered analogue of eudialyte with $R3$ symmetry.

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sian Academy of Sciences, Moscow, registration number 3620/1-4.

MODE OF OCCURRENCE, COMPOSITION, AND PROPERTIES OF VORONKOVITE

Mode of occurrence. The Shkatulka pegmatite body, where voronkovite was identified, is the second largest pegmatite body after the Yubelinaya vein at Mt. Karnasurt in the Lovozero alkaline pluton opened by underground workings at a significant depth (Men'shikov et al., 1996; Pekov, 2001). The lenticular pegmatite body is hosted in poikilitic nepheline-sodalite syenite in the middle part of the differentiated complex; the pegmatite is nearly vertical and traced along the strike for more than 20 m. This body is more than 5 m thick in a swell, 2 m of which fall on the ussingite core surrounded by aegirine and microcline zones up to 1 m thick. The 2–3 m thick zone enriched in giant (more than 1 m long and up to 0.5 m wide) microcline porphyroblasts occurs in the host nepheline-sodalite rock. This body is attributed to hyperalkaline pegmatite of type 4a comprising almost all fresh, highly mineralized pegmatites of the Mt. Alluaiv district (Khomyakov, 1990, 1995).

Like the Yubeleinaya vein, the described pegmatite is characterized by extremely variable mineral composition. More than 40 various minerals were identified therein, including a number of new species: shkatulkalite (Men'shikov et al., 1996), litvinskite (Pekov et al., 2000), bykovaite (Khomyakov et al., 2005) and voronkovite, which was found in the aegirine zone adjacent to the ussingite core of the pegmatite. Terskite—the most characteristic mineral of this part of the zone—occurs as rims or complete pseudomorphs after eudialyte and litvinskite crystals. Other minerals are microcline, nepheline, altered lomonosovite, vuonnemite, shkatulkalite, epistolite, manganoneptunite, and sphalerite. The described mineral is typically identified in ovoids 2–5 cm in diameter, where the marginal zone is composed of porcelain-like terskite, and the core is composed of voronkovite. The new mineral occurs as isolated, isometric, irregularly shaped grains 1–3 mm in size or as aggregates of the grains up to 1 cm across contacting with porcelainlike terskite along a sharp boundary.

The most important results of the study of voronkovite are summarized in Tables 1–3. The major characteristics of the examined mineral are compared with those of oneillite, raslakite, and typical eudialyte (Table 1).

Physical and optical properties. Voronkovite is a light brown, transparent, and brittle mineral with vitreous luster. The streak is white. The cleavage is indistinct. The Mohs hardness is 5. The measured density is 2.97(2) g/cm³ (microvolumetric method); the density calculated from the empirical formula is 2.95 g/cm³. Voronkovite is uniaxial, positive. Refractive indexes were determined by immersion ($\lambda = 589$ nm): $N_o =$

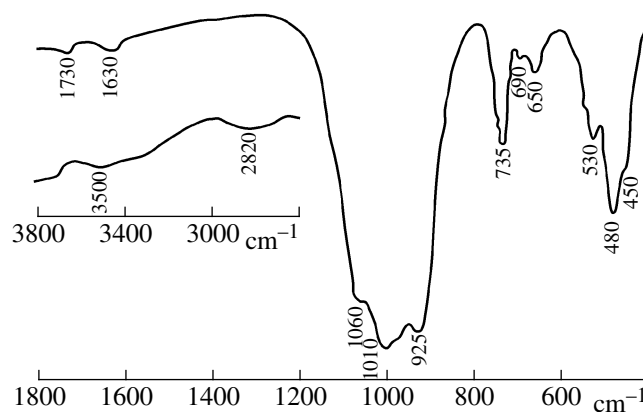


Fig. 1. IR spectrum of voronkovite.

1.610(2) and $N_e = 1.619(2)$. The new mineral is pleochroic from lemon-yellow along N_o to brownish pink along N_e and is not fluorescent in UV light ($\lambda = 240$ – 400 nm). Voronkovite easily dissolves and gels in acids at room temperature.

The infrared spectrum of voronkovite (Fig. 1) is characterized by the following absorption bands (cm⁻¹; s, m, and w are strong, moderate, and weak bands, respectively): 450m, 480s, 530s, 650m, 690w, 735s, 925s, 1010s, 1060s, 1630w, 1730w, 2820w, and 3500w. Clearly expressed bands in the range of 1630–3500 cm⁻¹ confirm the presence of water molecules and OH groups in the new mineral.

The chemical composition of voronkovite (Table 2) was determined by G.N. Nechelyustov on a Superprobe-733 electron microprobe operating at 15 kV, 20 nA, and a beam diameter of 5–10 μ m. Compositions of five grains have been analyzed (not less than five points in each grain). The following standards were used: chkalovite (Na), K₂ZrSi₂O₇ (K, Zr), diopside (Ca, Si), SrTiO₃ (Sr, Ti), almandine (Fe), rhodonite (Mn), LaF₃ (La), CeF₃(Ce), NdF₃ (Nd), AlPO₄ (Al), HfO₂ (Hf), LiNbO₃ (Nb), K₂ReCl₆ (Cl), fluorphlogopite (F). According to particular chemical analyses (analyst S.P. Purusova), the new mineral contains, wt %: 3.26 FeO, 0.40 Fe₂O₃, and 1.56 H₂O. The chemical composition of voronkovite has been satisfactorily recalculated on the basis of Si + Al = 26 apfu (in compliance with the typical formula of the eudialyte-group minerals and the results of determination of the mineral structure, see below) to the empirical formula (Na_{13.96}Sr_{0.54}K_{0.19}) Σ 14.69(Na_{1.64}Ca_{0.92}Ce_{0.26}La_{0.18}) Σ 3.00(Mn_{2.06}Ca_{0.81}Nd_{0.13}) Σ 3.00(Fe_{1.54}Zr_{0.60}Na_{0.48}Nb_{0.21}Ti_{0.13}Hf_{0.04}) Σ 3.00Zr_{3.00}(Si_{1.91}Al_{10.09}) Σ 2.00(Si₂₄O₇₂)[(OH)_{2.98}O_{1.02}] Σ 4(Cl_{0.39}F_{0.35}) Σ 0.74 · 1.23H₂O. The simplified formula is Na₁₅(Na,Ca,Ce)₃(Mn,Ca)₃Fe₃Zr₃Si₂₆O₇₂(OH,O)₄Cl · H₂O. A hypothetical end member of voronkovite may be expressed as the idealized formula Na₁₅(Na₃Mn₃)Fe₃Zr₃Si₂₆O₇₂(OH)₂ · 2H₂O.

The X-ray powder pattern of voronkovite (Table 3) is individualized, though the set of reflections and pro-

Table 1. Comparative characteristics of voronkovite, oneillite, raslakite, and eudialyte

Parameter	Voronkovite	Oneillite	Raslakite	Eudialyte
Formula	Na ₁₅ (Na,Ca,Ce) ₃ (Mn,Ca) ₃ Fe ₃ Zr ₃ Si ₂₆ O ₇₂ (OH,O) ₄ Cl · H ₂ O	Na ₁₅ (Ca ₃ Mn ₃) Fe ₃ Zr ₃ NbSi ₂₅ O ₇₃ (O,OH,H ₂ O) ₃ (OH,Cl) ₂	Na ₁₅ (Ca ₃ Fe ₃) (Na,Zr) ₃ (Si,Nb) Si ₂₅ O ₇₃ (OH,H ₂ O) ₃ (Cl,OH) ₂	Na ₁₅ Ca ₆ Fe ₃ Zr ₃ Si ₂₆ O ₇₂ (O,OH,H ₂ O) ₄ (Cl,OH) ₂
Symmetry	Trigonal	Trigonal	Trigonal	Trigonal
Space group	R3	R3	R3	R $\bar{3}m$, R3m
<i>a</i> (Å)	14.205	14.192	14.229	13.95–14.34
<i>c</i> (Å)	30.265	29.983	30.019	29.89–30.49
<i>V</i> (Å ³)	5289	5230	5263.5	5250–5370
<i>Z</i>	3	3	3	3
<i>D</i> , g/cm ³	2.99	3.20	2.95	2.62–3.08
Strong reflections in the X-ray powder pattern, <i>d</i> , Å, (<i>l</i>), (<i>hkl</i>)	2.970(100)(315) 4.316(85)(205) 2.848(84)(404) 3.221(43)(208) 3.536(41)(027) 3.039(41)(119) 3.166(37)(217) 2.157(34)(4.0.10) 2.601(32)(039) 7.096(31)(110)	2.964(100)(315) 2.844(89)(404) 11.348(44)(101) 3.389(43)(131) 4.291(36)(205) 6.021(36)(021) 3.150(35)(217) 7.100(33)(110) 5.683(31)(202) 3.199(31)(208)	2.853(100)(404) 2.974(86)(315) 4.311(66)(205) 3.209(58)(208) 3.023(40)(119) 4.095(37)(116) 5.72(35)(202) 2.592(34)(039) 7.14(33)(110) 3.401(33)(131)	2.857(100)(404) 2.977(84)(315) 4.312(55)(205) 3.217(47)(208) 5.714(45)(202) 3.403(42)(131) 7.124(38)(110) 3.165(35)(217) 3.807(34)(303) 3.563(32)(220)
Optical sign	(+)	(–)	(+)	(±)
<i>N_e</i>	1.610	1.6450	1.608	1.570–1.615
<i>N_o</i>	1.619	1.6406	1.611	1.575–1.620
Color	Light brown	Yellow-brown	Brownish red	Red, pink, and yellow

Notes: Sources: this paper for voronkovite; Johnsen et al. (1999) for oneillite; Chukanov et al. (2003) for raslakite; and JSPDS-ICDD dataset, card 41-1465 for eudialyte, etc.

portion of their intensities are similar to those of oneillite, raslakite, and eudialyte (Table 1). The unit-cell dimensions calculated from the X-ray powder pattern (*a* = 14.197(2), *c* = 30.272(6) Å) are close to the parameters obtained from X-ray single crystal study.

CRYSTAL STRUCTURE OF VORONKOVITE AND ITS POSITION IN THE EUDIALYTE GROUP

According to the modern concept on the eudialyte-group minerals (Johnsen and Grice, 1999; Khomyakov, 2002, 2004, 2007; Rastsvetaeva and Khomyakov, 2003; Johnsen et al., 2003; Khomyakov et al., 2006a; Rastsvetaeva, 2007), this group comprises trigonal zircono- and titanosilicates with the general formula $A(1)_3A(2)_3A(3)_3A(4)_3A(5)_3B_{3-6}CD\{M_6Z_3(T_{24}O_{72})\}(O,OH)_{2-6}X_2$ or a version of it: $N(1)_3N(2)_3N(3)_3N(4)_3N(5)_3M(1)_6M(2)_{3-6}M(3)M(4)Z_3[Si_{24}O_{72}]O'_{4-6}X_2$. The base of the eudialyte zeolite-type structure is a heteropolyhedral framework $\{M_6Z_3[T_{24}O_{72}]\}^{24-}$ formed by *M*-, *T*-, and *Z*-type

sheets alternating along axis *c* in the running order *MTZT*, where *M* sheets are six-membered rings consisting of Ca- and more complicated octahedrons, *T* sheets are isolated rings $[Si_9O_{27}]$ and $[Si_3O_9]$, and *Z* sheets are discrete Zr- and/or Ti-octahedrons. In zeolite sites *N*(1)–*N*(5), Na is usually predominant; selected sites are dominated by K, H₃O⁺, Mn, Ca, Sr, REE; *M*(1) = Ca, Mn, Sr, REE; *M*(2) = Fe²⁺, Fe³⁺, Mn, Zr, Na, K; *M*(3) = Nb, W, Ti, Mn, Si; *M*(4) = Si, Nb; *Z* = Zr, Ti. *O*' = O, OH, H₂O; *X* = Cl, F, H₂O, OH, CO₃.

The crystallochemical diversity of eudialytes is basically determined by their belonging to two different structural motifs: (i) 12-layered (*c* ~ 30 Å) or 24-layered (*c* ~ 60 Å) and (ii) one of three space groups (*R $\bar{3}m$* , *R3m*, or *R3*), the combination of which with 12-layered and 24-layered motifs allow subdivision of this group into six major crystallochemical subgroups: eudialyte, kentbrooksit, oneillite, alluaivite, rastsvetaevite, and labyrinthite. In the taxonomy of this group elaborated on this basis (Khomyakov, 2004, 2007,

Table 2. Chemical composition of voronkovite, wt %

Component	Content in five grains		Atoms per formula unit (Si + Al = 26)	Component	Content in five grains		Atoms per formula unit (Si + Al = 26)
	Range	Average			Range	Average	
Na ₂ O	15.54–16.02	15.84	16.08	SiO ₂	49.19–49.63	49.48	25.91
K ₂ O	0.23–0.35	0.28	0.19	TiO ₂	0.27–0.36	0.33	0.13
CaO	2.97–3.14	3.08	1.73	ZrO ₂	14.00–14.41	4.11	3.60
SrO	1.61–1.90	1.76	0.54	HfO ₂	0.20–0.25	0.23	0.04
FeO	3.40–3.71	3.53	1.54	Nb ₂ O ₅	0.84–1.23	0.91	0.21
MnO	4.46–4.79	4.65	2.06	Cl	0.35–0.51	0.44	0.39
La ₂ O ₃	0.78–1.11	0.93	0.18	F	0.21–0.21	0.21	0.35
Ce ₂ O ₃	1.22–1.43	1.36	0.26	H ₂ O		1.56	5.44
Nd ₂ O ₃	0.53–0.77	0.68	0.13	–O=(Cl,F) ₂		0.19	
Al ₂ O ₃	0.14–0.15	0.15	0.09	Total		99.34	

Notes: Superprobe-733 electron microprobe. Water content was determined by Penfeld method.

Table 3. X-ray powder data of voronkovite

<i>I</i>	<i>d</i> _{meas}	<i>d</i> _{calc}	<i>hkl</i>	<i>I</i>	<i>d</i> _{meas}	<i>d</i> _{calc}	<i>hkl</i>
9	11.44	11.40	101	13	2.384	2.386	048
10	10.12	10.09	003	5	2.362	2.364	330
31	7.096	7.102	110	10	2.318	2.318	241
26	6.450	6.444	104	8	2.288	2.287	1.0.13
10	6.026	6.028	021	8	2.263	2.264	1.3.10
29	5.697	5.698	202			2.262	238
7	5.429	5.431	015	34	2.157	2.157	4.0.10
85	4.316	4.314	205	15	2.143	2.143	336
17	4.113	4.112	116			2.142	3.1.11
19	4.079	4.079	107	9	2.129	2.129	0.1.14
22	3.963	3.961	214	8	2.122	2.121	514
24	3.799	3.799	303	6	2.063	2.064	3.2.10
10	3.685	3.687	125	9	1.980	1.981	428
10	3.617	3.616	018	11	1.835	1.835	526
41	3.536	3.537	027	18	1.776	1.776	4.2.11
22	3.388	3.390	131			1.776	440
26	3.351	3.350	223	13	1.753	1.754	351
14	3.326	3.328	312			1.754	2.2.15
43	3.221	3.222	208	15	1.675	1.675	446
37	3.166	3.166	217	11	1.643	1.645	2.4.13
41	3.039	3.039	119			1.642	265
100	2.970	2.972	315	21	1.612	1.613	4.1.15
13	2.935	2.934	128			1.611	4.0.16
17	2.903	2.904	226	12	1.571	1.571	3.2.16
84	2.848	2.849	404	6	1.545	1.545	1.5.14
4	2.772	2.774	323	6	1.526	1.527	4.3.13
19	2.716	2.716	0.2.10	10	1.481	1.481	5.3.11
13	2.685	2.685	0.1.11			1.481	0.7.11
		2.684	140	12	1.366	1.367	556
24	2.678	2.678	137			1.360	817
9	2.644	2.644	324	11	1.359	1.366	0.3.21
32	2.601	2.600	039			1.360	0.4.21
15	2.524	2.522	0.0.12			1.358	

Notes: Operating conditions: diffractometer, CuK_α radiation.

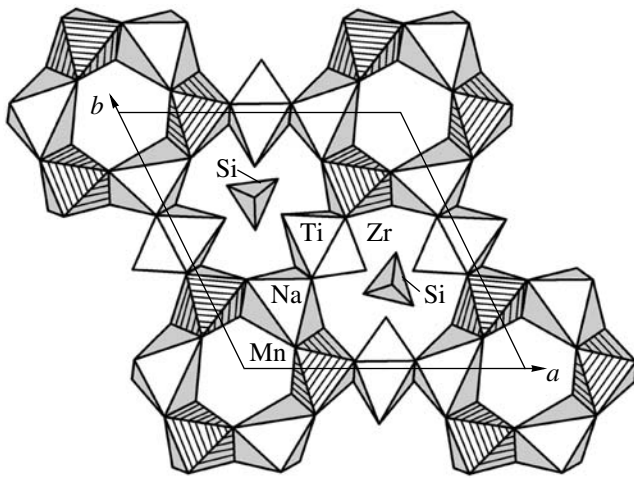


Fig. 2. A fragment of the crystal structure of voronkovite projected onto (001). Sites and types of coordination polyhedrons discussed in the text are marked.

2008; Khomyakov et al., 2006a), voronkovite belongs to the oneillite subgroup. In addition to the progenitor of this subgroup and voronkovite, raslakite (Chukanov et al., 2003) and aqualite (Khomyakov et al., 2007a) are included therein. This subgroup comprises eudialytes with 12-layered structural motif and space group $R3$; the composition of the subgroup members, written as $[N(1)N(2)N(3)N(4)N(5)]_3[M(1a)_3M(1b)_3]M(2)_3M(3)M(4)Z_3[Si_{24}O_{72}]O_4X_2$ (Johnsen et al., 2003), differs from the general formula of the eudialyte group in the subdivision of the 18-fold octahedral site $M(1)$ into two independent ninefold octahedral sites $M(1a)$ and $M(1b)$ differing in the volume and set of atoms.

The crystal structure of voronkovite (Fig. 2) has been solved on the basis of the dataset of reflections collected with a Syntex $P2_1$ (MoK_{α} radiation) four-circle diffractometer and is refined for 4004 independent reflections [$F_0 > 4\sigma(F)$] to an R index of 3.60% (Rastsvetaeva and Khomyakov, 2000). The space group is $R3$, $a = 14.205(7)$ Å, $c = 30.265(15)$ Å, $V = 5288.8$ Å³, $Z = 3$. The following distribution of atoms by key cation sites (without splitting into subsites, $Z = 3$) was established: $N(1) = (Na_{2.82}K_{0.18})_{3.0}$, $N(2) = Na_{3.0}$, $N(3) = (Na_{2.7}Sr_{0.3})_{3.0}$, $N(4) = (Na_{2.85}Sr_{0.15})_{3.0}$, $N(5) = Na_{2.7}$, $M(1a) = (Na_{1.35}Ca_{1.05}Ce_{0.45}Sr_{0.15})_{3.0}$, $M(1b) = (Mn_{2.1}Ca_{0.72}Ce_{0.18})_{3.0}$, $M(2) = (Fe_{1.5}Zr_{0.63}Na_{0.57}Ti_{0.17}Nb_{0.13})_{3.0}$, $M(3) = (Si_{0.9}Al_{0.1})_{1.0}$, $M(4) = Si_{1.0}$, $Z = Zr_{3.0}$. The major compositional and structural features of the mineral are reflected in the crystallochemical formula $(Na_{15})^{V-VIII}[Na_{1.35}Ca_{1.05}Ce_{0.45}Sr_{0.15}]^VI[Mn_{2.1}Ca_{0.7}Ce_{0.2}]^VI$

$[Fe_{1.5}Zr_{0.65}Na_{0.55}(Ti,Nb)_{0.3}]^V[Zr_3]^VI[Si_{1.9}Al_{0.1}]^IV(Si_3O_9)_2(Si_9O_{27})_2(OH,O)_4(H_2O,Cl)_2$, where the compositions of key sites $M(1a)$, $M(1b)$, $M(2)$, $M(3)$, $M(4)$, and Z are

placed in brackets and coordination numbers of cations are marked with Roman numerals.

This formula is consistent with the results of chemical analysis of voronkovite and the derived simplified formula $Na_{15}(Na,Ca,Ce)_3(Mn,Ca)_3Fe_3Zr_3Si_{26}O_{72}(OH,O)_4Cl \cdot H_2O$, which significantly differs from that of typical eudialyte, $Na_{15}Ca_6Fe_3Zr_3Si_{26}O_{72}(O,OH,H_2O)_4(Cl,OH)_2$. If the formula of eudialyte with $R3m$ symmetry contains six Ca atoms necessary and sufficient to construct octahedral ring Ca_6O_{24} , then in Ca-deficient voronkovite, the homogeneous six-membered rings are subdivided into two triplets of octahedrons, which are nonequivalent in composition and size. As a result, plane m disappears and symmetry lowers down to $R3$.

In crystallochemical features, voronkovite is most closely related to oneillite, $Na_{15}Ca_3Mn_3Fe_3Zr_3Nb(Si_{25}O_{73})(O,OH,H_2O)_3(OH,Cl)_2$ (Johnsen et al., 1999) and raslakite, $Na_{15}Ca_3Fe_3(Na,Zr)_3(Si,Nb)(Si_{25}O_{73})(OH,H_2O)_3(Cl,OH)_2$ (Chukanov et al., 2003), which, like voronkovite, differ from typical eudialyte in low Ca and are characterized by $R3$ symmetry. The individuality of the described mineral in comparison with its nearest analogues is clearly demonstrated by the distribution of extraframework atoms that dominate in the most informative cation sites:

	$M(1a)$	$M(1b)$	$M(2)$	$M(3)$	$M(4)$
Voronkovite	Na	Mn	Fe	Si	Si
Oneillite	Mn	Ca	Fe	Nb	Si
Raslakite	Ca	Fe	Na	Si	Si

The contrasting differences of the compared minerals in regular cation partitioning between crystallochemically independent sites $M(1a)$ and $M(1b)$ of six-membered ring are noteworthy. If in oneillite and raslakite, one of these sites is Ca-dominant and the other is Mn- or Fe-dominant, then in voronkovite, these sites are dominated by Na and Mn. The difference in cations agree with the size of nonequivalent octahedrons. In Ca-octahedrons of typical eudialytes, the mean cation–anion distances range from 2.32 to 2.37 Å, whereas in the structure of voronkovite, the Mn- and Na-dominant octahedrons substantially different in volume and with mean cation–anion distances of 2.25 and 2.45 Å, respectively, were established.

As a result of subdivision of the six-membered ring into two triplets of octahedrons with different volumes, all atoms in the voronkovite structure are displaced from the positions relative to pseudoplane m , and other cation polyhedrons are significantly distorted as well. For example, the well-known polyhedron as a flat square formed by edges of Ca-octahedrons in the structure of eudialyte is transformed into a distorted trapezoid with the sides ranging from 2.80 to 3.14 Å. If the site in the center of the square of typical eudialyte is completely occupied by Fe atoms, in the center of trapezoid structure of voronkovite, it is half-occupied by Fe atoms only. This site is supplemented by three subsites

formed on the basis of a trapezoid: two fivefold polyhedrons (pyramids) with opposite orientation of apical vertices and a distorted octahedron (not shown in Fig. 2), which are occupied by Zr, (Ti, Nb), and Na atoms, respectively. In the described structure, all subsites of site *M*(2) approach one another and are statistically occupied with Fe predominant over other cations in this site. In the cation occupancy of other key sites, the structure of voronkovite is close to that of typical eudialytes. The sites of large cations are occupied exclusively by Na or are Na-dominant with addition of K in site *N*(1) and Sr in sites *N*(3) and *N*(4). Sites *M*(3) and *M*(4) are occupied by Si with an insignificant admixture of Al in the former. Therefore, the nine-membered Si rings of the examined structure are transformed into flat nine-membered radicals with variously oriented additional Si tetrahedrons.

In summary, we emphasize once again that the basic features of the voronkovite structure are predominance of Na and Mn atoms in the centers of octahedrons of the six-membered ring [*M*(1a)₃*M*(1b)₃]O₂₄, resulting in lowering of symmetry from *R3m* to *R3*, and the absence of a Ca-dominant site; this has been established in eudialyte group minerals for the first time.

Voronkovite is a typomorphic mineral of hyperalkaline pegmatite whose formation conditions correspond to maximum alkalinity of the peralkaline process (Khomyakov, 1990, 1995). The composition and structure of voronkovite characterized in this paper are consistent with the extremely alkaline setting of the formation of not only this mineral and its analogues from the oneillite subgroup, but also of the pleiad of 24-layered eudialytes unique in constitution, including alluaivite, dualite, rastsvetaevite, and labyrinthite described from hyperalkaline rocks and pegmatites of the Khibiny–Lovozero Complex (Khomyakov et al., 1990, 2006a, 2006b, 2007b). As follows from the cited papers, typical eudialyte, being a typomorphic mineral of agpaitic rocks of moderate alkalinity, becomes unstable under extremely high alkalinity. It breaks down, is replaced by various secondary phases, recrystallizes, and transforms into eudialyte-like minerals that are more alkaline and therefore stable in a hyperalkaline environment. It may be suggested that in addition to voronkovite, the overwhelming majority of highly ordered eudialyte-group minerals formed in a similar way.

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