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This volume contains articles on new mineral species and new finds of rare minerals, among them – Nalivkinite, a new mineral of the astrophyllite group; new finds of Dzhaliindite, Mo-bearing Stolzite and Greenockite in ores of the Budgaya, Eastern Transbaikalia; new finds of black Powellite in molybdenum-uranium deposit of Southern Kazakhstan. Corundum-bearing Pegmatite from the Khibiny massif and Columbite-Tantalite group minerals of rare-metal tantalum-bearing amazonite-albite granites from Eastern Transbaikalia and Southern Kazakhstan are described. There is also an article on mineralogical and geochemical features of uranium ores from Southeastern Transbaikalia deposits. New data on titanium-rich Biotite and on polymorphs of anhydrous dicalcium orthosilicate are published.

"Mineralogical Museums and Collections" section contains articles on collections and exhibits of Fersman Mineralogical Museum RAS: on the collection of mining engineer I.N. Kryzhanovsky; on Faberge Eggs from the funds of this museum (including a describing of symbols on the box with these eggs); on the exhibition devoted to A.E. Fersman's 125th anniversary and to 80 years of the first edition of his famous book "Amazing Mineralogy" and the review of Fersman Mineralogical Museum acquisitions in 2006 – 2008. This section includes also some examples from the history of discovery of national deposits by collection's specimens.

In "Personalities" section there is article on A.E. Fersman's Uralian expeditions and on his role in the organization of the Ilmeny State Reserve; article on the life and the activity of Professor G.P. Barsanov, the director of the Fersman Mineralogical Museum in 1952 – 1976.

"Mineralogical Notes" section is devoted to Fe-dominant Bogdanovite from cementation zone of the Aginsky gold-telluride deposit, Kamchatka; and on the find of Mackinawite inclusions in grossular at the Talnakh Achatarandite locality.

In "Discussions" section there is a paper on problems of species formation in mineralogy where minerals of variable composition and with variable structure are discussed on the example of eudialyte-eucolites.

The volume is interesting for mineralogists, geochemists, geologists, collaborators of Natural History museums, collectors and minerals-amateurs.

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CONTENTS

New Minerals and Their Varieties,

New Finds of Rare Minerals, Mineral Paragenesis Assemblages

Agakhanov A.A., Pautov L.A., Uvarova Y.A., Sokolova E., Hawthorne, Frank C., Karpenko V.Y.

Nalivkinite $\text{Li}_2\text{NaFe}_7^{2+}\text{Ti}_2(\text{Si}_8\text{O}_{24})\text{O}_2(\text{OH})_4\text{F}$, a New Mineral of the Astrophyllite Group from the Darai-Pioz Massif, Tadjikistan,5

Kiseleva G.D., Kovalenker V.A., Trubkin N.V., Borisovsky S.E., and Mokhov A.V.

Rare Minerals of In, Cd, Mo, and W in Gold-base Metal Veins of the Bugdaya Au-Mo(W)-porphyry Deposit, Eastern Transbaikalia, Russia13

Sidorenko G.A., Chistyakova N.I., Doinikova O.A., Chukanov N.V., Naumova I.S., Kuzmin V.I.

Black Powellite from Molybdenum-Uranium Deposit23

Azarova Yu.V., Shlyukova Z.V.

Corundum-bearing Pegmatite of Crossing Trend of Evolution of the Khibiny Massif and their Role in Reconstruction of Parental Rocks of Host Pre-Proterozoic Hornfels31

Povarennykh M.Yu.

Typomorphism of the Columbite-Tantalite Group Minerals in the Rare-Metal Tantalum-bearing Amazonite-Albite Granites37

Chernikov A.A., Dubinchuk V.T., Tolkachev A.E., Chistyakova N.I., and Nechelyustov G.N.

Mineralogical and Geochemical Features of Deposits in the Southeastern Transbaikalia for Local Forecast of Uranium Ore45

Crystal Chemistry, Minerals as Prototypes of New Materials, Physical and Chemical Properties of Minerals

Yamnova N.A., [Egorov-Tismenko, Yu.K.], Gobechiya E.R., Zadov A.E., Gazeev V.M.

New Data on Polymorphs of Anhydrous Dicalcium Orthosilicate54

Chukanov N.V., Rozenberg K.A., Rastsvetaeva R.K., Mäkel Steffen

New Data on Titanium-rich Biotite: a Problem of "Wodanite"72

Mineralogical Museums and Collections

Matvienko E.N.

Collection of Mining Engineer I.N. Kryzhanovskiy79

Generalov M.E. Fabergé Eggs for Everyone. Point of Value86

Kuzmin V.I., Skorobogatova N.V.

To the History of Discovery of Some National Deposits by Collection's Specimens90

Borisova E.A., Pavlova T.M., Evseev A.A.

«Amusing Mineralogy» in Stone: the Exhibition Devoted to Alexander E. Fersman's 125th Anniversary97

Belakovskiy D.I. and Pekova N.A.

The Review of Fersman Mineralogical Museum Acquisitions in 2006 – 2008109

Personalities

Butorina L.A. Alexander E. Fersman in the Ilmeny Mountains125

Chistyakova M.B. G.P. Barsanov – the Director of the Fersman Mineralogical Museum (1952 – 1976)132

Gur'eva E.Ya. Georgiy Pavlovich Barsanov as I Remember Him138

Mineralogical Notes

Spiridonov E.M. Fe-dominant Bogdanovite from Cementation Zone of the

Aginsky Gold-Telluride Deposit, Kamchatka Peninsula, Russia144

Alferova M.S.

About Mackinawite Inclusions in Grossular Crystals at the Talnakh (Mt. Otdel'naya) Achtarandite Locality ..147

Discussions

Borutzky B.Ye. The Essays on Fundamental and Genetic Mineralogy:

3. *Minerals of Variable Composition with Variable Structure*

and Problems of Species Formation in Mineralogy. Eudialyte-Eucolites149

Alferova M.S.

International Scientific Conference "Fersman Days" and its youth session

"Fersmaniada" devoted to the 125th anniversary of academician Alexander E. Fersman174

Manuscript preparation guide for the journal "New Data on Minerals"175

**New Minerals
and Their Varieties,
New Finds of Rare
Minerals,
Mineral Paragenesis
Assemblages**



NALIVKINITE¹, Li₂NaFe₇²⁺Ti₂(Si₈O₂₄)O₂(OH)₄F, A NEW MINERAL OF THE ASTROPHYLLITE GROUP FROM THE DARAI-PIOZ MASSIF, TADJIKISTAN

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Nalivkinite, a new astrophyllite-group mineral, was discovered in the moraine of the Darai-Pioz alkaline massif located at the intersection of the Zeravshansky, Turkestansky and Alaisky Ridges, Tadjikistan. Nalivkinite occurs in the amphibole-quartz-feldspar rock in association with calcybeborosilite-(Y), bafertisite, jinshajiangite, zircon and thorite. Nalivkinite is brown with a bronze hue and a vitreous luster; in thin plates, it is transparent. Mohs hardness is 3, $D_{\text{meas.}} = 3.32(2) \text{ g/cm}^3$, $D_{\text{calc.}} = 3.315 \text{ g/cm}^3$. It is biaxial positive, $n_p = 1.703(2)$, $n_m = 1.716(2)$, $n_g = 1.745(2)$, $2V_{\text{meas.}} = +68(2)^\circ$, $2V_{\text{calc.}} = +68.6^\circ$. Nalivkinite is triclinic, space group $P-1$, $a = 5.3745(6) \text{ \AA}$; $b = 11.9299(15) \text{ \AA}$; $c = 11.6509(14) \text{ \AA}$; $\alpha = 113.325(3)^\circ$, $\beta = 94.524(2)^\circ$, $\gamma = 103.080(2)^\circ$, $V = 656.2(2) \text{ \AA}^3$, $Z = 1$. Cell dimensions refined from X-ray powder diffraction data are as follows: $a = 5.3707(2) \text{ \AA}$; $b = 11.9327(5) \text{ \AA}$; $c = 11.6546(4) \text{ \AA}$; $\alpha = 113.384(1)^\circ$, $\beta = 94.547(1)^\circ$, $103.047(1)^\circ$, $V = 655.85(2) \text{ \AA}^3$. The strongest reflections in the X-ray powder diffraction pattern are as follows: $[(d, \text{ \AA}), (I, \%), (hkl)]: 10.56 (100) (001), 3.50 (100) (003), 2.780 (80) (1-42), 2.648 (45) (-211), 2.578 (70) (130), 2.474 (15) (-212), 2.295 (30) (131), 2.106 (35) (-142), 1.760 (30) (133), 1.660 (15) (0-73)$. The infrared spectrum of nalivkinite is similar to that of astrophyllite, and the strongest lines are as follows (cm^{-1}): 3600, 1621, 1077(sh), 1056, 975, 929, 696, 649, 566, 441, 438. The chemical composition (electron microprobe, wt. %, Li₂O and Rb₂O by ICP OES, H₂O by the Penfield method): Al₂O₃ – 0.67, SiO₂ – 35.92, TiO₂ – 10.50, Nb₂O₅ – 1.68, CaO – 1.29, MgO – 0.09, MnO – 5.26, FeO – 32.76, Na₂O – 1.62, K₂O – 2.49, Li₂O – 3.76, Cs₂O – 1.40, Rb₂O – 0.85, H₂O – 3.13, F – 0.75, -O=F₂ – 0.32, total – 100.04. The empirical formula of nalivkinite is $(\text{Li}_{1.03}\text{K}_{0.69}\text{Cs}_{0.13}\text{Rb}_{0.12})_{1.97}(\text{Na}_{0.69}\text{Ca}_{0.30})_{0.99}(\text{Fe}_{5.97}^{2+}\text{Mn}_{0.97}\text{Mg}_{0.03})_{6.97}(\text{Ti}_{1.72}\text{Nb}_{0.16}\text{Zr}_{0.08})_{1.96}[\text{Si}_{7.83}\text{Al}_{0.17}]_8\text{O}_{25.98}\text{OH}_{4.07}(\text{F}_{0.52}\text{OH}_{0.48})_{1.00}$ and the ideal formula is $\text{Li}_2\text{NaFe}_7^{2+}\text{Ti}_2(\text{Si}_8\text{O}_{24})\text{O}_2(\text{OH})_4\text{F}$. The crystal structure of nalivkinite was refined to an R₁ index of 6.26%. The name honors Dmitry Vasiljevich Nalivkin, a famous Russian geologist (1889–1982), author of numerous works on the geology, stratigraphy and paleontology of Central Asia. The holotype sample of nalivkinite is deposited at the Fersman Mineralogical Museum, Russian Academy of Sciences, Moscow.

3 tables, 3 figures, 12 references.

Keywords: nalivkinite, astrophyllite lithium analogue, Darai-Pioz alkaline massif.

Introduction

Minerals of the astrophyllite group have the general formula $\text{A}_2\text{BC}_7\text{D}_2\text{T}_8\text{O}_{26}(\text{OH})_4\text{X}_{0-1}$, where $^{[10]-[13]}\text{A} = \text{K}, \text{Cs}, \text{Rb}, \text{H}_2\text{O}, \text{H}_3\text{O}^+, \text{Li}, \text{Na}$ and \square ; $^{[10]}\text{B} = \text{Na}$ and Ca ; $^{[6]}\text{C} = \text{Fe}^{2+}, \text{Fe}^{3+}, \text{Mn}, \text{Na}, \text{Mg}$ and Zn ; $^{[6]}\text{D} = \text{Ti}, \text{Nb}$ and Zr ; $^{[4]}\text{T} = \text{Si}$ and Al ; $\text{X} = \text{F}, \text{OH}, \text{O}$ and \square (Piilonen *et al.*, 2003; Uvarova *et al.*, 2008).

The astrophyllite group includes nine mineral species: the structurally characterized species astrophyllite, magnesioastrophyllite, kupletskite (with two polytypes: kupletskite-1A and kupletskite-2M) and niobokupletskite, and the structurally uncharacterized species niobophyllite, cesium-kupletskite (recently renamed into a kupletskite-Cs) and zircophyllite. The minerals of the astrophyllite

¹ – Nalivkinite is recommended for the publication by the Commission on New Minerals and Mineral Names of the Russian Mineralogical Society, and was approved by the Commission on New Minerals, Nomenclature and Classification of the International Mineralogical Association on December 4, 2006.

group are commonly accessory minerals, but may be rock-forming minerals in alkaline rocks. There has been much work on the latter occurrence: a detailed review of the 19th and early 20th Century literature (including the original data on astrophyllite) are given by Bonshtedt (1931); later reviews and new data are given by Semenov (1972), Macdonald and Saunders (1973), Piilonen *et al.* (2003) and Uvarova *et al.* (2008).

Ganzeev *et al.* (1969) first drew attention to a deficiency of potassium and enrichment of lithium in astrophyllite from the Darai-Pioz massif: Li, % – 0.59; 0.59; 0.27, equivalent to 1.27; 1.27; 0.58 wt. % Li₂O. Higher contents of lithium (Li₂O – 1.30; 1.36 wt. %) in astrophyllite from Darai-Pioz were reported by Burova and Dusmatov (1971). Their work prompted re-investigation of this unusual astrophyllite from Darai-Pioz. Accordingly, the Li analogue of astrophyllite was discovered in rocks from the Upper Darai-Pioz massif, and was named nalivkinite in honour of Dmitry Vasiljevich Nalivkin (1889–1982), participant of the Pamiro-Tadjik expedition (1920–1930) and author of numerous works on the geology, stratigraphy and paleontology of Central Asia.

Occurrence

Nalivkinite was found in fenitized rocks of the Upper Darai-Pioz massif by the upper reaches of the Darai-Pioz river, started from the same glacier (Tadjikistan). In plan, the massif is slightly elongated in a northwesterly direction and adjoins the core of a large synclinal fold of C₂₋₃ slates, and the northern part of the massif an anticlinal fold of interbedded S_{1w}–S_{2ld} slates and limestones. The exposed part of the massif consists of granites, aegirine and quartz syenites, and cancrinite foyaites, and covers 18 km² (Dusmatov, 1971). A significant part of the massif is covered by glaciers and is completely inaccessible. In the last century, the glaciers of Central Asia have receded extensively, and the Darai-Pioz glacier is no exception. The receding glacier has left a steep-walled trough valley. Some parts of the massif can be seen but close examination is not possible without special equipment. As a result, knowledge of the massif is, in many respects, rather fragmentary in nature,

and the lion's share of mineralogical and petrographic work has been done on material collected from glacial debris. The vein rocks are even less accessible to observation in situ, particularly granitic pegmatites, subalkaline granitic pegmatites with rare-metal and rare-earth mineralization, reedmergnite pegmatites, carbonatites, pectolite-microcline-calcite veins, etc. Among the hydrothermally-altered rocks are albitites, aegirine-quartz-microcline-albite rocks with wollastonite, miserite, agrellite, as well as fenites. Detailed descriptions are given by Dusmatov (1968, 1971).

An important feature of rocks of the massif is their enrichment in Li. According to Dusmatov (1971), the following Li (ppm) contents were recorded: biotite granites – 135, quartz syenites – 45, aegirine syenites – 70, cancrinite syenites – 180, fenitized rocks – 250. There are sixteen Li minerals recorded from the Darai-Pioz massif, seven of which were discovered there. Indeed, Ganzeev *et al.* (1969) wrote: "Astrophyllite is a sensitive indicator of enrichment of Rb, Cs and Li in alkaline-rock massifs". These words prove to be true for the Darai-Pioz massif.

Nalivkinite occurs in boulders of the glacial moraine; in-place exposures have not been found. The samples consist of fine- to coarse-grained amphibole-quartz-feldspar rock of leucocratic appearance, with a patchy texture caused by aggregates of amphibole, bafertisite, calcybeborosilite-(Y) and nalivkinite. Microcline forms large grayish-yellow idiomorphic grains 1–8 cm in size, and the albite component does not exceed Ab₄₁, although intergrowths of virtually pure albite are observed. Quartz forms light grey, translucent, sometimes smoky, icy coarse-grained aggregates. Sodic amphibole occurs as prismatic crystals, frequently deformed, up to 3 cm long, in which relict aegirine can be observed. Fine-grained albite is common. The characteristic mineral of nalivkinite-bearing rocks is calcybeborosilite-(Y) which occurs as anhedral dark-grey-to-brown crystals up to 3 cm in size. There are thick lamellar aggregates of brown-red manganous bafertisite and jinshajiangite (fig.1), and rectangular pseudomorphs of fine-grained quartz-calcite-microcline up to 5–15 mm in size.

There are minor concentrations of dipyrimidil lilac crystals of zircon (1–3 mm), black octahedral crystals of uraniferous pyrochlore

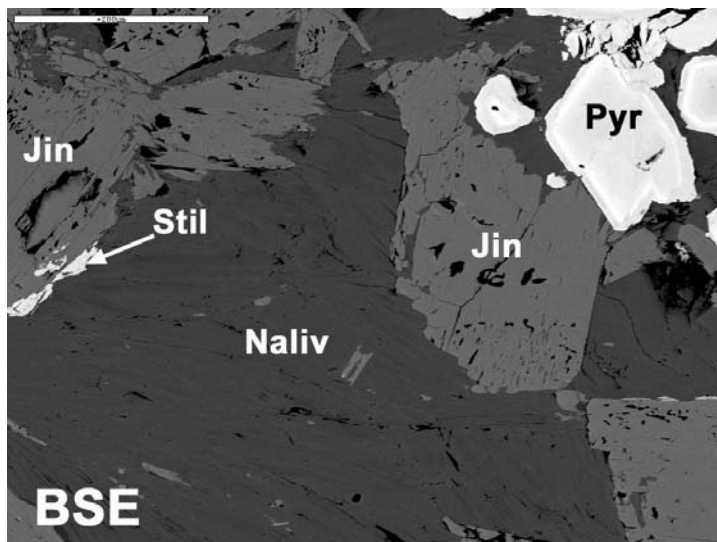
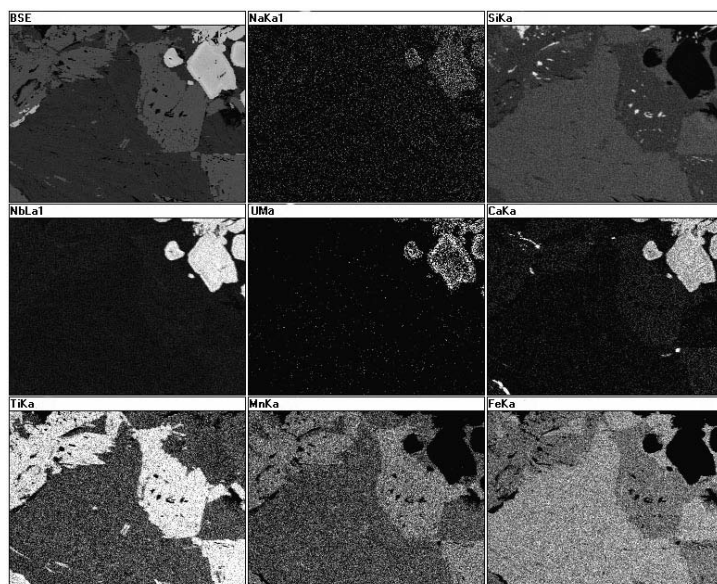


Fig. 1. Intergrowth of nalivkinite (Naliv) with jinshajiangite (Jin), pyrochlore (Pyr) and stillwellite-(Ce) (Stil). The BSE image of a polished section (top) and characteristic X-ray maps of the specified elements (bottom).



(0.5–2 mm), and pinkish-red prismatic crystals of stillwellite-(Ce) from 4 to 10 mm, grains of pale-violet fluorite up to 1 mm, crystals of pale-green thorite, yellow wedge-shaped crystals of Nb-bearing titanite ($\text{Nb}_2\text{O}_5 = 2.64$ wt. %, size <1 mm). Willemite, smithonite and barite occur in cavities caused by leaching of sphalerite.

Nalivkinite forms large gold-brown lamellar aggregates up to 4 x 5 cm (fig. 2) that are frequently deformed, shattered and penetrated by a network of quartz veinlets to 0.1–0.2 mm thick. The same veinlets also cut the lamellar aggregates of bafertisitite.

Physical properties

Appearance of nalivkinite is very similar to that of astrophyllite. In hand specimen, it is brown with a bronze hue; in thin plates, it is pale brown and transparent. Cleavage is perfect on (001), good on (010), and imperfect on (100). On breaking, lamellae and thin mica-like layers frequently occur. Nalivkinite is brittle with a pale-yellow streak and a vitreous lustre that is particularly prominent on cleavage fragments. In short-wave and long-wave UV-light, the mineral does not fluoresce. The Mohs hardness is 3. Micro-indentation VHN was determined with a 20g load on a PMT-3

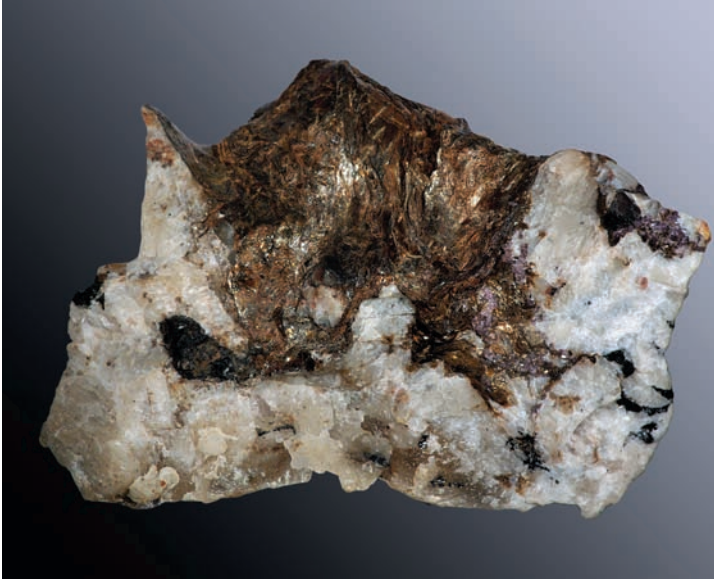


Fig. 2. A general view of the amphibole-quartz-feldspar rock in which nalivekinite was discovered. Large platy aggregates of brownish-golden nalivekinite in microcline, intergrown with black anhedral crystals of sodic amphibole and pale-violet euhedral crystals of zircon. Size of sample: 5 x 4 x 1.5 cm

instrument standardized on NaCl; the mean value is 190 kg/mm^2 (average of 10 measurements in the range $170\text{--}218 \text{ kg/mm}^2$). A density of $3.32(2) \text{ g/cm}^3$ was determined by weighing grains in water-diluted Clerichi solution. The calculated densities for grains A and B are 3.315 g/cm^3 and 3.299 g/cm^3 , respectively.

Nalivekinite is biaxial positive; refractive indices were measured by spindle stage and are as follows: $n_p = 1,703(2)$; $n_m = 1,716(2)$; $n_g = 1,745(2)$ (for a wavelength of 589 nm). The optical-axial angle, measured on a Fedorov stage, is as follows: $2V_{\text{meas.}} = +68(2)^\circ$; $2V_{\text{calc.}} = +68.6^\circ$ (because of strong dispersion, it was necessary to make our measurements with Na light). Dispersion is strong, $r > v$. In the immersion liquids, practically all nalivekinite particles lay on the cleavage plane (001). Most grains resemble elongate parallelepipeds, and there are two discernable types of fragments: one has positive elongation and direct extinction $\text{Ng} \parallel a$, whereas the other less regular fragments with cross cleavage on (010) have negative elongation and inclined extinction $\text{Nm} : b = 3^\circ$. In convergent light, all fragments laying on (001) give an obtuse-bisectrix figure. The optic-axial plane is almost perpendicular to the (001) cleavage. Nalivekinite is pleochroic, $\text{Ng} =$ light yellowish-brown, $\text{Nm} =$ reddish brown, $\text{Np} =$ intensive brown, with absorption $\text{Np} > \text{Nm} > \text{Ng}$.

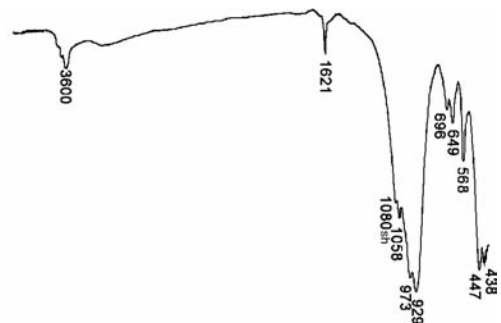
The infrared spectrum of nalivekinite (fig. 3) was measured on a Fourier-transform IR-spec-

trometer (Avatar, Thermo Nicolet, specimen: powder dispersed in KBr pellet). It has strong absorption bands as follows (cm^{-1}): 3600, 1621, 1077 (shoulder), 1058, 975, 929, 696, 649, 568, 447 and 438, and is very similar to that of astrophyllite. Presence of a narrow peak around 1620 cm^{-1} was noted by Morgunova et al. (2000) for potassium-poor astrophyllite and cesium-kupletskite from Darai-Pioz.

Chemical composition

The chemical composition of nalivekinite was determined primarily by electron-microprobe analysis in a polished section embedded in epoxy resin and prepared from sample No 5321. Grains for the determination of alka-

Fig. 3. IR spectrum of nalivekinite.



lis and H_2O content (and for determination of physical properties) were extracted from this sample. Grains were analyzed on a JEOL JXA-50A with an accelerating voltage of 20 kV and a current of 2 nA for energy-dispersive examination, and an accelerating voltage of 15 kV and a probe current of 25 nA for wavelength-dispersive analysis. Al, Si, Ti, Ca, Mg, Mn, Fe, Zr, Na, K, Cs, Ti and Nb were analysed with a Link EDS system, and F was measured by WDS. Standards used were as follows: microcline USNM 143966 (Al, Si, K), ilmenite USMN 96189 (Ti, Fe), anorthite USNM 137041 (Ca), LiNbO_3 (Nb), MgF_2 (Mg), Mn (Mn), omphacite USNM 110607 (Na), $\text{CsTbP}_4\text{O}_{12}$ (Cs) and MgF_2 (F). Data were reduced using the PAP program.

Concentrations of Li and Rb were measured by ISP OES. Carefully selected grains of nalivkinite were digested in heated polypropylene tubes with 40 % hydrofluoric acid (HF) and nitric acid (HNO_3). The resulting solution was evaporated twice with addition of HNO_3 to dissolve the dry residue. The solution was analysed with a Varian ICP-OES VISTA Pro. The content of H_2O was determined by the Penfield method using 40 mg of sample. The results of analysis are shown in table 1 (analyses 1 – 12). Lithium content and of some other components in nalivkinite were also determined by S.G. Simakin using secondary-ion mass spectrometry (SIMS) with a Cameca IMS-4F (Institute of Microelectronics and Information science, Russian Academy of Science). Concentrations of each element were calculated from the intensity relations of the ion current of an element normalized to 30 Si^+ using calibration constants from reference samples. For three points, the data are as follows (wt. %): Li_2O – 1.03, 1.23, 0.99; Rb_2O – 1.14, 0.92, 0.97; K_2O – 2.61, 2.37, 3.21; F – 0.74, 0.77, 0.89. Taking into account the precision of the SIMS method and the natural variability of these constituents in nalivkinite, these results are in good agreement with those obtained by electron-microprobe analysis and ICP OES. The composition of the nalivkinite grain on which the single-crystal X-ray data were collected (and the crystal structure was refined) is given in table 2 (column B). The FeO (i.e., Fe^{2+}) content was determined on the sample of grains from which the grain used for structural analysis was extracted. A weight of 10.32 mg was digested in a fluoroplastic crucible by boiling in 40% HF to which a known

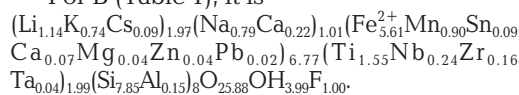
amount of the ammonium vanadate solution was added, the abundance of which was titrated with 0.01M Mohr's Salt solution (Sizykh et al., 1977). Two aliquots of diabase W-2a reference sample were analysed simultaneously to check for accuracy. The measured content of FeO in nalivkinite is 29.46 wt. %. This value is close to the amount of FeO measured by electron microprobe: 30.84 wt. %, indicating that there is negligible Fe_2O_3 in nalivkinite.

Inspection of the table of nalivkinite analyses shows that some variation in Fe, Mn, Nb, Cs, F and some other elements (that are not essential with regard to the nomenclature of the group). Some of these variations are shown in the BSE image in figure 2.

The chemical formula of nalivkinite, normalized on the basis of 8 (Si + Al) atoms using the average composition of A (Table 1) is as follows:



For B (Table 1), it is



The ideal formula of nalivkinite is: $\text{Li}_2\text{NaFe}_7^{2+}\text{Ti}_2(\text{Si}_8\text{O}_{24})\text{O}_2(\text{OH})_4\text{F}$.

The compatibility index, calculated for the average composition of A is as follows:

$$(1 - K_p/K_c) = 0.024 \text{ (excellent);}$$

that for B is $(1 - K_p/K_c) = 0.013$ (superior).

X-Ray powder diffraction data

X-ray powder diffraction data (tab. 2) were recorded with a RKU-114M camera (114.6 mm diameter), and with a DRON-2.0 X-ray diffractometer using quartz as an internal standard. The X-ray powder diffraction pattern of nalivkinite is similar to that of astrophyllite. The unit-cell parameters refined from the powder data are as follows: $a = 5.3707(2)$ Å, $b = 11.9327(5)$ Å, $c = 11.6546(4)$ Å, $\alpha = 113.384(1)^\circ$, $\beta = 94.547(1)^\circ$, $\gamma = 103.047(1)^\circ$, $V = 655.85(2)$ Å³, with $Z = 1$.

Crystal structure

The crystal structure of nalivkinite (Uvarova *et al.*, 2008) was refined to an R_1 index of 6.26% based on 2041 observed [$\text{Fo} > 4\sigma(\text{FI})$] unique reflections measured with $\text{MoK}\alpha$ X-radiation on a Bruker P4 diffractometer equipped with a Smart 4K CCD

Table 1. Chemical composition of nalivkinite, wt. %

Compo- nents	A													B
	1	2	3	4	5	6	7	8	9	10	11	12	Avg	
SiO ₂	36.57	36.45	35.41	35.81	35.95	36.46	36.30	35.02	35.88	36.01	35.08	36.13	35.92	36.11
Al ₂ O ₃	0.44	0.65	0.78	0.59	0.65	0.48	0.76	1.29	0.52	0.58	0.58	0.72	0.67	0.58
TiO ₂	10.26	10.03	10.58	11.14	10.40	11.11	10.41	9.23	10.91	10.94	10.57	10.40	10.50	9.48
Nb ₂ O ₅	1.39	1.60	1.74	1.07	1.90	1.81	1.49	3.35	1.16	1.13	1.19	1.93	1.65	2.40
ZrO ₂	0.58	0.99	0.61	0.65	0.54	0.40	1.34	0.62	1.16	1.02	0.89	0.74	0.80	1.47
MnO	5.01	5.21	5.16	5.05	5.19	5.53	5.33	5.42	5.13	5.31	5.58	5.15	5.26	4.86
FeO	33.47	32.56	32.84	32.53	32.52	32.71	33.66	33.11	32.92	32.30	32.11	32.43	32.76	30.84
CaO	1.38	1.43	1.19	1.12	1.42	1.06	1.43	1.27	1.28	1.31	2.43	2.20	1.29	1.24
MgO	0.00	0.11	0.00	0.12	0.04	0.18	0.13	0.00	0.11	0.30	0.02	0.03	0.09	0.11
Na ₂ O	1.54	1.72	1.81	1.68	1.58	1.59	1.51	1.73	1.55	1.34	1.67	1.76	1.62	1.88
K ₂ O	2.62	2.35	2.58	2.31	2.48	2.49	2.56	3.12	2.37	2.32	2.43	2.20	2.49	2.68
Cs ₂ O	1.56	1.07	1.46	1.57	1.89	1.76	0.23	0.57	1.27	1.70	1.80	1.87	1.40	0.93
Rb ₂ O*	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	0.85	
Li ₂ O*	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.18	1.30
H ₂ O**	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13	3.13	2.75
F	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	1.45
Total	100.73	100.08	100.07	99.55	100.47	101.49	101.64	100.64	100.17	100.17	99.11	100.61	100.36	100.20
-O=F ₂	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.32	0.61
Total	100.41	99.76	99.75	99.23	100.15	101.17	101.32	100.32	99.85	99.85	98.79	100.29	100.04	99.59

A – analyses of grains from sample No 5321. Main components determined by electron microprobe JCXA-50A;

*Li₂O and Rb₂O determined by ICP OES;

**H₂O determined by the Penfield method; analysts: A.A. Agakhanov, L.A.Pautov.

B – analysis of the single crystal used for structure refinement of nalivkinite from the same sample. Main components determined by electron microprobe Cameca SX-100; Li₂O by ICP MS; H₂O was calculated from the crystal structure; total also includes SnO₂ – 0.89; Ta₂O₅ – 0.61; ZnO – 0.23; PbO – 0.39 wt. % (Uvarova et al., 2008).

detector. The cell parameters are as follows: $a = 5.3745(6)$ Å, $b = 11.9299(15)$ Å, $c = 11.6509(14)$ Å, $\alpha = 113.325(3)^\circ$, $\beta = 94.524(2)^\circ$, $\gamma = 103.080(2)^\circ$, $V = 656.2(2)$ Å³, space group $P-1$, $Z = 1$.

The structure of nalivkinite is similar to that of triclinic astrophyllite (Uvarova et al., 2008, Piiilonen et al., 2003). It consists of alternating heteropolyhedral sheets (H) of composition $[\text{TiSi}_4\text{O}_{12}]^{8-}$, with (SiO₄) tetrahedra and D (= Ti) octahedra, and octahedral sheets (O), with M (1), M (2), M (3) and M (4) octahedra connected by common edges. The H and O sheets are stacked along the c -axis, forming HOH layers that link through common vertices (F atoms) of D octahedra. The interlayer space contains the A (1) and B sites. There are four tetrahedrally coordinated T sites, five octahedrally coordinated M sites and two

interstitial A sites, A (1) and B in nalivkinite. The T sites, with $\langle T-O \rangle = 1.623$ Å, are occupied mainly by Si with minor Al. The occupancy of the octahedrally coordinated M sites is as follows: M (1) = (Fe_{1.97}²⁺□_{0.03}) with $\langle M(1)-O \rangle = 2.164$ Å; M (2) = Fe_{2.00}²⁺ with $\langle M(2)-O \rangle = 2.146$ Å; M (3) = (Fe_{1.03}²⁺Mn_{0.97}) with $\langle M(3)-O \rangle = 2.140$ Å; M (4) = (Fe_{0.97}²⁺Mg_{0.03}) with $\langle M(4)-O \rangle = 2.140$ Å; $D = (\text{Ti}_{1.72}\text{Nb}_{0.16}\text{Zr}_{0.08})$ with $\langle D-O \rangle = 1.959$ Å. Of the two interstitial A (1) and B sites, A (1) splits into two half-occupied sites, A (1a) and A (1b), with A (1a) – A (1b) = 1.28(4) Å. The [5]-coordinated A (1b) site is occupied by $[\text{Li}_{1.00}\square_{0.00}]$ with $\langle A(1a)-O \rangle = 2.280$ Å, which gives 1.00 Li *apfu*; the [10]-coordinated A (1a) site is occupied by $(\text{K}_{0.75}\text{Li}_{0.14}\text{Cs}_{0.09}\text{Na}_{0.02}\square_{1.00})$ with $\langle A(1a)-O \rangle = 3.310$ Å, which gives $(\text{K}_{0.75}\text{Li}_{0.14}\text{Cs}_{0.09}\text{Na}_{0.02})$

apfu. The aggregate content of the A(1) site is $(\text{Li}_{1.14}\text{K}_{0.75}\text{Cs}_{0.09}\text{Na}_{0.02})_{2.00}$. The [10]-coordinated B site is occupied by $(\text{Na}_{0.78}\text{Ca}_{0.22})$ with $\langle\text{B}-\text{O}\rangle = 2.612 \text{ \AA}$. All site occupancies are reported in accord with Uvarova *et al.* (2008).

In nalivkinite, lithium is dominant at the A(1) site, which gives 2 *apfu*, and the end member is written as Li_2 , whereas in astrophyllite, K is dominant at this site. Thus, nalivkinite, $\text{Li}_2\text{NaFe}_7^{2+}\text{Ti}_2(\text{Si}_8\text{O}_{24})\text{O}_2(\text{OH})_4\text{F}$, is the Li analogue of astrophyllite, $\text{K}_2\text{NaFe}_7^{2+}\text{Ti}_2(\text{Si}_8\text{O}_{24})\text{O}_2(\text{OH})_4\text{F}$, and the first Li mineral in the astrophyllite group.

The properties of astrophyllite and nalivkinite are compared in table 3.

The origin of nalivkinite

The mineral association and observed paragenesis of nalivkinite show that it is associated with fenitization. It seems likely that nalivkinite crystallized directly in a lithium-rich environment. It is possible that nalivkinite formed later as a result of Li-K ion exchange in astrophyllite. According to the work of Chelishchev (1972), astrophyllite is a typical ion-exchange mineral, whose interlayer sites serve as active sites of ion exchange (the ion exchanges Rb-K and Cs-K were experimentally proven, but exchange of K by Li was not studied).

The holotype specimen of nalivkinite is deposited at the Fersman Mineralogical Museum of the Russian Academy of Sciences, Moscow.

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This article is dedicated to V.D. Dusmatov's memory.

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Table 2. X-ray powder diffraction data of nalivkinite

Camera		Diffractometer		Calculated		<i>hkl</i>
<i>I</i>	<i>d</i>	<i>I</i>	<i>D</i>	<i>I</i>	<i>d</i>	
		100	10.56	100	10.52	0 0 1
		8	9.88	10	9.83	0 -1 1
		2	5.80	4	5.79	0 -2 1
		1	5.26	2	5.26	0 2 0
		2	4.39	4	4.40	-1 -1 1
		2	4.31	3	4.33	-1 2 0
				2	4.31	-1 2 0
		1	4.05	2	4.06	0 2 1
		2	3.76	3	3.76	-1 2 1
				1	3.75	1 -1 2
10	3.56	100	3.51	27	3.502	0 0 3
		3	3.26	2	3.27	0 -3 3
				6	3.25	-1 -1 3
		3	3.07	4	3.06	-1 2 2
		3	3.03	5	3.02	1 -2 3
		2	2.965	1	2.966	0 3 1
				2	2.965	0 1 3
		3	2.855	5	2.853	1 1 2
10	2.79	80	2.780	20	2.780	1 -4 2
				18	2.780	-1 -3 1
7h	2.64	45	2.638	18	2.650	-2 1 1
				12	2.627	0 0 4
10	2.57	70	2.578	20	2.578	1 3 0
				21	2.575	1 -4 3
2	2.49	15	2.474	15	2.475	-2 1 2
1	2.40	4	2.399	5	2.398	-1 4 1
4	2.30	30	2.295	7	2.296	1 3 1
2	2.22	14	2.223	10	2.223	-2 1 3
5	2.10	35	2.106	5	2.106	-1 4 2
1	2.05	9	2.041	6	2.042	2 -1 3
			1.963	1	1.963	-2 1 4
			1.930	1	1.930	0 -6 3
4	1.760	30	1.760	5	1.761	1 3 3
			1.757	5	1.758	1 -4 6
2	1.729	10	1.728	6	1.728	-2 1 5
2	1.664	15	1.660	10	1.660	0 -7 3
2	1.622	11	1.620	2	1.619	-1 4 4
			1.595	1	1.594	-2 0 6
1	1.576	6	1.576	7	1.577	3 -5 1
				7	1.576	-3 -2 2
1	1.432	4	1.432	2	1.433	-1 4 5
				2	1.430	-1 -3 8
1	1.407	2	1.407	2	1.408	2 -8 2
				2	1.406	-2 -6 4

Camera: *RKU 114M*, Fe-anode, Mn filter, *URS-501M*;

Diffractometer: *DRON-2.0*, Fe – anode, graphite monochromator, scan rate 1 deg/min, quartz as internal standard.

Analyst *A.A. Agakhanov*.

The most intense lines are shown in bold.

Table 3. Comparison of the properties of nalivkinite and astrophyllite

	Nalivkinite	Astrophyllite
Formula	$K_2NaFe_7^{2+}Ti_2Si_8O_{26}(OH)_4F$	$Li_2NaFe_7^{2+}Ti_2Si_8O_{26}(OH)_4F$
Sp.group	<i>P</i> -1	<i>P</i> -1
<i>a</i> , Å	5.3776(6)	5.3745(6)
<i>b</i> , Å	11.899(1)	11.9299(15)
<i>c</i> , Å	11.662(1)	11.6509(14)
α , °	113.114(2)	113.325(3)
β , °	94.630(2)	94.524(2)
γ , °	103.090(2)	103.080(2)
Z	1	1
Strong	10.6 (100)	10.56 (100)
lines of	3.51 (80)	3.50 (100)
X-ray - powder diffraction pattern	2.648 (45)	2.648 (45)
d_{obs} (Å) (<i>l</i>)	2.578 (70)	2.578 (70)
	2.474 (15)	2.474 (15)
	2.295 (30)	2.295 (30)
	2.106 (35)	2.106 (35)
	1.760 (30)	1.760 (30)
	1.660 (15)	1.660 (15)
Colour	Brownish-golden	Bronze-yellow, golden
Lustre	Pearly to vitreous	Pearly
Density _{meas.} (g/cm ³)	3.3–3.4	3.32(2)
Density _{calc.} (g/cm ³)	3.315	
Mohs hardness	3	3
Optic sign	Biaxial (+)	Biaxial (+)
2 <i>V</i>	70–80°	68°
n_p	1.678	1.705
n_m	1.703	1.716
n_g	1.733	1.745

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RARE MINERALS OF In, Cd, Mo, AND W IN GOLD-BASE METAL VEINS OF THE BUGDAYA Au-Mo(W)-PORPHYRY DEPOSIT, EASTERN TRANSBAIKALIA, RUSSIA

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New data on a number of rare minerals of In, Cd, Mo, and W, which have been obtained using modern analytical techniques, are described in this article. These minerals have been identified in gold-rich polymetallic ore superimposed on Mo(W) stockwork porphyry mineralization. Indium mineralization presents extremely rare dzhallindite $\text{In}(\text{OH})_3$ that was previously described in Russia only from deposits Dzhallinda, Amur region and Verkhnee, Primorsky krai as supergene mineral. Tungsten and molybdenum are concentrated in rare intermediate phase of the wulfenite-stolzite series $\text{Pb}(\text{W}_{0.74}\text{Mo}_{0.26})\text{O}_4$, and Cd, in greenockite CdS. Occurrence of well-shaped cubic crystals of dzhallindite exclusively in quartz and association of the mineral with sphalerite, native silver, and electrum allow suggesting its hypogene origin (in contrast to previous findings as supergene pseudomorphs after indium sulfide). However, additional investigation is required to establish formation conditions of dzhallindite.

4 figures, 22 references.

Keywords: dzhallindite, Mo-bearing stolzite sphalerite, greenockite, Bugdaya porphyry deposit, Eastern Transbaikalia, polymetallic veins, gold mineralization.

Geological structure, ore mineralogy, and stages of mineralization

The Bugdaya Au-Mo(W) porphyry deposit, eastern Transbaikalia located 18 km SW of the Shakhtama mine in the interfluvium of the Gazimur and Unda rivers is hosted in the central volcanic dome of concentric-radial structure. This dome is located in the southeastern large Variscan granitoid pluton that was intruded by the Late Jurassic subvolcanic granite-porphyry and rhyolite-porphyry.

Mo-W ore is hosted in a stockwork that is column-shaped in vertical section and oval, in plan of 1100 x 800 m in size. This stockwork comprises variably oriented quartz-molybdenite veins and veinlets (few to tens cm thick) with local scheelite, which arrange around stock of silicified rhyolite (granite) porphyry. Gold (1–2 to 100–150 g/t, less frequent higher) is hosted in steep quartz-sulfide veins (250–300 m long and from few to 3–4 cm thick), which also contain the main resources of Pb and Zn (Kharitonov *et al.*, 2003).

Our investigations indicated that ore of the Bugdaya deposit where about 70 minerals were identified is characterized by more variable and complex mineralogy that previously reported. Pyrite, galena, sphalerite, molybdenite, chalcocopyrite, and scheelite are the most abundant. Arsenopyrite, fahlores, As-rich pyrite, magnetite, and hematite are less abundant. Small amounts of various bismuth (aikinite series, matildite-galena series, and Cu-Ag-Pb-Bi-S system) and antimony (polybasite, pearceite, and their Te-bearing analogues; boulangerite; and bourmonite) minerals are frequently observed. Rare minerals are native silver, kustelite, tellurides and sulfotellurides, wurtzite, dzhallindite, and greenockite. Two latter minerals are described below. Gold-silver alloy with fineness ranging from 962 to 223 were found to be associated with minerals from base metal veins and veinlets.

Quartz is dominant gangue mineral; chalcedony, carbonates, muscovite (sericite), phlogopite, tourmaline, potassi-

um feldspar, kaolinite, smectites, and fluorite are minor. Covellite, chalcocite, bornite, ferrimolybdenite; rare ilsemannite and stolzite; cerussite, barite, and anglesite were described from supergene zone.

Four major stages of hydrothermal mineralization are recognized: (1) pre-ore; (2) quartz-molybdenite; (3) gold-base metal; and (4) post-ore (Kovalenker *et al.*, 2007). Pre-ore K-feldspatization and strong silicification occurred after emplacement of sub-volcanic rhyolite-(granite)-porphyry stock. Then, Mo-W stockwork of the quartz-molybdenite stage was formed. Gold-base metal veins accompanied with sericitization and pyritization of wall rocks are located in the structures cutting Mo-W mineralization. Precipitation of late stage chalcedony, quartz, and carbonates as veins and veinlets accompanied with argillization and insignificant redeposition of earlier minerals complete the hydrothermal mineral-forming process.

Rare dzhalindite and greenockite were probably precipitated at the end of gold-base metal stage.

Dzhalindite

Indium mineralization was found as dzhalindite $\text{In}(\text{OH})_3$ that had been previously described in Russia only from tin ore of deposits Dzhalinda, Amur region, Khingan Minor (Genkin and Murav'eva, 1963) and Verkhnee, Kavalerovo district Primorsky krai (Gorelikova *et al.*, 2008) as pseudomorphs after indite. Dzhalindite was identified at some tin deposits in the other countries including Zinnwald-Cinovec (border between Czechia and Germany) (Jansa *et al.*, 1998); Mangabeira, Brazil (Moura and Francisquinibotelho, 2000); and Mount Pleasant, Canada (Sutherland, 1971). The mineral was found at the Flambeau Cu-Au-Ag deposit, Wisconsin, USA; Kamazu Au-Ag-Te-Mn deposit, Japan; and Lavrion, Greece nickel (annabergite) deposit. Octa-

hedral crystals of dzhalindite were mentioned, when hydroxides of rare and trace elements at the Tsumeb deposit, Namibia and deposits of Nevada, USA were described (Yakhontova and Zvereva, 2000).

Complete description of dzhalindite from deposits in other countries is available only from the Mount Pleasant deposit (Sutherland, 1971), where this mineral associated with quartz, calcite, and galena was found in veinlet cutting sphalerite.

Mode of occurrence and mineral assemblage. For the present, we identified cubic crystals of dzhalindite $\text{In}(\text{OH})_3$ only in one section of quartz-sulfide vein at 50 m depth below surface. Ore minerals replacing minerals of quartz-molybdenite stage occurred close to dzhalindite are quartz-galena-chalcopyrite-sphalerite segregations with small amount of pyrite and fahlore (predominant tennantite) and enriched in gold (predominant electrum with fineness 698 to 748). Aggregates of base metal sulfides are strongly fractured, healed by tennantite, then brecciated again, and cemented by fine-grained quartz with crystal size ranging from 40 to 70 μm .

Dzhalindite presents square and rectangular well-crystallized grains, and less frequent other sections of cube (triangular, rhombic, trapezoid, and hexagonal) (Fig. 1, 2). Size of crystals varies from 30 to 94 μm , most frequent, from 50 to 70 μm . Locally, intergrowths of several crystals are observed. Frequency of dzhalindite is 70 crystals in section 4 x 2 cm in size.

Dzhalindite occurs only in the areas, where late quartz cements fragments of grains of high-Fe sphalerite-I (4.1–6.54 wt. % Fe). According to spectral analysis, this sphalerite contains, %: 0.03–3 Cu, 0.1–0.2 Cd, 0.03–0.5 Mn, 0.008–0.08 Ag, and 0.002–0.05 In. Fine disseminated chalcopyrite is frequently observed in sphalerite-I. Few 1 mm grains of galena-I intergrown with rare tennantite occur among fragments of sphalerite-I.

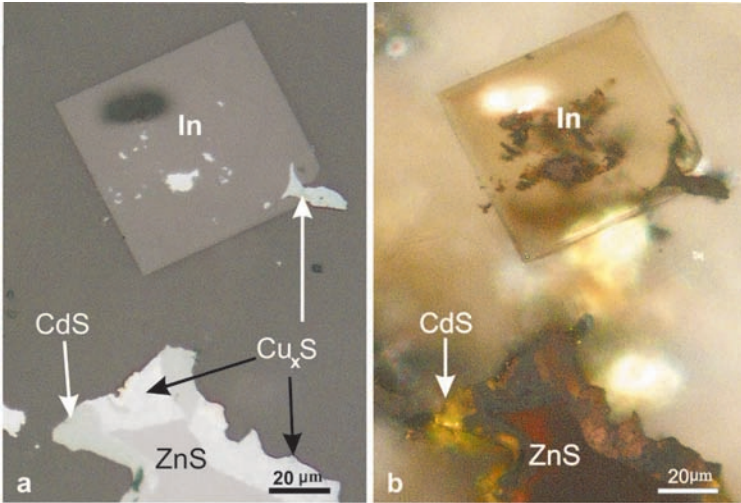


Fig. 1. Dzhaldindite and associated minerals. (a) Photomicrograph of well-shaped crystal of dzhaldindite (In) overgrown by minerals of the CuS-Cu₂S (Cu_xS) system in quartz (dark gray), the same minerals together with greenockite (CdS) overgrow sphalerite (ZnS), thin polished section. (b) Photomicrograph of the same dzhaldindite crystal that is transparent with weak coloration, yellow reflections of greenockite are well seen in sphalerite, cross polars, strong light. (c) BSE image of dzhaldindite (rotated 30°) with pronounced zoning. (d) BSE image of greenockite rim (light gray) with admixture of chalcocite in quartz.

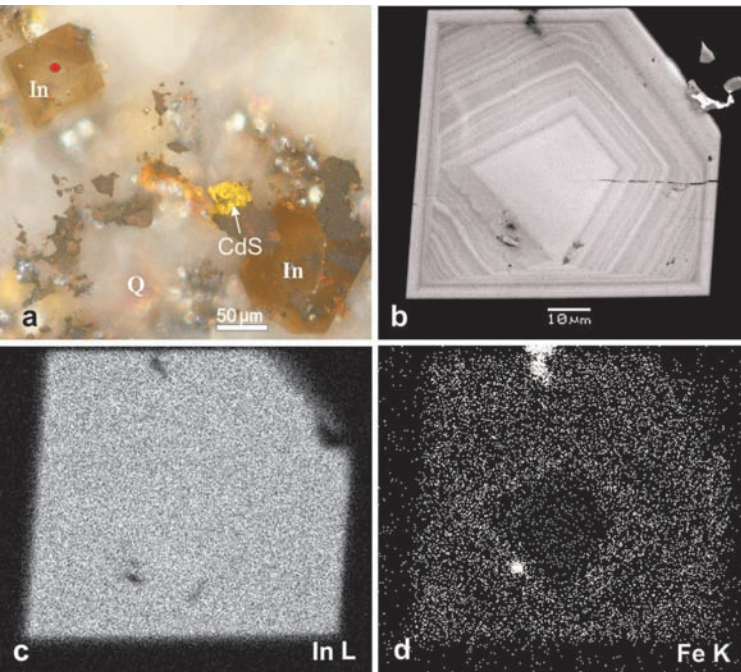
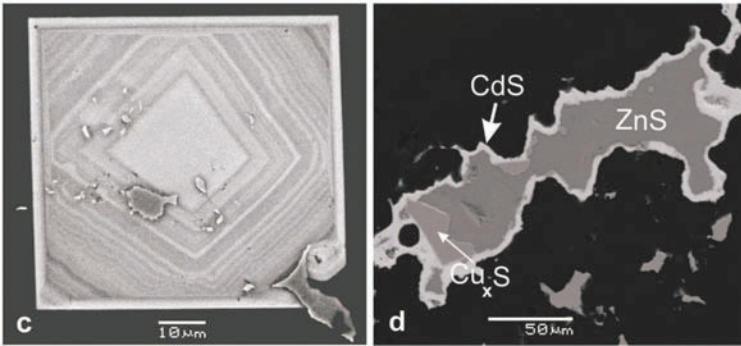


Fig. 2. Fe-rich variety of dzhaldindite and distribution of Fe and In in it. (a) Photomicrograph of brown crystals of dzhaldindite in quartz; one of the crystals (right low) is overgrown by minerals of the CuS-Cu₂S system; yellow mineral is greenockite; thin polished section, cross polars, strong light. (b) BSE image of dzhaldindite crystal (red point in Fig. 2a). (c) X-ray map of In in the crystal; (d) X-ray map of Fe (zoning is remarkable, Fe is lower in the core) in the crystal.

Most fragments of sphalerite-I are rimmed by thin (from portions to first tens μm ; less frequent more) aggregates of the $\text{CuS-Cu}_2\text{S}$ system minerals (Fig. 1). Microscopically and chemically, covellite and phases $\text{Cu}_{1.79}\text{S}$ $\text{Cu}_{1.82}\text{S}$, which are optically and compositionally close to chalcocite were identified among these minerals. Non-stoichiometric composition is probably caused by fine admixture of covellite in chalcocite but other minerals of the $\text{CuS-Cu}_2\text{S}$ system such as djurleite and anilite are also possible. Elevated Ag (1.1–1.7 wt. %) is a feature of these minerals. Silver substitutes univalent copper or is related to fine inclusions of Ag-bearing minerals. In addition to these minerals, greenockite (Fig. 1a, b, d) and galena-II are frequently observable in the rims. Development of galena-II after covellite and its few tens μm thick veinlets filled interstices between grains of greenockite and chalcocite are remarkable.

Sphalerite-II, greenockite, pyrite, native silver, and electrum were identified in dzhalindite-bearing quartz. Few sphalerite-II is observed adjacent to fragments of sphalerite-I as euhedral isometric or slightly elongated and rounded crystals of several tens μm in size. In contrast to sphalerite-I, it is characterized by strong brownish yellow reflections and does not contain inclusions of chalcopyrite; rims of the other minerals are extremely rare.

Pyrite was observed in small amount as trails of tiny (4–5 μm) well-shaped cubic crystals. Such trails can overgrow crystals of dzhalindite.

Relatively small amount of native silver is hosted only in dzhalindite-bearing quartz as intergrowths of curved 80 μm long wire-shaped crystals and less frequent, as clotted segregations with uneven lobe-shaped outlines of few to first tens μm in size. Native silver (8 point analyses) is distinguished by insignificant (tenths wt. %) Zn, Cu, and S; 0.04–0.3 wt. % Te and 0.2–0.43 wt. % Au.

Electrum is present in quartz in slightly less amount than native silver and occurs as small clotted segregations and isometric grains (2–70 μm) with imperfect faces. Much larger (up to 176 μm) segregations of electrum in sphalerite-I are isometric or slightly elongated and have smooth and more frequently rounded outlines. Fineness of electrum (about 700) from this assemblage (mean of 40 point analyses) is usual for rich ore and slightly lower than average value (about 730) at the deposit.

All these minerals spatially associated with dzhalindite are not intergrown with it and occur not more than tens microns of the mineral. In single instance, 4 μm inclusion of electrum with approximately equal weight portions of Au and Ag was observed in dzhalindite.

Optical parameters and physical properties. Dzhalindite was identified on the basis of composition, optical parameters, and symmetry similar to synthetic phase $\text{In}(\text{OH})_3$ produced by reaction of alkalis and salts of indium during boiling (Fricke, Seitz, 1947) and natural dzhalindite, that was described as new mineral in (Genkin and Murav'eva, 1963). Due to small sizes of the dzhalindite segregations, X-ray diffraction study of the mineral was failed.

Dzhalindite is dark gray under reflected light and significantly brighter than quartz but darker than scheelite. Reflectance of dzhalindite is about 8–9% that is consistent with measurements at $\lambda = 589 \text{ nm}$ (yellow light) 8.2% (Genkin and Murav'eva, 1963). Internal reflections are weak, whitish or yellowish, with slight translucence on crystal margins.

Cross polars microscopic observation at maximum lighting shows that sections of the dzhalindite cubes are transparent and semitransparent, locally pinkish-yellowish or practically colorless, with yellowish amber (to light brown) tint (Fig. 2a). Between these varieties, there are all intermediate varieties dominated by practically col-

orless transparent crystals (Fig. 1b). Relief is substantially lower than that of quartz and slightly lower than sphalerite. Dzhalindite is well polished; surface of crystals is smooth and flaw-free.

All crystals of dzhalindite are zoned with alternated darker and lighter zones. It is clearly seen in back scattered electron (BSE) images (Figs. 1c, 2b) made with JSM-5610 and JSM-5300 analytical scanning electron microscopes (ASEM). ASEM study of the crystal surface shows that zoning is also displayed in relief probably indicating different density and hardness of zones. The revealed zoning is caused by different composition of the zones (Fig. 2 d).

Thickness of the zones decreases outward from 4 μm to portions of microns. Intermediate zones have smoothed tops (edges) with smoothing increasing to the margin that can testify to certain dissolution of the growing crystals. Same faces of the intermediate zones are curved. Outer zone of the crystal is compared with core and nearly elsewhere is cubic. In many cases, these outer zones (as crystal faces) are oriented at approximately 45° to the earlier intermediate zones. The normal rhythmic zoning without crystallographic reorientation of the outer zone and final faces occurs in the smaller crystals. In such crystals, no features of dissolution (smoothed apices, inclusions of other minerals, roughness of faces of intermediate zones etc.) during growth are observed.

The chemical composition of the mineral was determined with a JSM-5300 analytical scanning electron microscope equipped with energy dispersion system. The near colorless transparent variety of dzhalindite contains, wt. %: 63.27 In, 34.68 O, and insignificant Fe. In this case, Fe is minimal (0.61 wt. %) in homogeneous core and reoriented outer zone of the crystals. Slightly more Fe (1.08 wt. %) is detected in one of the darker (in back-scattered electrons) intermediate zones. The light brown semitrans-

parent variety of dzhalindite was analyzed for comparison (Fig. 2). Like the transparent variety, Fe content in the core is low but slightly higher (0.9 wt. %). Concentration of iron in one of the darkest zones is four times higher (3.6 wt. %). Thus, the observable zoning in dzhalindite results from oscillated Fe content in the crystals. It should be noted, the iron concentration in dzhalindite from type locality is much higher ($\text{In}/\text{Fe} = 4$) that is caused different mode of its formation, pseudomorphous replacement of indite, which contains Fe.

Species of iron in dzhalindite are not yet established. Light brown tint of the mineral can indicate three-valence iron and in this case, Fe is probably present as fine compounds rather than substitutes In in the mineral structure because of sufficiently great difference in ionic radii (nm, coordination number is 6): 0.076 Fe^{3+} and 0.094 In^{3+} . Presence of iron as fine compounds of Fe^{3+} is confirmed by variable mineral color that is probably caused by local enrichment of mineralizing fluids in Fe^{3+} .

According to (Roy and Shafer, 1954), just $\text{In}(\text{OH})_3$ is stable phase at 245°C and below (pressure 703 kg/cm^2). At temperature higher than 245° (the same pressure), $\text{In}(\text{OH})_3$ transformed into InOOH . Over 435°C , only phase In_2O_3 is stable. The temperature of formation of studied dzhalindite can be estimated only indirectly, because there are no fluid inclusion data for host quartz and dzhalindite itself. However, homogenization temperature of fluid inclusions in gold-bearing quartz from similar quartz-base metal veins at the Bugdaya deposit ranges from 225 to 205°C (Kovalenker *et al.*, 2007); inclusions in cleiophane homogenize at $217 - 140^\circ\text{C}$. Fluids are sulfate-hydrocarbonate with high degree of oxidation ($\text{CO}_2/\text{CH}_4 > 100$). The results obtained combined with spatial association of dzhalindite with low-temperature minerals (gold-silver mineralization, sphalerite-II, greenockite, and galena-II) most probably testify to the

formation temperature of the minerals no higher than 225°C. All these data can indirectly indicate that in contrast to supergene dzhalindite from the Dzhalinda and Verkhnee deposits, this mineral found at Bugdaya is probably formed under hypogene conditions. However, additional study is required to infer certain conditions of its formation. Yakhontova and Zvereva (2000) emphasized ambiguous formation conditions of dzhalindite; Sutherland (1971) just states a fact that dzhalindite cuts sphalerite.

Greenockite

Mode of occurrence and mineral assemblage. Greenockite is constantly associated with dzhalindite and is observed only in sections with dzhalindite. It is more abundant than sphalerite-II. The mineral occurs as irregular and more frequent, elongated rounded clusters up to 50 µm in size hosted in late quartz usually adjacent to dzhalindite. Traces of the mineral are observed some distance of dzhalindite. Greenockite as few to 10 µm thick rims around sphalerite-I (Fig. 1d) is extremely characteristic. Locally, chalcocite invading to both minerals occurs along contact between sphalerite-I and greenockite. Locally, late galena emplaced as fine inlets into intergrain space of sphalerite-I and greenockite fills interstices between these minerals. No intergrowths of greenockite with other minerals were established.

Optical parameters and physical properties. Under reflected light, greenockite is gray with weak greenish tint. Its reflection is slightly higher than that of sphalerite. Cross polars microscopic observation at maximum lighting shows that greenockite is bright lemon or yellow, transparent or semitransparent (Figs. 1b, 2a). Strong internal reflections hide anisotropy. Relief is lower than that of sphalerite. Greenockite is well polished; surface of crystals is smooth and flawless.

The chemical composition of greenockite (2 point analyses) determined using a JSM-5300 analytical scanning electron microscope equipped with energy dispersion system is close to stoichiometric, wt. %: 74.08 – 76.5 Cd, 21.93 – 23.5 S. Theoretical composition is as follows, wt. %: 77.81 Cd and 22.19 S. Deficiency of Cd is caused by admixture of Zn (up to 2.19 wt. %) and Cu (up to 1.71 wt. %).

Conditions of formation. According to most publications, natural greenockite is formed exclusively under low-temperature conditions. In this case, it can be both supergene and hypogene. Often, the exact determination of the origin is difficult. It is caused by similar morphology of supergene and hypogene grains (for example, in our case, a presence of the mineral as rims) and associated minerals whose precipitation is possible in both settings. Recently, papers, where greenockite is attributed with high validity to hypogene minerals, were published. For example, Pletnev (1998) assigned greenockite to hypogene minerals. Greenockite is present in sublimates of the lowest temperature (300 – 600°C) fumarole field of the Kudryavy volcano (Chaplygin, 2008). According to fluid inclusion study (Tombros *et al.*, 2005), deposition temperature of the Ag-Au-Te epithermal mineralization associated with greenockite is 215°C that is within range of precipitation of late quartz and cleiophane 225 – 140°C given when dzhalindite was described.

Impurities of Cd in sphalerite (up to tenths wt. %) and tetrahedrite containing up to 2.97 – 3.64 wt. % Cd in rich ore were probable source of cadmium to form greenockite. Cadmium appears to release during dissolution and recrystallization of these minerals at late stage of hydrothermal process.

Mo-bearing stolzite (“chillagite”)

Name of rare mineral “chillagite” existed for almost whole last century starting

¹ – The mineral that we identified should be apparently called Mo-rich stolzite due to strong predominance of W over Mo.

* – mineral was discredited by the Commission on New Minerals and Mineral Names, International Mineralogical Association (CNMNMN) IMA.

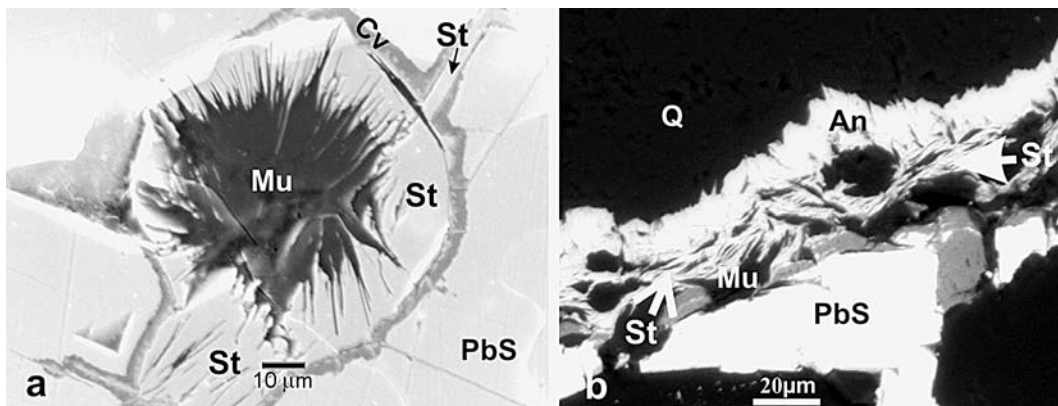


Fig. 3. BSE images of the stolzite-wulfenite series mineral. (a) Rosette-shaped Mo-rich stolzite (St) in galena (PbS); the mineral fills fracture in galena and is rimmed by covellite (Cv) (upper part); muscovite (Mu) in the core of Mo-rich stolzite; white spot in the upper part is sputtering defect. (b) Veinlet-shaped Mo-rich stolzite intergrown with anglesite (An) at the contact between galena and quartz (Q); laths of muscovite (Mu) are observed in Mo-bearing stolzite.

from the first original description of this mineral in 1912 from Christmas Gift Mine, Chillagoe, Queensland, Australia (Ullman, 1912). The mineral turned out intermediate member of the $PbWO_4$ (stolzite) - $PbMoO_4$ (wulfenite) solid solution series, where stolzite and wulfenite have the same space group $I4_1/a$. Later investigation of the mineral from the same deposit showed that it should be considered as W-rich wulfenite, which, in contrast to its pure variety, crystallizes in space group $I4$ due to W-Mo ordering (Jury *et al.*, 2001).

The phases similar in composition and called as "chillagite" were described from ores of several deposits in the eastern Transbaikalia (Syritso *et al.*, 1964), including the Shakhtama mine group in Gazimur-Zavodsky district (Chureva, 1948) and Dzhida tungsten deposit (Korzinsky *et al.*, 1959). It was found at deposits in other regions (Smol'yaninova *et al.*, 1963; Yushkin *et al.*, 1972).

Mode of occurrence and mineral assemblage. The mineral was identified in the vein gold-base metal mineralization superimposed on the earlier tungsten-molybdenum stockwork. Such superimposition resulted in the complex Au-Ag-Mo-W-Pb-Zn-Bi mineralization. In addition, in consequence

of supergene transformation (sampling depth is 50 m below surface) mineralogy of ore became more complex and along with appearance of ferrimolybdate and less frequent ilsemannite formed after molybdenite, this rare intermediate phase of the lead molybdate-tungstate series fills fractures and cavities in galena and some other minerals of the gold-base metal veins.

The sample containing Mo-rich stolzite is highly sulfidized gold-rich fragment of vein with content of sulfides about 75%. Sulfides are dominated by practically fresh pyrite of two generations, chalcopyrite, and galena with covellite and insignificant chalcocite, which occur as thin films on these minerals or fill microfractures in them. Other minerals, sphalerite, various sulfosalts including tetrahedrite and Cd-bearing tetrahedrite, Te-bearing polybasite (average ~4% Te), matildite, and wittichenite are subordinated. Quartz is predominant gangue mineral. In addition, there are muscovite (no more than 2%) and anglesite (no more than 1%) filling fractures in quartz and galena. In the sample, we observed extremely great amount (for this deposit) of native gold and electrum grains of three generations with fineness ranging from 962 to 504. Gold-silver phases cutting covellite

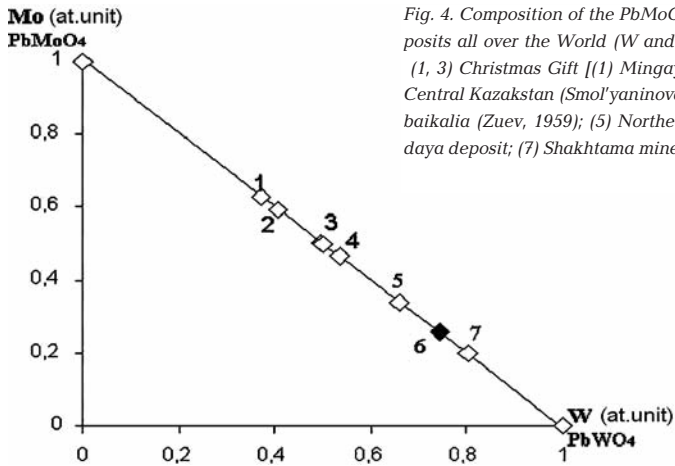


Fig. 4. Composition of the PbMoO_4 - PbWO_4 series minerals from various deposits all over the World (W and Mo concentrations – in atomic percent). (1, 3) Christmas Gift [(1) Mingaye, 1916; (3) Ullman, 1912]; (2) Akchatau, Central Kazakhstan (Smol'yaninova and Senderova, 1963); (4) Eastern Transbaikalia (Zuev, 1959); (5) Northeastern Russia (Gladyshev, 1949); (6) Bugdaya deposit; (7) Shakhtama mines, Eastern Transbaikalia (Chureva, 1948).

as thin (1–3 μm) veinlets have the lowest fineness.

Mo-rich stolzite occurs predominantly in cavities and along cleavage in galena; and less frequent, at the contact of galena with quartz, muscovite and other minerals of the gold-base metal veins (Fig. 3). Therefore, galena and occasionally other sulfides of the Bugdaya deposit are enriched in molybdenum and especially in tungsten (up to 4125 g/t W), with inclusions of primary minerals of these elements being absent in them. Mo-rich stolzite overgrows laths of potassium mica if they occur in galena or at contact with it. Segregations of Mo-rich stolzite are locally rimmed by covellite (Fig. 3a). Mo-rich stolzite is also observed in veinlets as intergrowths with anglesite (Fig. 3b).

Optical parameters and physical properties. Segregations of Mo-rich stolzite do not exceed hundredths mm in size. It occurs as spear- or lath-shaped crystals elongated along cleavage and locally slightly curved with the length/width ratio ranging from 6 to 10. In cavities, the mineral occurs as rosette radiant intergrowths (Fig. 3a). Under reflected light, it is light gray, with reflection being higher than that of anglesite and close to sphalerite. Mo-rich stolzite is anisotropic with remarkable birefractance that is slightly smoothed by very strong yellowish internal reflections. Under electron

beam, the mineral has bluish-greenish luminescence with intensity close to fluorite and scheelite.

The chemical composition of the mineral determined with a CAMECA MS-46 electron microprobe corresponds to formula $\text{Pb}(\text{W}_{0.74}\text{Mo}_{0.26})\text{O}_4$. Insignificant Fe, Ca, and in one analysis Sr were detected. The W/Mo ratio of previously described "chillagites" widely ranges from 0.59 to 4.03 (Fig. 4). The chemical composition of the examined mineral significantly dominated by W (W/Mo = 2.9) is the closest to "chillagite" from the Shakhtama mines. Small sizes of the grains prevented more detailed study of this mineral, particularly, investigation of its crystal structure. Intimate association of examined Mo-rich stolzite with covellite and anglesite, which are characteristic minerals of the oxidized zone, indicate supergene origin of the mineral.

Conclusions

1. The following factors favored the formation of rare and exotic minerals at the Bugdaya deposit: (1) ore-forming fluids evolved from high-temperature through medium- and low-temperature to supergene; (2) juxtaposition (telescoping) of different stage mineral assemblages in some structures; and (3) multiple brecciation of

ores, corrosion and dissolution of minerals with release of trace elements and their incorporation into new compounds at local geochemical barriers.

2. According to spatial association of Cd and In minerals with early sphalerite, one of the major ore component, they were formed as a result of dissolution and recrystallization of sphalerite.

In-bearing early sphalerite is characteristic of many deposits in the eastern Transbaikalia, though indium content in this mineral rarely reaches tenths percent and intimate correlates with a presence of tin minerals at the deposits implying identification of Sn minerals at the Bugdaya deposit. It is more probable because at the neighboring Shakhtama Mo-porphyry deposit, where indium (up to 50 g/t) was detected in minerals of the base metal ore (bulk analysis), stannite was found (Sotnikov *et al.*, 1995).

Crystallization of dzhalindite and shape and composition of the mineral similar to phase synthesized by the reaction of ammonia with indium salts during boiling and mineral assemblages allow suggesting the formation of dzhalindite at the Bugdaya deposit as a result of neutralization of thermal solutions corroding sphalerite and containing indium released from the latter. The formation temperature of dzhalindite probably was close to that of late cleiophane (about 140°C). Planned study of fluid inclusions from dzhalindite will provide more valid conclusions on the origin of the mineral.

3. Despite greenockite was found at the uranium deposits in the eastern Transbaikalia, it is rare mineral in base metal ores of this region. Lack of local analytical equipment to study minerals probably prevented the findings of greenockite in ores of the base metal deposits in the eastern Transbaikalia, which were investigated in detail mainly in the middle of the last century. It should be added that Cd content in some generations of sphalerite from most de-

posits in the region is comparable to that in sphalerite from the Bugdaya deposit.

Coexisting greenockite and dzhalindite in ore of the Bugdaya deposit can indicate a generality of the processes, which formed these minerals.

4. Spatial combination of late gold-base metal and earlier high-temperature Mo-W mineralizations and ore fracturing favored the formation of rare supergene mineral of the $PbWO_4 - PbMoO_4$ series with formula $Pb(W_{0.74}Mo_{0.26})O_4$ and similar in composition to that at the Shakhtama mines at the near-surface levels of the Bugdaya deposit.

5. Localization of examined minerals in gold-rich areas, which are characterized by elevated jointing and combination of different stage assemblages is important to indicate multiple reworking of these areas of orebodies and unique formation conditions of such rare minerals.

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BLACK POWELLITE FROM MOLYBDENUM–URANIUM DEPOSIT

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New data on black powellite from a Mo-U deposit, South Kazakhstan are given. Bipyramidal crystals of the mineral have been found in intimate association with uranium minerals of the oxidized zone, including uranyl-arsenate mica (uramarsite) and uranyl silicate uranophane-beta. X-ray diffraction, infrared spectroscopy, differential thermal analysis (DTA), analytical scanning electron microscopy (ASEM), electron microprobe, X-ray fluorescence analysis (XRFA), and laser spectrography have been performed to examine the mineral. Two varieties of powellite have been identified: crystalline in uranophane and amorphous in uranate. The causes of black color of powellite are discussed. This coloration of powellite can be prospecting guide for deposits of radioactive elements. 9 figures, 10 references.

Keywords: powellite, uramarsite, uranophane, uranate, Mo-U deposit Bota-Burum, South Kazakhstan.

Tetragonal bipyramidal black crystals of 0.3–1 mm in size, whose chips are translucent in red attracted attention of mineralogists, when they studied oxidized zone of the Bota-Burum Mo-U deposit, South Kazakhstan. Isolated crystals are sealed in crystalline uranate (Fig. 1) (Sidorenko *et al.*, 2007). Intergrowths of these variably oriented crystals cover a surface (Fig. 1c) or heal cracks in host carbonated felsite porphyry. Regular black bipyramids were identified as inclusions in radiant aggregates (Fig. 2) of amber-coloured uranophane-beta (matrix mineral was determined by X-ray diffraction).

The composition of black mineral from various assemblages (various mineral matrices) was examined using electron microprobe, X-ray fluorescence analysis (XRFA) and laser spectrography. The compositions of the black crystals from various assemblages (uranate and uranyl-silicate) are the same; Ca and Mo are mineral-forming elements. X-ray element-distribution maps for a sample of uranate assemblage are shown in Fig. 3. The chemical composition of these black bipyramids was investigated with a JXA-8100 (JEOL, Japan) electron microprobe. Similar contents of Ca and Mo were

established in various samples. The compositions of the mineral from uranyl-silicate and uranate assemblages are as follows, wt. %: 26.91 CaO and 73.12 MoO₃; and 26.63 CaO and 73.69 MoO₃, respectively. These correspond to the composition of powellite and the formula CaMoO₄. Iron less than 1% was detected in the first analysis that is caused by oxide films; insignificant content of other elements (Cu, U, Pb, Y, As) is due to the admixture of uranyl and clay minerals.

The luster of crystals ranges from adamantine to resinous, more frequent sub-metallic. Microscopically, bipyramidal crystals with adamantine luster are characterized by imperfect and rough faces. However, there are some differences in optical properties of powellite from various assemblages. The crystals included in uranophane-beta (call them "silicate") are *anisotropic*, whereas those disseminated in uranate are *isotropic*. Infrared spectra of powellite from these assemblages are substantially different (Fig. 4). Such distinction in IR spectra reflects the structural state of the mineral and can be resulted from both variable conditions of formation and post-crystallization history of the mineral. This fact caused separated description of each

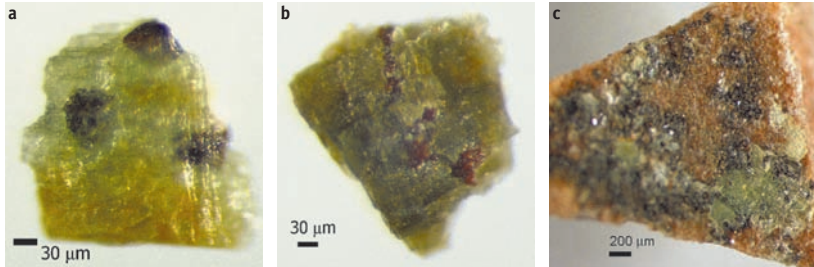


Fig. 1. Black powellite from uranate assemblage. (a, b) Isolated bipyramidal crystals included in uranarsite; (c) intergrowths of crystals covering surface of the rock.

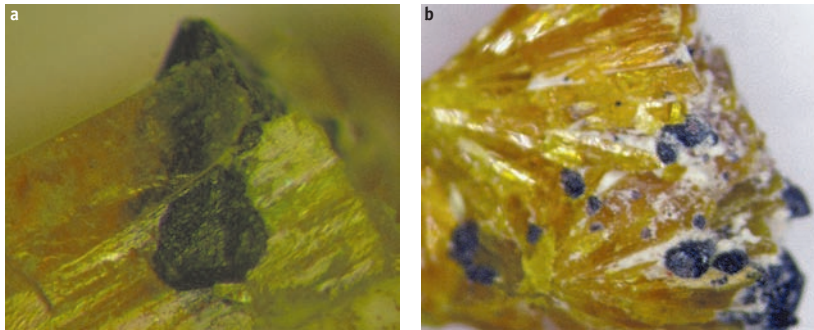


Fig. 2. (a) Inclusions of bipyramidal crystals black powellite in segregations of yellow β -uranophane; (b) black powellite associated with talc from uranophane-beta assemblage.

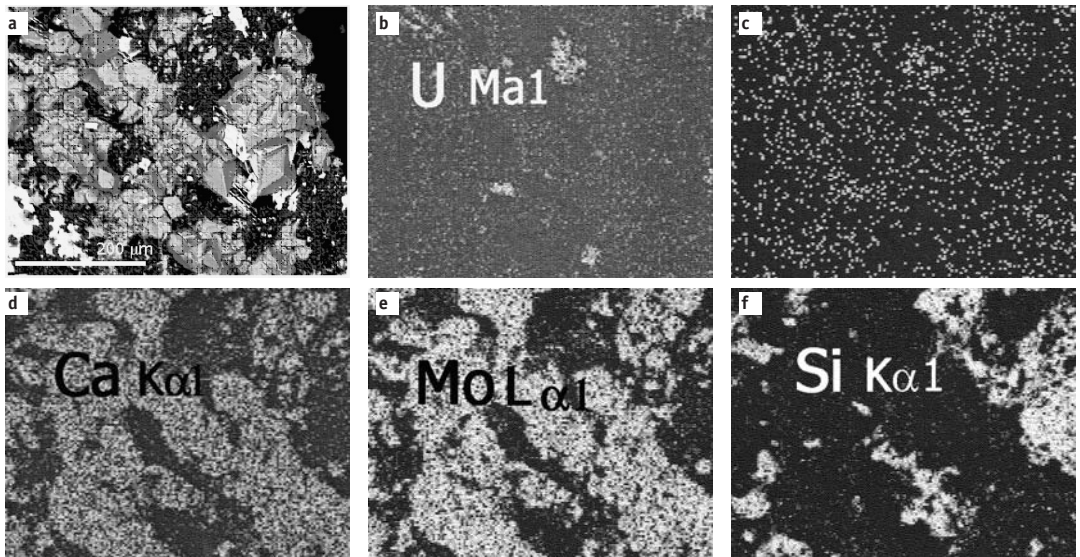


Fig. 3. (a) BSE image of intergrowths of metamict powellite crystals (grey) with grains of uranate (white) in silicate matrix (black); (b–f) X-ray element-distribution maps of U, As, Ca, Mo, and

variety of powellite. Anisotropic Ca-molybdate with IR spectrum of powellite was studied in more detail. Despite initial object for research, isotropic variety was examined in less detail due to extremely small amount.

The aim of this study is to explain rare black color of powellite. There are few reasons for change of typical color of a mineral: (1) disseminated mineral micro-admixture (for example, pink coloration of quartz is caused by the microphase of goethite); (2)

isomorphous impurity; (3) structural damages caused by radioactive emanation (for example, smoky coloration of quartz), which can be removed by ignition to restore primary color of mineral.

Black powellite associated with uranyl silicate

The crystals are uniaxial, with refractive index more than 1.780. The density of po-

wellite measured with microvolumetric method by Vasilevsky ranges from 4.023 to 4.195 g/cm³; the average value (six measurements) is 4.128 g/cm³ that is much less than in handbooks [4.54–4.23 (Feklichev, 1977); 4.25–4.52 (Lazarenko, 1963)]. The density becomes typical of powellite 4.249 g/cm³ after one hour ignition at 600°C.

X-ray powder diffraction pattern of the crystals from silicate assemblage corresponds to well-crystallized powellite with insignificant admixture of -uranophane (X'Pert PRO Panalytical diffractometer; CuK radiation). The tetragonal unit-cell dimensions of black powellite are: $a = 5.227 \text{ \AA}$, $c = 11.428 \text{ \AA}$, $c/a = 2.186$. Sharp X-ray diffraction pattern was remained after ignition of powder up to 700°C; no changes of the unit-cell dimensions were documented: $a = 5.229 \text{ \AA}$, $c = 11.430 \text{ \AA}$, $c/a = 2.186$.

IR spectrum recorded with a SPECORD 75 IR spectrometer is typical of powellite (Fig. 4) characterized by insignificant admixture of silicate (talc).

Differential thermal analysis (DTA) of powdered black crystals indicated that a broad exothermal peak with total weight loss of 1.46% (Fig. 5) is observed at DTA curve at heating up to 900°C and the further ignition results in textural and structural ordering. This exothermal peak can be probably caused by that the thermal effect removes stress and elevated potential energy accumulated by crystal.

Analytical scanning electron microscopic (ASEM) study using a JSM 5300 JEOL scanning electron microscope equipped with INCA energy dispersion system was performed to explain black coloration of powellite. The assumption of

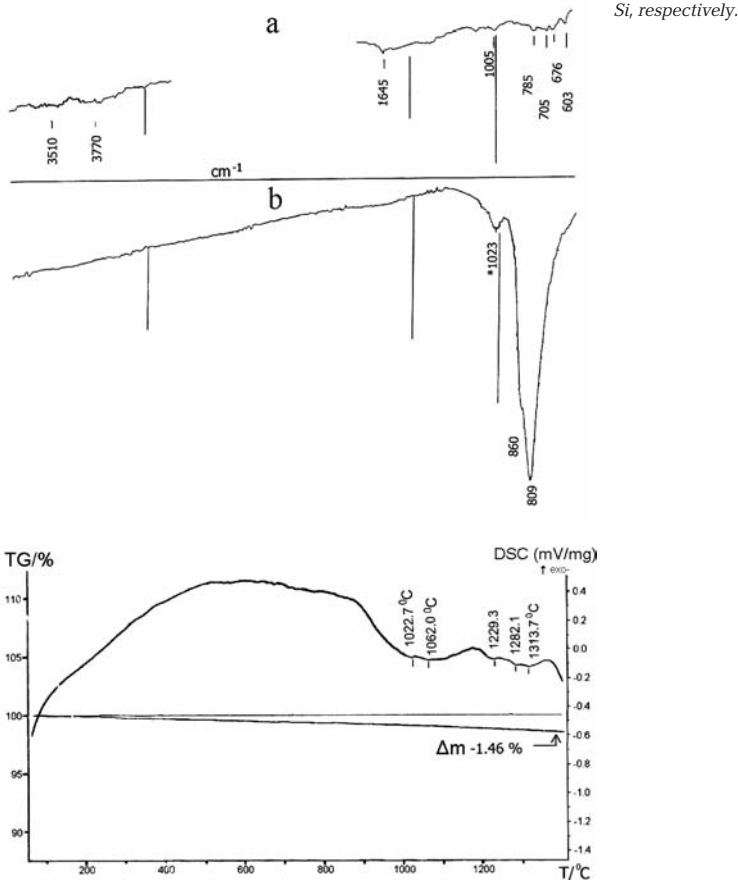
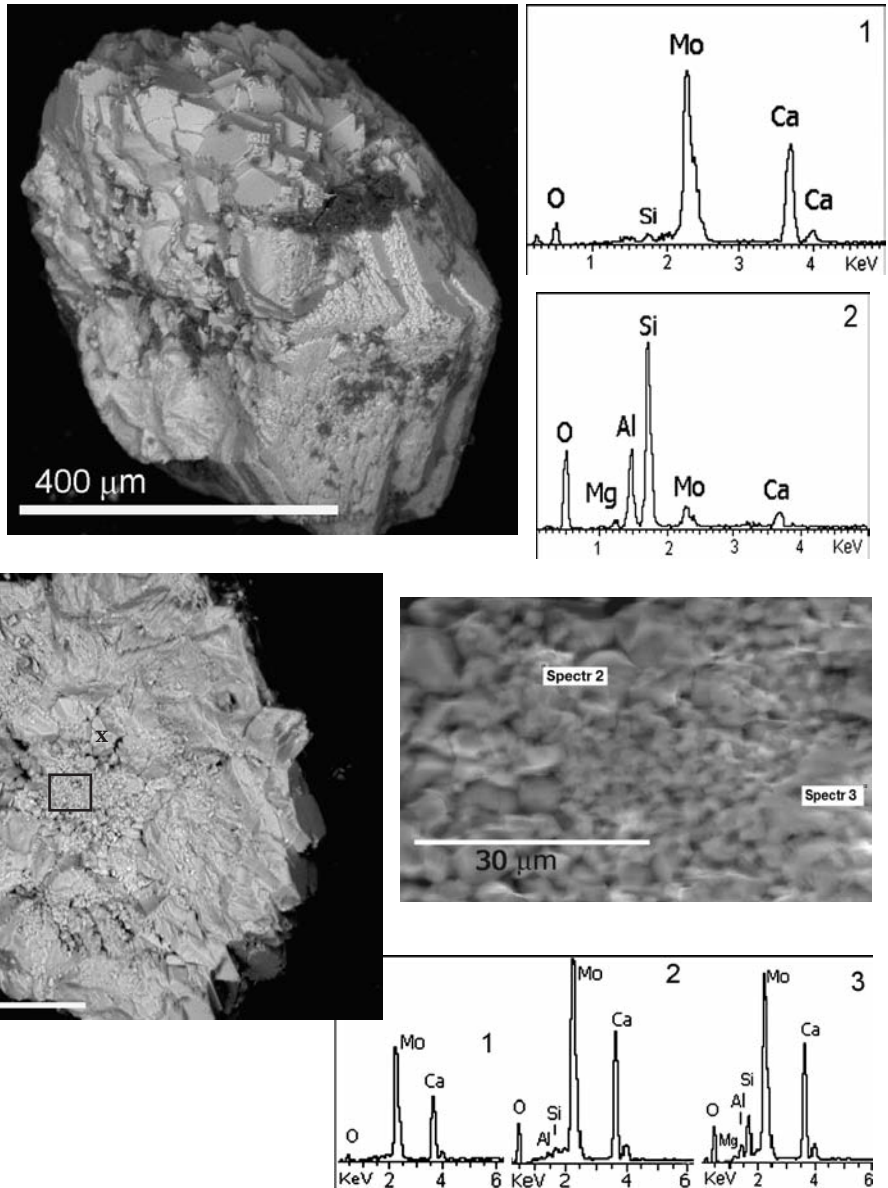


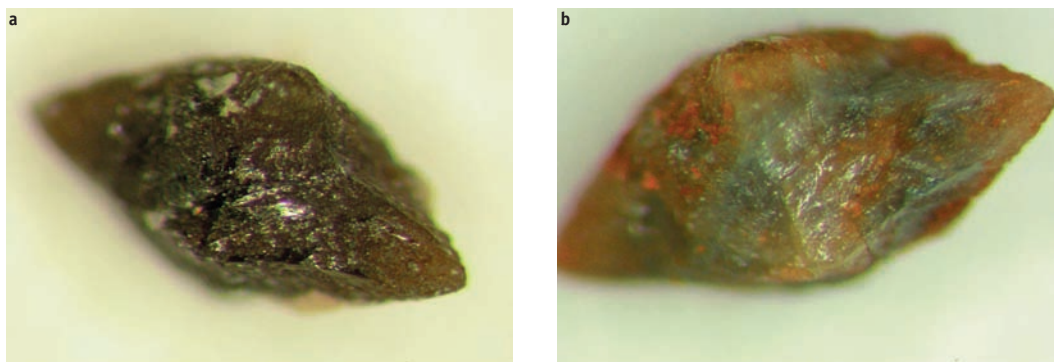
Fig. 4. IR absorption spectra of powellite: (a) metamict (uranate assemblage); (b) crystalline (uranophane-beta assemblage). Asterisk denotes admixture of clay matter.



disseminated highly dispersed mineral phase in powellite resulted in color transformation was checked. No extraneous mineral phases were identified in powellite.

Imperfect surface of faces of tetragonal bipyramid is clearly seen under electron microscope. These faces are covered by heads of variable-sized microcrystals (Fig. 6). The inner structure on the fractured surface of bipyramidal crystallites is very

interesting. The secondary emission image shows sheath-shaped character of bipyramidal microcrystal having wide solid layer at the surface, disoriented mosaicism in the intermediate part, and powder-like porous structure in the core (Fig. 7). The dispersivity of crystallite increases toward the core that is like loose submicroblock (polycrystalline) segregation. The composition of calcium molybdate is unchangeable in the whole volume.



In addition to Ca and Mo, traces of U or Pb were locally detected. E.V. Kopchenova and K.V. Skvortsova (1958) identified these trace elements in powellite from Bota-Burum. We suggest that this fact is caused by failure of textural homogeneity of crystals during post-crystallized alteration. Such continuous superegene alteration led to micro-mosaicism and porosity of mineral matter within crystal. The solutions penetrating bipyramidal powellite crystals along microfractures destroyed the central part composed of numerous nuclei. Disorientation of microcrystals generated during growth and further natural selection of larger blocks terminating growing single crystal favored disintegration. Superegene destruction of the powellite crystal was gradual with introduction of trace elements appeared in solutions during superegene transformation (U, Pb, As etc.). We can conclude this on the basis of the texture revealed by ASEM study of crystal chip.

Is it a combination of intrastructural features that is an original cause of unusual black coloration of powellite? According to the handbook (Lazarenko, 1963), the typical pale yellow color of powellite is diagnostic feature of the mineral. Specified structural failures can be removed by heat treatment, which was performed.

Black bipyramidal crystals ignited up to 700°C in air in muffle changed their color to conventional slightly grayish greenish

yellow (Fig. 8). Solid surface on chip of ignited crystal (Fig. 9) indicates compaction of micro-blocky structure of the matter observed in black crystals before ignition (Fig. 7). Point analyses did not show changes in composition of the surface of ignited crystal. Small admixture of Al is observed in the grain core; in wide marginal zones Al peak slightly increases and insignificant Si peak appears; these elements are probably related to the primary admixture of talc.

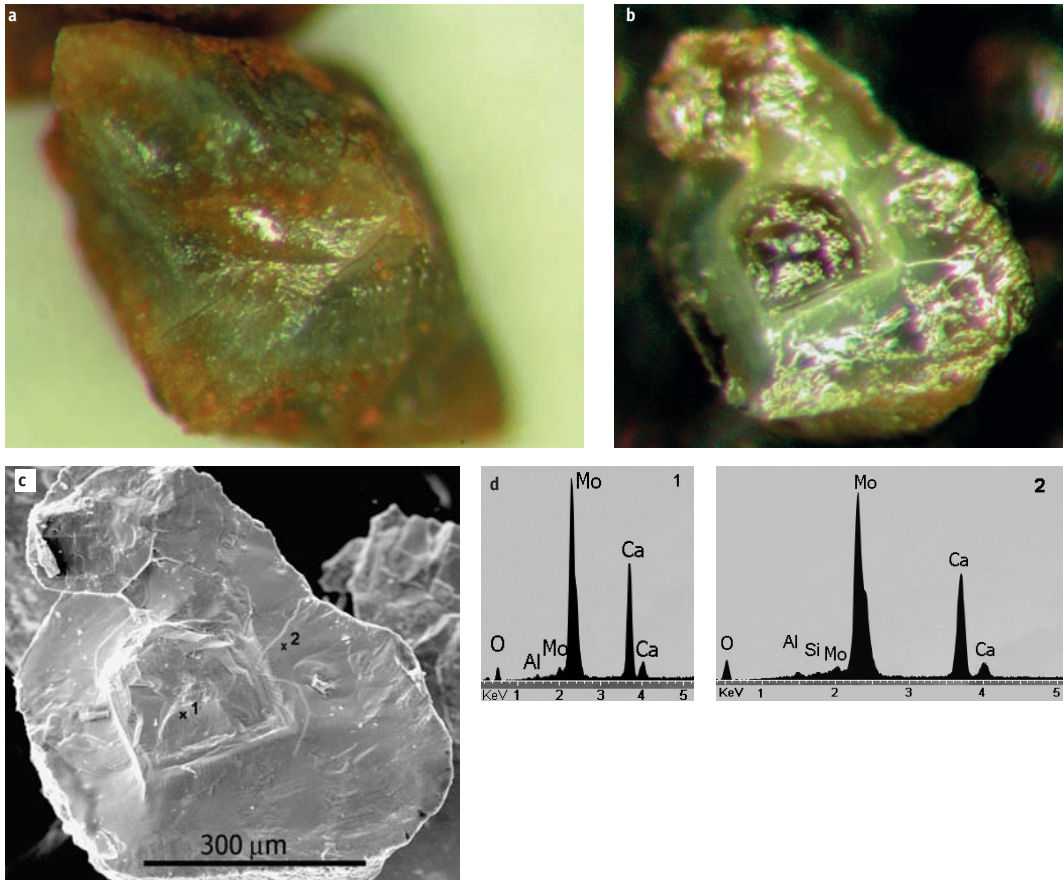
Black powellite associated with uranate

Isolated powellite crystals (Fig. 1) were identified in uramarsite $(\text{NH}_4, \text{H}_3\text{O})_2(\text{UO}_2)_2(\text{AsO}_4, \text{PO}_4)_2 \cdot 6\text{H}_2\text{O}$, uranium mica discovered at Bota-Burum (Sidorenko *et al.*, 2007). Black bipyramids are included in lamellar uramarsite.

Microscopically, in immersion liquids, black crystals of powellite recovered from lamellar uranate are isotropic. Despite tetragonal bipyramidal shape, powellite crystals do not demonstrate X-ray diffraction pattern, thus they are X-ray amorphous.

There are no bands of powellite in IR spectra (Fig. 4a). Characteristic bands of water molecules and a molybdenum oxide indicate substantial transformation of the mineral.

Combination of crystal shape of powellite, optical isotropy, X-ray amorphism,



and bands of H₂O and Mo oxide in IR spectrum shows the metamict state of powellite crystals associated with uranate. Godovikov (1975) reported certain instability of powellite, which "under supergene conditions ... is easily transformed into molybdenum acid and hydromolybdates".

A term "metamict mineral" introduced in mineralogy by Brögger (1896) implies notion "mix otherwise" meaning a mineral, where the arrangement of molecules in the crystal structure differs from that in an initial crystal. In an extreme case, this results in amorphous state of mineral with preserved crystal shape, but with optical isotropy, absence of cleavage, and conchoidal fracture. Thus, the preservation of crystal shape with the failure (to complete destruction) of three-dimensional lattice periodicity in a crystal structure is the major feature of metamict state. Just these fea-

tures are characteristic of black powellite from uranate assemblage. This structural failure can be caused by sufficiently strong radiation that results in the displacement of atoms in the crystal structure of the mineral. Most important lithospheric radioactive elements are U, Th, and ⁴⁰K whose decay is accompanied with α-, β-, and γ-emission are attributed to such natural sources of radiation. -component that can displace atoms in crystal structure is the most effective. For example, colored halos around mineral inclusion containing radioactive elements in transparent colorless single crystals of quartz visualize such effect.

X-ray amorphous (metamict) state is characterized by higher potential energy as compared to the same matter but in crystalline state. Heating of metamict mineral releases this energy that is recorded on the DTA curves as exothermal peak at tempera-

ture (temperature of recalescence) lower than that of destruction or melting of the mineral. The similar energy release can cause exothermal effect on the DTA curve of uranophane associated powellite, which lost typical yellowish color (indicating transformation of mineral matter) but preserved ability of diffraction. Probably, maximum transformation leading to complete amorphization occurs in powellite associated with uranate. Unfortunately, due to lack of material, thermal analysis of powellite associated with uranate was not performed.

Ignition of metamict mineral either restores initial crystal structure (recrystallization when minimum fragments of initial structure were preserved in the structure) or results in crystallization of simple oxides of mineral-forming elements. In any case, amorphous matter is devitrified. The similar devitrification of porous, but crystalline matter we observed after ignition of black bipyramidal crystals of powellite associated with uranophane.

Metamict state is not typical of powellite. Therefore, the following remains undecided: what did lead crystal structure of the examined mineral with heterodesmic interatomic bonds (degree of Ca-O ionic bond is near two times more than Mo-O) to metamict, i.e., amorphous state with the preservation of crystal shape. As aforementioned, transition from crystalline to metamict state as a rule is caused by the irradiation of the own matter of the crystal. In our case, the mineral matrix composed of secondary uranium minerals is a source of radioactive emanation because black crystals of powellite are dipped in it.

Close sizes of powellite grains from different above-described mineral matrices and quite identical shape of bipyramidal crystals indicate simultaneous formation of powellite from different assemblages at the deposit. According to the shape of powellite crystals, the mineral predates uranyl mineralization. Different structural state of powellite (from uranate and uranyl silicate assemblages) can testify to varied duration

of the contact of the mineral with radioactive elements and variable degree of supergene alteration of powellite (for example, hydration, micro-mosaicism etc.). This fact can be explained on the basis of general features and stages of supergene formation of uranium minerals (Belova, 2000; Belova and Doinikova, 2003; Doinikova *et al.*, 2003). Uranate are formed at the later oxidized stage than uranyl silicates. Uranate characterize longer process of uranyl mineralization. Hence, powellite associated with uranate was longer affected by radioactive medium. Powellite from the uranophane assemblage was shorter affected by uranium mineralization that resulted only in the failure of the matter continuity (texture) within crystals but was sufficient for disappearance of anisotropy and ability for diffraction of the mineral. G.K. Krivokoneva (pers. comm.) noted that crystals of powellite associated with uranyl silicate are black only on the surface, whereas inside, they are yellowish white. This observation supports our assumption of radiation nature of black color of the mineral. In other words, longer contact with radiation leads to both failure and metamict radioactive decay that occurs in case of uranate assemblage. Relatively less irradiated powellite from the uranyl silicate assemblage preserves three-dimensional order of crystal structure with high mosaicity.

The distinction in mineral assemblages containing bipyramids of powellite is caused by irregular formation conditions of secondary uranium minerals that were reported by E.V. Kopchenova and K.V. Skvortsova (1958), who studied mineralogy of this deposit for a long period: "Nasturane-sulfide mineralization at the Bota-Burum deposit hosted in altered felsitic volcanic rocks oxidize along highly jointed zones that causes extremely irregular secondary mineralization". Therein and in description of stages of supergene uranium mineralization (Belova and Doinikova, 2003), there was reported that uranium hydroxides and silicates precipitate in neu-

tral and weak-acid media, whereas uranium micas, in acid.

Summarizing the results obtained, we conclude that black color of powellite is related to radiation effect upon the mineral resulted in the transformation of its structure from micro-blocky to the complete loss of three-dimensional order. In other words, blocks of coherent scattering (BCS) decrease and powellite becomes metamict. Radiation medium leads to the failure of definite molybdenum coordination in powellite. In the mineral structure, character of chemical bond changes and coordination polyhedron of molybdenum is distorted with invariability of hexavalent Mo in supergene zone. We suggest that this phenomenon is similar to darkening of phosphate (or arsenate) uranate as a result of pyrophosphate (pyroarsenate) complexes in the crystal structure of this mineral (Belova *et al.*, 1992). The change of black color of powellite to characteristic greenish yellow clearly testifies to radiation origin of structural failure of this mineral and its unusual color.

Thus, black color of powellite can be considered as an indicator of radioactivity of host rocks. Such specific color of powellite can serve as a prospecting guide for deposits of radioactive elements.

Intimate association of powellite with secondary uranium minerals, whose conditions of formation are known, testifies to the stability of powellite in near-neutral and acidic media. This allows recalling numerous publications concerning reasons of metamictisation of minerals, where role of hydration was noted. In our case, revealed micromosaicity favored this process and supergene solution along with other elements introduced uranyl, which was radioactive source in an interblock space of crystallites.

The conclusion on the existence of metamict powellite is an interesting result of this study. Up to date, metamictisation was associated with radioactive elements (U,Th), which form proper minerals or

incorporate by isomorphic substitution into the structure of the other minerals. Probably, small size (few mm) of powellite crystals in comparison with volume of host uranium mineralization played important role. Such significant structural failure was favored by polyvalency of Mo.

The documented amorphization of powellite should attract attention of mineralogists because metamictization of calcium molybdate indicates the possibility of similar transformation for other minerals.

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CORUNDUM-BEARING PEGMATITES OF CROSSING TREND OF EVOLUTION OF THE Khibiny MASSIF AND THEIR ROLE IN RECONSTRUCTION OF PARENTAL ROCKS OF HOST PRE-PROTEROZOIC HORNFELS

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Corundum-bearing pegmatoids located within the Svintsovy (Lead) Creek, Mount Kukisvumchorr are studied. Mineralogy of these pegmatoid bodies and its changes in the direction from nepheline syenite to xenolith of hornfels are described in detail. Microinclusions in corundum, sodalite, and nepheline are investigated. Formation process of the pegmatoids and initial composition of annite-feldspar hornfels are proposed.

2 tables, 6 photos, 13 references.

Keywords: corundum, corundum-bearing pegmatoids, pegmatites of crossing trend of evolution, Khibiny massif, peraluminous hornfels, melt inclusions.

Introduction

In the central Khibiny massif there are various xenoliths of hornfelses of pre-Proterozoic host rocks. Most of them are aluminous (cordierite, sillimanite, corundum-bearing or corundum-free cordierite-andalusite, annite-feldspar, and annite-feldspar-chlorite), clay slate, carbonaceous shale, phyllite, and pyrrhotite-bearing hornfels (Kupletsky, 1932; Simon and Shlyukova, 1972; Men'shikov, 1978; Shlyukova, 1986; Men'shikov *et al.*, 2000). Probably, these are metamorphosed and metasomatically altered sedimentary-volcanic rocks of several formations in the Imandra-Varzuga structure (phyllite, clay slate, chlorite-sericite schist, two-mica schist, siltstone, and carbonate rocks). Xenoliths of pre-Proterozoic rocks mainly occur at the contact between nepheline syenite (foyaite, khibinite, and lyavochorrite) and rischorrite and/or ijolite-urtite of the Central arc of the massif within paleoboundary of Proterozoic rocks. (Simon and Shlyukova, 1972; Shlyukova and Borutsky, 1976; Shlyukova, 1986). Heterogeneity of xenolith rocks interacted with nepheline-syenite magma resulted in the formation of distinctive pegmatites with peraluminous

mineral assemblages atypical of nepheline syenite and pegmatite of the massif both in the xenoliths and at the contact with nepheline syenite. Such mineralogy is characteristic of granite and non-granite pegmatites, whose solution-melt was contaminated by components of chemical contrasting host rocks. Similar pegmatites were repeatedly described as pegmatites of crossing trend of evolution including alkaline massifs (Fersman, 1940; Uspensky, 1968; Shlyukova *et al.*, 2003; Chukanov *et al.*, 2003).

Geological and mineralogical characteristics of corundum-bearing pegmatites of crossing trend of evolution

According to Men'shikov (1978), two major types of corundum-bearing pegmatites are recognized in the Khibiny massif: nepheline [major minerals are nepheline, orthoclase, and lepidomelane (annite); sodalite, hercynite, and corundum are minor] and nepheline-free [major minerals are orthoclase, and lepidomelane (annite); sodalite, hercynite, and corundum are minor].

We have studied a number of the first type corundum-bearing pegmatites found

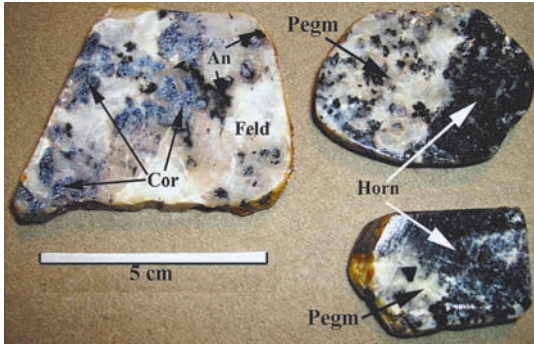


Fig. 1. Samples of corundum-bearing pegmatite, Mount Kukisvumchorr; contact of pegmatite and feldspar-annite hornfels. Cor – corundum, Feld – feldspar, An – annite; Pegm – pegmatite, Horn – hornfels.

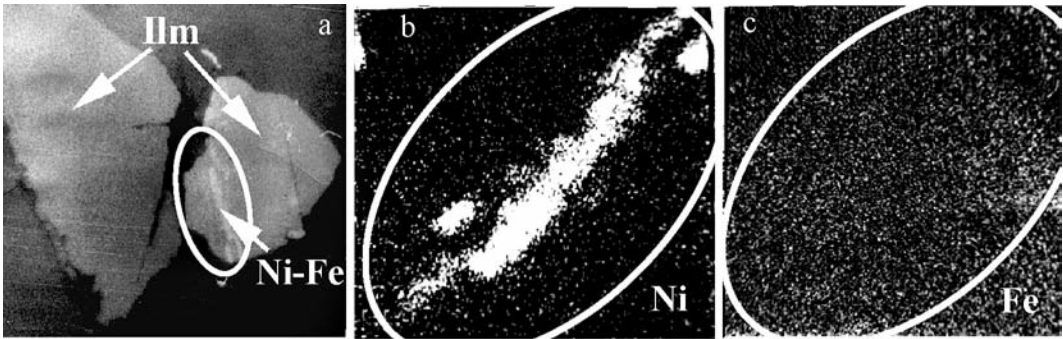


Fig. 2. Natural nickel-iron (Ni-Fe) alloy in ilmenite (Ilm) from corundum-bearing pegmatite.

at both the surface at Mts. Rischorr, Kukisvumchorr, Yuksporr, and Aeveslogchorr and great depth (observed in cores of holes drilled through hornfels after relicts of ancient rocks in the Maly Vudyavr Lake area and at the Partomchorr apatite deposit). The pegmatites occur at the contact between nepheline syenite and aluminous hornfels. These are schliere-shaped irregular bodies frequently divided into several apophysises. Veins are few meters to 200 m long along striking and 0.2 to 1.5 m thick. In the pegmatites, minerals are irregularly distributed. Arfvedsonite, aegirine, nepheline, biotite (annite), and feldspar are major minerals. In addition, blue corundum (sapphire), hercynite as crystals and rims around corundum, lepidomelane, ilmenite, monazite, graphite, eskolaite, and Co-bearing lullingite were identified in apophysises of nepheline-feldspar pegmatite hosted in hornfels. Most pegmatites are highly sodalitized. Apatite, gadolinite, zircon and titanobates occur in sodalite areas (Shluykova, 1996; Shluykova *et al.*, 2003).

Corundum-bearing pegmatoids located within the Svitsovy Creek, Mount Kukisvumchorr hosted in peraluminous (52.10 wt. % Al_2O_3) annite-feldspar hornfels are studied in most detail. Corundum-bearing annite-nepheline-feldspar apophysises (Fig. 1) of nepheline-feldspar-aegirine pegmatite with lamprophyllite cut hornfels xenolith, which is surrounded by foyaite hosting pegmatite body. Contacts of the pegmatoids with hornfels are fuzzy due to phenitization. Change of mineralogy of apophysises outward major pegmatite body is clearly documented: aluminous mineral assemblage, corundum, hercynite, annite, and cordierite, is formed instead of arfvedsonite, aegirine, and lamprophyllite (Bukonov and Lipovsky, 1980).

Rock-forming minerals in the apophysises are K-Na-feldspar, nepheline, and mica whose composition according to (Rieder *et al.*, 1998) corresponds to annite depleted in phlogopite (magnesium) component. Extremely high Al content (17 wt. % Al_2O_3 instead of usual 7–10 wt. %) is a feature of

Table 1. **Chemical compositions of rock-forming minerals and accessories from corundum-bearing pegmatite, Svintsovy Creek, Mt. Kukisvumchorr**

Component, wt. %	Rock-forming mineral					Accessory				
	Annite		Nepheline	Feldspar		Hercynite	Muscovite	Mona-zite	Bornite	Chalcopyrite
	1	2	3	4	5	6	7	8	9	10
Na ₂ O	0.36	0.00	17.50	1.94	9.85	—	2.37	—	—	—
K ₂ O	9.97	14.35	5.88	14.82	0.27	—	6.88	—	—	—
CaO	0.06	0.00	—	0.18	0.62	—	—	—	—	—
MnO	—	0.68	—	—	—	1.29	—	—	—	—
FeO/Fe*	31.01	36.59	0.07	n.a.	n.a.	53.00	—	—	59.35	38.19
CuO/Cu*	—	—	—	—	—	—	—	—	18.57	28.37
Ce ₂ O ₃	—	—	—	—	—	—	—	34.18	—	—
La ₂ O ₃	—	—	—	—	—	—	—	24.91	—	—
Pr ₂ O ₃	—	—	—	—	—	—	—	2.18	—	—
Nd ₂ O ₃	—	—	—	—	—	—	—	5.85	—	—
Al ₂ O ₃	17.42	14.16	32.62	18.58	19.85	42.44	34.81	—	—	—
SiO ₂	31.58	25.66	43.43	63.08	66.97	—	42.22	0.68	—	—
TiO ₂	4.73	2.94	—	—	—	0.27	—	—	—	—
ThO ₂	—	—	—	—	—	—	—	1.12	—	—
P ₂ O ₅	—	—	—	—	—	—	—	29.46	—	—
S	—	—	—	—	—	—	—	—	24.32	30.22
O = F	0.50	—	—	—	—	—	—	—	—	—
Total	95.86**	94.38	99.50	98.60	97.56	97.00	86.28	98.46	102.24	96.78
Minerals, %)	—	—	Nef – 78	Ort – 83	Ort – 1	—	—	—	—	—
			Ks – 17	Ab – 16	Ab – 96					
			Q – 5	An – 1	An – 3					

Notes: * – content of elements are given for sulfides. ** – 0.73% MgO was detected in annite. (1) wet chemical analysis, analyst G.F. Egorova. (2) JSM-5300 scanning electron microscope equipped with energy dispersion system, analyst N.V. Trubkin. (3–9) Cameca MS-46 electron microprobe: (3–6, 8, 9) analyst T.I. Golovanova; (7) analyst A.I. Tsepin. n.a. is not analysed. Dash denotes that content is below detection limit.

this annite; its composition corresponds to the formula: $(K_{1.04}Na_{0.05})_{1.09}(Fe^{2+}_{1.95}Ti_{0.29}Al_{0.28}Fe^{3+}_{0.16}Mg_{0.09}Mn_{0.06})_{2.83}Al(Si_{2.66}Al_{0.34})_3O_{10}(OH)_2$ (Table 1, anal. 1). It is interesting that we identified annite of similar composition in host hornfels. The composition of Al-rich annite from hornfels is as follows: $K_{1.07}(Fe_{1.91}Mg_{0.54}Al_{0.19}Ti_{0.18})_{2.82}[Al(Si_{2.66}Al_{0.34})_3O_{10}](OH)_2$ (Table 1, anal. 2). Fe^{2+} and Fe^{3+} are calculated by charge balance. Sufficiently low sums of analyses of annite in Table 1 are probably caused by its partial hydration. Similar annite is characteristic rock-forming mineral of hornfels in Vudyavr block (Menshikov *et al.*, 2000; our data).

Feldspar occurs as block-crystals with macroperthites. Electron-microprobe analysis revealed two phases in these block-crystals: K-rich (Table 1, anal. 4) and Na-rich (Table 1, anal. 5). The composition of

nepheline (Table 1, anal. 3) is typical of nepheline syenite from the Khibiny massif.

The following minerals were found in the pegmatoid: spheric segregations of graphite; natural nickel-cobalt alloy (Fig. 2); Co-bearing löllingite; chalcopyrite and bornite (Table 1, anal. 9, 10); corundum (sapphire reaches 1.5 cm across, Fig. 1); hercynite of two generations: large isometric crystals of 1–2 mm to 1 cm in size (Table 1, anal. 6) and rims overgrown crystals of corundum (Shlyukova, 1986; Borisova *et al.*, 2001); zirkelite and other titanoniobates; Al-rich mica of the muscovite-paragonite series (table 1, anal. 7; low sum of analysis is probably caused by partial hydration of the mineral and bad polishing quality); andalusite, schorlomite, zircon, gadolinite, analcime,

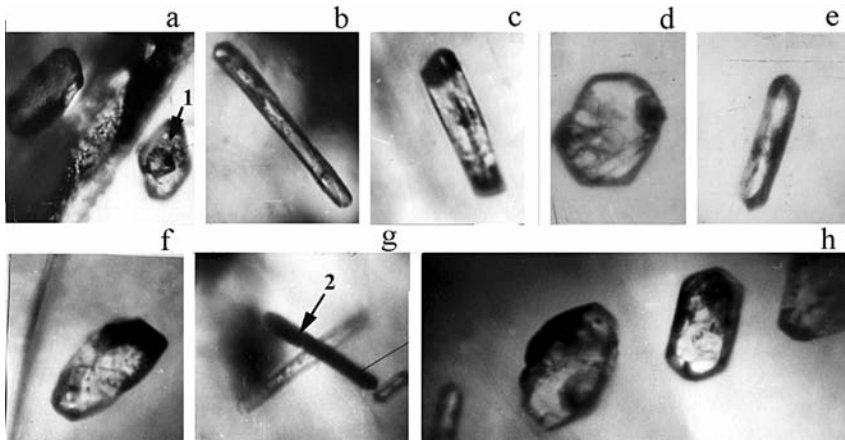


Fig. 3. Primary inclusions in corundum.

sodalite, monazite (Table 1, anal. 8), and apatite. Microinclusions in minerals from this type pegmatite were studied in samples of the corundum-bearing pegmatite (Shlyukova *et al.*, 2003).

Petrography and microthermometry of inclusions

Microinclusions in minerals of the studied pegmatite were examined by A.R. Groshenko.

Few types of inclusions of mineral-forming media differed in arrangement in crystal, composition, shape, and size were recognized in **corundum (dark blue sapphire)**:

(1) The largest elongated inclusions up to few hundreds microns in size as negative crystals are arranged singly, as small clusters, and locally, along growth zones. Most inclusions are glass devitrified to variable degree with numerous solid phases and few gas (3–8%) occurred in interstices (Fig. 3a–h). These inclusions are reliably identified as primary.

(2) Melt inclusions of 2 to 3 μm in size (locally, 10–20 μm long) healing thin fractures within crystal are pseudosecondary.

(3) Secondary gas-dominated rounded and tubular inclusions were trapped along long thin fractures, which cut crystal.

Melt inclusions are also observed in **nepheline** but they are vitreous and contain great gas (up to 40–80%). Primary inclusions are very rare; pseudosecondary inclu-

sions are observable more abundant; yellowish and dark brown secondary inclusions are dominant. They are spherical, oval, and less frequent elongated. Nepheline crystals are troubled and opaque. Size of inclusions ranges from few to tens microns (Fig. 4).

Primary inclusions were not identified in **sodalite**. Yellowish and dark brown spherical, oval or elongated secondary inclusions are liquid-gas and gas-dominated with size ranging from few to hundreds microns (Fig. 5).

Microthermometry of inclusions was performed with a T-1400 heating-freezing stage designed by A.R. Groshenko. No any changes were documented during heating primary inclusions in corundum up to 700–800°C; clarification of content at softening solid phases, individualization of gas bubble (occasionally, two or three bubbles), and gradual dissolution of solids were observed at 980–1030°C. Only secondary inclusions homogenized into gas at 380–520°C were studied in sodalite.

Compositions of some solid phases of devitrified melt inclusions in corundum (Fig. 6; Table 2) correspond to albite (Fig. 6a, phase 1; Fig. 6b, phase 1) and mica of the paragonite-muscovite series (Fig. 6a, phase 2; Fig. 6b, phase 2; Figs. 6c, 6d, 6e).

Discussion

Mineral assemblages of corundum-bearing pegmatite described in this paper and melt inclusions in minerals provide certain assumptions of the formation of

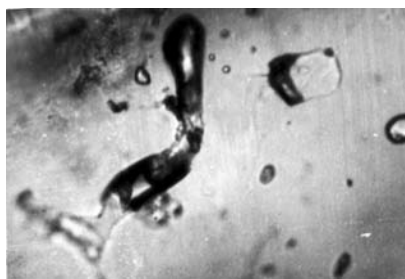


Fig. 4. Secondary inclusions in nepheline.

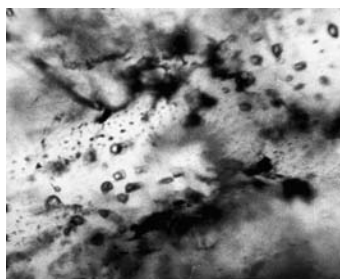
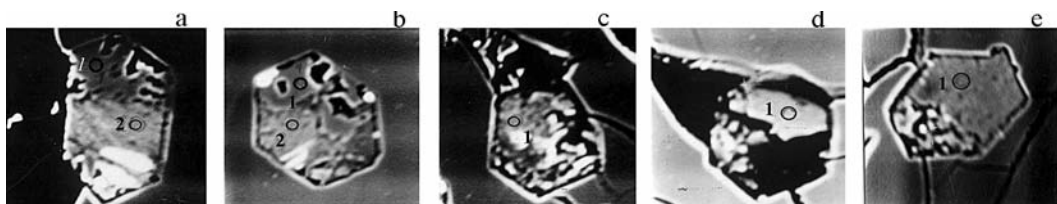


Fig. 5. Secondary inclusions in sodalite.

Fig. 6. Solid inclusions in corundum: (1) albite; (2) muscovite.



corundum-bearing pegmatites and composition of source rocks for host annite-feldspar hornfels.

Firstly, according to microthermometric measurements, temperature of formation did not exceed 700–1030°C that is consistent with crystallization temperature of nepheline estimated from geothermometer by Hamilton 800–850°C. On the basis of the data obtained, the pegmatite was formed from residual melt-solution at final stage of crystallization of syenite magma. It may be suggested that earlier, relics of Proterozoic Imandra-Varguza rocks (shale and/or chlorite-sericite schist) were metamorphosed to annite-feldspar hornfels under effect of nepheline-syenite melt. Probably, high-temperature aluminous minerals (cordierite, andalusite, and sillimanite) were formed at this time. Pegmatite-forming melt-solution

was intruded along fractures in the previously formed hornfels.

Secondly, high Al content in the hornfels determined unusual pegmatite mineral assemblage found in the area of Svitsovy Creek and differed from assemblages of standard nepheline-syenite pegmatites. As aforementioned, mineralogy of pegmatite apophyses changes moving away major pegmatite body. Aluminous mineral assemblage, corundum, hercynite, unusual Al-rich annite, cordierite, andalusite, and sillimanite, is formed instead of arfvedsonite, aegirine, and lamprophyllite of nepheline-syenite pegmatite. It is most probably that annite, cordierite, sillimanite, andalusite, and hercynite were captured by pegmatite-forming melt-solution together with xenolith rocks. Most likely, corundum crystallized as a result of fixation of excess alumina formed

Table 2. Chemical compositions of phases in melt inclusions in sapphire

Component,	Albite	Muscovite	Albite	Muscovite	Muscovite	Muscovite	Muscovite
wt. %	6a (1)*	6a (2)	6b (1)	6b (2)	6c	6d	6e
Na ₂ O	11.71	1.67	11.26	1.19	3.38	0.98	2.86
K ₂ O	0.02	9.38	0.04	9.60	6.65	9.68	6.94
FeO	0.07	0.91	0.04	1.26	0.97	1.04	0.99
Al ₂ O ₃	21.53	39.36	21.62	38.52	38.01	39.33	37.14
SiO ₂	67.67	48.95	63.87	45.58	41.45	45.26	43.02
TiO ₂	0.03	0.39	0.02	0.47	0.47	0.40	0.17
Total	101.03	100.66	96.85	96.62	90.93	96.69	91.12

Notes: * – number corresponds to the number of the points in Fig. 6.

during interaction of nepheline-syenite melt-solution and aluminous hornfels. Absence of corundum in both hornfels and pegmatite supports this suggestion. In addition, excess alumina can be resulted from removal of alkalis from Al-rich nepheline, when pegmatoid veins intruded hornfels.

Nepheline, rare metal and REE minerals probably crystallized from melt-solution during formation of the major nepheline-syenite pegmatite and were not modified by the interaction with hornfels.

Thirdly, secondary hydrocarbon inclusions and graphite in nepheline and sodalite indicate the effect of "dry" reducing fluids during late stage of pegmatite formation. Homogenization temperature of secondary liquid-gas and gas-dominated inclusions in sodalite is relatively low and ranges from 380 to 520°C. It may be suggested that this late reworking corresponds to the late hydrothermal transformation of nepheline syenite and its pegmatites. Sodalitization and zeolitization, which are characteristic of alkaline massifs including Khibiny, are related to this stage.

Fourthly, muscovite was trapped in primary inclusions in corundum formed in pegmatoid bodies hosted in hornfels. Muscovite is not typical of both nepheline-syenite pegmatite and nepheline syenite; micas are only minor minerals as products of transformation of amphiboles and pyroxenes. According to this, muscovite is suggested to be characteristic of hornfels protolith (rocks of the Imandra-Varzuga Formations). Muscovite was converted into Al-rich annite under effect of nepheline-syenite magma at high activity of alkalis (uppermost K) and mafic elements (uppermost Fe).

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TYPOMORPHISM OF THE COLUMBITE-TANTALITE GROUP MINERALS IN THE RARE-METAL TANTALUM-BEARING AMAZONITE-ALBITE GRANITES

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Mineralogical investigation of three tantalum-bearing granite massifs Orlovskoe and Aetykinskoe (Transbaikalia) and Maykul'skoe (Kazakhstan) has been conducted. Typomorphic peculiar features of the columbite – tantalite (Col-Ta) group minerals in these massifs according to their connection with different age phase and facial granite varieties have been revealed. It has been shown that combined with the other typomorphic signs crystal morphology peculiar features of the Col-Ta group minerals could be advantageously used during the geological prospecting for the survey and estimation of tantalum ore occurrences within the massifs of amazonite – albite rare metal subalkalic type granites. Col-Ta typomorphic signs may be also used at the stage of the detailed and exploitation exploration during the mineralogical and technological mapping of tantalum deposits in such massifs.

3 figures, 22 references.

Keywords: columbite tantalite group, manganocolumbite, typomorphism, phase variety, facial variety, rare metal granite massif, crystal morphology, habitus form.

Introduction

Minerals of the columbite – tantalite (Col-Ta) group are the most important in commercial aspect minerals of tantalum: more than 50% of the world reserves of this rare metal is connected with these minerals.

The main suppliers of tantalum are the deposits connected with granite pegmatites and rare metal granites of subalkalic type. Due to the known tendency of working out of rich in tantalum pegmatite deposits, great in reserves but poor in tantalum content and hardly enriched deposits connected with rare metal granites become more and more significant.

There are two such deposits in the Eastern Transbaikalia, Russia (Orlovskoe and Aetykinskoe) connected with the same names rare metal granite massifs. The Orlovskoe deposit was intensively exploited up to the end of the 1980s (its ore was gravity enriched at the neighboring Orlovsky mining-and-processing combine). At that time, the Aetykinskoe deposit was prepared for exploitation introducing, but failed; only recently, tantalum production was initiated in moderate volumes with consequent processing by gravity enrichment at the Pervomaysky mining-and-processing factory. At these deposits, a significant part of tantalum is contained in the minerals of the Col-Ta group along with pyrochlore – microlite (Prch-Mcr) and, to a lesser degree, with cassiterite (Css) being the main tantalum-bearing minerals. As it is known from the literature devoted to these deposits, the spatial

distribution of these minerals with concentration of Prch-Mcr in the granite massifs endocontact zones and relatively even occurrence of Col-Ta and Css (Lugovskoy et al., 1972) allows to predict the increase of importance of the columbite – tantalite type ores in the tantalum balance as these deposits quarry mining.

That is why it is so important and actual to investigate Col-Ta group minerals from this type deposits and reveal their typomorphic features effecting the values of the ore technological processing during the exploration and estimation of such deposits.

The work was based on the materials obtained by the author as well as submitted for the investigation by S.M. Beskin, V.N. Pavlova, and A.E. Tsyganov (Institute of Mineralogy, Geochemistry and Crystal Chemistry of Rare Elements, Moscow), V.V. Matias (All-Russian Institute of Mineral Resources, Moscow), B.A. Levichev (Orlovsky Mining-and-Processing Combine, Chita oblast), A.M. Grebennikov and I.I. Kursinov (Pervomaysky Mining-and-Processing Combine, Chita oblast), Yu.K. Lebedev and A.N. Fedorov (Aetykinskaya Geological-and-Exploration Party, Zolotorechensk, Chita oblast).

Altogether there were investigated 224 disintegrated and panned samples from different phases and facia of the following rare metal amazonite – albite granite massifs containing Col-Ta group minerals: Orlovsky and Aetykinsky (Eastern Transbaikalia) and Maykul'sky (Southern Kazakhstan).

The massifs investigated are close to each other by the following several features: a) Late Hercynian age of formation; b) formation affiliation and connection with a unified extended Urals – Mongol – Okhotsk geosyncline belt and zones of tectono – magmatic activation of intermediate massifs; c) asymmetrical – fungiform (graptolitic) intrusion shape with intersecting interrelations with enclosing significantly silicate rocks; d) wide development of postmagmatic autometamorphic processes of albitization and greisenization; e) assembly and quantitative correlations of rock-forming, accessory, and ore minerals; f) increased concentrations of the lithophile rare elements in comparison with their clarkes. Composite geological characteristics of the mentioned granite massifs have been described in our paper (Povarennykh, 1994) and numerous publications of the other researchers (Zalashkova, 1969; Lugovskoy *et al.*, 1972; Alexandrov, 1989; Zaraysky, 2004; A. Rub, M. Rub, 2006; Beskin, 2007).

Analyses and determination of mineral features have been performed by the author and scientific researchers of several geological institutes and Lomonosov Moscow State University.

Chemical typomorphism of the columbite tantalite group minerals

Variations of chemical composition of these minerals reflect the complete isomorphism between two pairs of species-forming elements: Mn and Fe, Ta and Nb. The following several mineral species belonging to the columbite – tantalite group are nowadays distinguished: ferrocolumbite $\text{Fe}^{2+}\text{Nb}_2\text{O}_6$, ferrotantalite $\text{Fe}^{2+}\text{Ta}_2\text{O}_6$, manganocolumbite $(\text{Mn}, \text{Fe}^{2+})(\text{Nb}, \text{Ta})_2\text{O}_6$, and manganotantalite MnTa_2O_6 . Continuous isomorphic series exist between these mineral species. Concentrations of other isomorphic impurity elements are regularly insignificant and reach as follows: Ti (<12.8%), W (<4.56%), Sn (<2.5%), TR (<2%), Al (<1.5%), Sc (<1.34%), and U (<0.5%) (Povarennykh, 1966; Voloshin, 1993; Povarennykh, 1985, 1991, 2008; A. Rub, M. Rub, 2006).

Specimens of the Col-Ta group minerals from the objects belonging to the following row of different formation types "carbonatites – alkaline rare metal granites – subalkalic rare metal granites – granitic pegmatites" are significantly distinguished from one another by content of the main species-forming cations (Ta, Nb, Fe, and Mn) and tantalitic and manganiferous characteristic relations ($\text{Ta}/(\text{Ta} + \text{Nb})$ and

$\text{Mn}/(\text{Mn} + \text{Fe})$, respectively). Within this row, average values of the tantalitic characteristic relation in Col-Ta specimens gradually increases from 0.02 (central type carbonatites) to 0.93 (granitic pegmatites), and average values of the manganiferous characteristic relation vary approximately in the same limits.

Specimens of Col-Ta from the Maykul'sky massif of subalkalic rare metal granites (Southern Kazakhstan) are characterized by the following features of chemical composition: a) values of manganiferous characteristic relation $\text{Mn}/(\text{Mn} + \text{Fe})$ vary from 0.28 to 0.37; b) values of tantalitic characteristic relation $\text{Ta}/(\text{Ta} + \text{Nb})$ vary from 0.04 to 0.17; c) rather high concentrations of impurity elements (in mas. %): titanium (1.00 TiO_2), tungsten (0.46 WO_3), scandium (0.28 Sc_2O_3), and tin (0.17 SnO_2). Contents of impurity elements in Col-Ta have been determined by microprobe analysis (Camebax), INAA and with the help of X-ray radiometric method ("Quant" device).

Variations of the main species-forming cations (in mas. %) and their correlations in the Col-Ta specimens from the Orlovsky massif (Aginsky Buryatsky autonomous okrug, Eastern Transbaikalia) are as follows: Ta_2O_5 15.7 – 65.1, Nb_2O_5 26.6 – 47.8, FeO 0.9 – 4.6, MnO 12.2 – 21.5, $\text{Ta}/(\text{Ta} + \text{Nb})$ 0.2 – 0.94 (average 0.44), and $\text{Mn}/(\text{Mn} + \text{Fe})$ 0.49 – 0.97 (average 0.89). These specimens are characterized by rather high average contents (in mas. %) of tungsten (0.75 WO_3), titanium (0.6 TiO_2), scandium (0.15 Sc_2O_3), and tin (0.2 SnO_2).

Specimens of Col-Ta from the Aetykinsky massif of rare metal granites (Eastern Transbaikalia) are characterized by the following variations of chemical composition and correlations of the main species-forming cations (by bulk samples of great weight 250 – 300 kg, in mas. %): Ta_2O_5 3.31 – 40.01, Nb_2O_5 39.26 – 75.67, FeO 1.94 – 11.18, MnO 7.93 – 16.00, $\text{Ta}/(\text{Ta} + \text{Nb})$ 0.04 – 0.53 (average 0.2), and $\text{Mn}/(\text{Mn} + \text{Fe})$ 0.29 – 0.9 (average 0.66). Concentrations of impurity elements vary in the following intervals (in mas. %): TiO_2 0.11 – 4.76, Sc_2O_3 0.06 – 1.34, WO_3 0.31 – 4.56, SnO_2 0.04 – 0.86, and UO_2 0.0 – 1.57.

In comparison with the values of tantalitic and manganiferous characteristic relations of Col-Ta from the Maykul'sky and Orlovsky massifs, these parameters of Col-Ta from the Aetykinsky massif occupy intermediate position. Scandium is the most characteristic impurity element for the Col-Ta specimens from the Aetykinsky massif: its average content is very high (0.54 mas. % Sc_2O_3). Titanium, tungsten, and tin are also very

common for these Col-Ta specimens (average contents, in mas. %): TiO_2 1.15, WO_3 0.85, and SnO_2 0.14.

Within the massifs investigated, Col-Ta is regularly distinguished by chemical composition depending on different phase and facial (autometasomatically altered and greisenized) varieties of rare metal granites and remoteness from endocontact. So in the Aetykinsky massif, the early phase γ_3^1 of fine-grained albite granites ("ongonites" xenoliths) and early facia of the amazonite – albite with zinnwaldite granites γ_3^3 (middle-grained structure, homogenous texture) contain manganocolumbite with characteristic relations $\text{Ta}/(\text{Ta} + \text{Nb}) = 0.11$, $\text{Mn}/(\text{Mn} + \text{Fe}) = 0.44$, and relatively decreased contents of the following impurity elements (in mas. %): SnO_2 0.03, Sc_2O_3 0.42, WO_3 0.48, and TiO_2 0.48. Col-Ta from the later rare metal facia γ^{4-6}_3 (fine-grained structure, with lepidolite, homogenous texture; coarse-grained structure, with zinnwaldite – lepidolite, taxitic texture; coarse-grained structure, vein-like quartzitic and lithium mica quartzitic amazonitites) is presented by manganocolumbite with greater values of tantallic and manganiferous characteristic relations ($\text{Ta}/(\text{Ta} + \text{Nb}) = 0.3$, $\text{Mn}/(\text{Mn} + \text{Fe}) = 0.78$) and uplifted concentrations (in mas. %) of tin (SnO_2 0.2), scandium (Sc_2O_3 0.75), tungsten (WO_3 1.52), and titanium (TiO_2 2.11). Within the limits of the same facial variety of the Aetykinsky rare metal granite massif, the following definite vertical zonality occurs: more niobian and ferruginous Col-Ta varieties are found in the deeper sites and more tantallic and manganiferous Col-Ta specimens are found closer to the endocontact or paleo-surface.

For the Orlovsky massif, the character of zonality in distribution of Col-Ta with different chemical composition is close, to a first approximation, to those described for the Aetykinsky massif. So, the specimens of Col-Ta from the later rare metal granite facies (small-grained structure, lepidolite – amazonite – albite composition) are enriched with tantalum and manganese in comparison with those from the earlier facies (middle-grained structure, cryophyllite – amazonite – albite composition): values of tantallic characteristic relation $\text{Ta}/(\text{Ta} + \text{Nb})$ equal to 0.45 and 0.23, and values of manganiferous relation $\text{Mn}/(\text{Mn} + \text{Fe})$ equal to 0.94 and 0.73, respectively in the first and second cases. However, the most tantallic Col-Ta specimens do not occur immediately close to the endocontact, but in a 30 – 40 (up to 60) meter distance from it. They are characterized by tantallic relation value $\text{Ta}/(\text{Ta} + \text{Nb}) =$

0.7 and rather decreased value of manganiferous characteristic relation $\text{Mn}/(\text{Mn} + \text{Fe}) = 0.78$. Presence of such specific zone of tantallic "secondary enrichment" of Col-Ta specimens in the Orlovsky massif may be explained, in our opinion, by the action of the following two factors: 1) redistribution of tantalum between its two main tantalum-bearing minerals Prch-Mcr and Col-Ta (their simultaneous occurrence is observed only at the mentioned distances from endocontact where tantalum is spent for Prch-Mcr formation with synchronous depletion of Col-Ta in this element), 2) wave-like character of acidity – basicity conditions evolution of mineral formation during the post-magmatic high-temperature autometasomatal alteration of granite by albitization and greisenization processes.

Specimens of Col-Ta from the Maykul'sky massif belonging to the same phase of rare metal granite (small-middle-grained structure, amazonite – albite with protolithionite – zinnwaldite) become more and more tantallic and manganiferous with approaching to the endocontact with quartzite of the Maykulian suite O_2mk ($\text{Ta}/(\text{Ta} + \text{Nb}) = 0.048 - 0.172$ and $\text{Mn}/(\text{Mn} + \text{Fe}) = 0.284 - 0.367$). Col-Ta specimens from the small-grained albite granites of additional intrusions occurring within the amazonite – albite granites in the form of narrow lenticular xenolith-like bodies are distinguished by decreased values of tantallic characteristic relation ($\text{Ta}/(\text{Ta} + \text{Nb}) = 0.07$). They also contain lesser amounts of the following elements (in mas. %): tin (SnO_2 0.06 and 0.19), titanium (TiO_2 0.4 and 1.01), scandium (Sc_2O_3 0.15 and 0.33), and tungsten (WO_3 0.26 and 0.44) (greater concentrations correspond to Col-Ta from the main phase granite).

Trends of Col-Ta chemical composition variations in the investigated Transbaikalian massifs in comparison with those from several other amazonite – albite massifs of the Urals – Mongol – Okhotsk belt are shown on Fig. 1. These trends coincide in directivity with the geochemical ones revealed by G.P. Zaraysky for these massifs according to Zr – Hf relation (Zaraysky, 2004) and mineragenic established by S.M. Beskin (Beskin, 2007). Distinct discreteness of figurative spot fields of Col-Ta group minerals in the investigated amazonite – albite Transbaikalian massifs with the presence of the unified trend may be interpreted as an indication of the following two great Col-Ta generations occurrence: earlier primary magmatic (ongonitic), and later high-temperature, hydrothermal – autometasomatal genetically connected

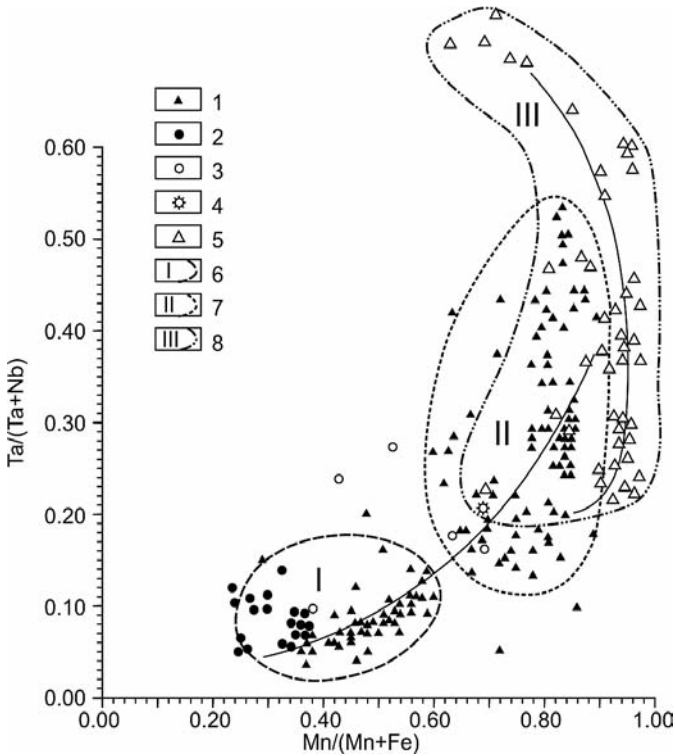


Fig. 1. Distribution of the composition figurative spots of the columbite–tantalite (Col-Ta) group minerals from different age phases and facial varieties of the subalkalic type rare metal amazonite–albite granites (according to 339 microprobe and 6 microchemical analyses data) at the diagram $Ta/(Ta + Nb) - Mn/(Mn + Fe)$: 1 – specimens from the Aetykinsky massif (Eastern Transbaikalia); 2 – specimens from the Maykul'sky massif (Southern Kazakhstan); 3 – specimens by A.A. Sitnin (Aetykinsky massif, 1962); 4 – specimen by V.V. Matias (Aetykinsky massif, 1964); 5 – specimens from the Orlovsky massif (Eastern Transbaikalia); 6(I) – area of distribution of the Col-Ta composition figurative spots of the Maykul'sky massif and early phases and facial varieties of the Aetykinsky massif; 7(II) – the same from the later facial varieties of the Aetykinsky massif; 8(III) – the same from the later facial varieties of the Orlovsky massif. Trends of the Col-Ta composition changes in the investigated massifs are shown by solid lines.

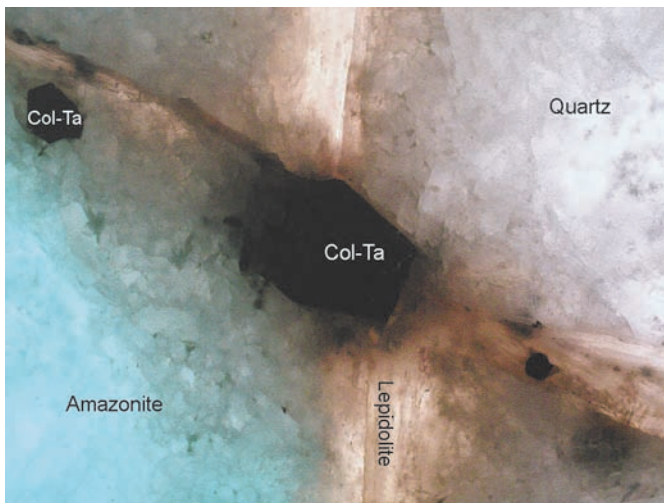


Fig. 2. Formation of manganocolumbite (Col-Ta) within the flakes of lithium mica (zinnwaldite–lepidolite) during the autometasomatal alteration of the subalkalic type rare metal amazonite–albite granite. Aetykinsky massif (Eastern Transbaikalia). Middle-grained amazonite–albite granite of the homogenous and taxitic texture (τ_2^2) of the apical parts of the massif. Thick polished section. Transparent light. Magnification 15.

with the ore–magmatic system development from the unified magmatic chamber without external matter introduction.

Typomorphism of morphology (properly typomorphism)

Morphology of crystals of the Col-Ta group minerals varies greatly in deposits of different

genetic types. The simplest morphology is observed in Col-Ta crystals from the granitic pegmatites (12–15 simple forms). The most complicated morphology is observed in ferrocolumbite crystals from carbonatites (40–50 simple forms). According to our data and other information from the literature, including the data for the Ukrainian Pripetov granitic massifs, Col-Ta specimens from the rare metal granites

occupy an intermediate position: maximal amount of simple forms identified by us with the help of two-circle reflecting goniometer GD – 1 on manganocolumbite crystals from the Orlovsky massif reaches 19 (Povarennykh, 1988, 1991, 1994; Matias *et al.*, 1984).

Col-Ta specimens from carbonatites are distinguished by the often presence of complication simple forms such as {321}, {211}, {342}, {121}, {151}, {161}, and other as well as roundness of edges and tops (Povarennykh, 1990). Crystals of Col-Ta from rare metal alkaline granites are characterized by the presence of the following simple forms facets: {010}, {111}, {130}, {110}, {150}, and other. Along with the presence of simple forms common to the Col-Ta crystals from the rare metal alkaline granites, the specimens from the rare metal amazonite – albite subalkalic (the so called persilic) granite massifs investigated by the author, Orlovsky and Aetykinsky, also contain the following habitus simple forms: {021}, {031}, {051}, {230}, and {170}. For crystal face indexing, we have used goniometer GD – 1 as well as modified for this purpose Fedorov's stage and photogoniometer with laser exposor (Institute of Geochemistry and Physics of Minerals, Kiev, V.M. Krochuk). Drawing of crystals has been conducted manually by the known method or with the help of computer ES-1033 and adopted japanese program of crystal drawing KRISTAL.

The widest variation of Col-Ta crystal habitus types has been observed in the specimens from the Orlovsky massif. According to their occurrence in different age phase and facial varieties of the amazonite – albite granites, evolution row of Col-Ta crystal habitus forms has been constructed (Fig. 3). Col-Ta crystals in this massif vary in morphology from columnar – needle-shaped elongated by [001], plate-like flattened by [010] and elongated by [001] through tabular

and thick tabular, tabular – columnar flattened by [010] and elongated by [001] to isometric and short columnar shortened by [001].

Simple forms and habitus types' spectrum of Col-Ta crystals from the Aetykinsky massif is not so wide in comparison with those from the Orlovsky massif: a) amount of simple forms does not exceed 15, b) crystals distinct elongation by [001] has not been observed, and c) share of columnar – needle-shaped and thick tabular crystals is significantly lower.

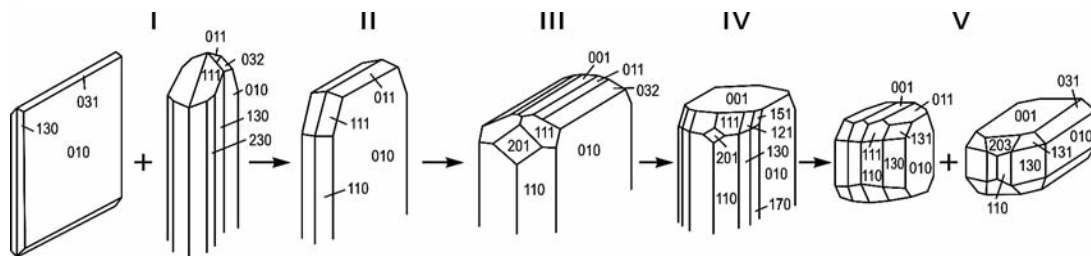
Spectrum of simple forms (up to 11) and habitus types of Col-Ta crystals observed in specimens from the Maykyl'sky massif is much more poor. Tabular, plate-like, and thick tabular flattened by [010] Col-Ta individes are the most abundant in this massif. Columnar – needle-shaped and thick tabular crystals occur rarely with minor occurrence of more isometric crystal forms.

The following regularities of Col-Ta crystal morphology has been observed for the investigated rare metal granites: 1) more isometric form crystals are connected with apical parts of massifs or their endocontacts, and anisometric form crystals are connected with more deep massif parts; 2) more late facial varieties of granites contain, as a rule, more isometric form crystals; 3) for the same facial variety of granites, more isometric form crystals occur in the upper horizons, and anisometric ones for lower horizons.

Typomorphism of inner structure (structure typomorphism)

According to the structure degree of ordering of the Col-Ta group minerals, very wide variation occurs for the specimens belonging to different genetic type's deposits. Ferrocolumbites from carbonatites are commonly most ordered, normally rhombic. Most unordered up to ixio-

Fig. 3. Schematical evolution row of habitus forms of the Col-Ta group minerals of the Orlovsky rare metal granite massif (Transbaikalia) (Povarennykh, 1991, 1994). Habitus types: I (columnar – needle-shaped and lamellar crystals) {010}+{031}+{130}+{hk0}; II (tabular crystals) {010}+{110}+{011}; III (thick tabular crystals) {010}+{110}+{0kl}+{111}; IV (tabular – columnar crystals) {010}+{001}+{hk0}+{hkl}; V (isometric and short columnar crystals) {001}+{010}+{0kl}+{hk0}+{h0l}.



lites (rhombic) and wodgenites (monoclinic), in contrast, are the Col-Ta specimens from granitic pegmatites (Nickel *et al.*, 1963, Giese, 1975). According to the degree of structure ordering, Col-Ta from the rare metal granites of subalkalic type investigated by the author occupies the intermediate position between the mentioned extreme values.

X-ray diffraction investigations has been conducted with the help of the monocrystal autodiffractometer Syntex, diffractometer DRON-3.0, and RKU chamber with $D = 114$ mm (Lomonosov Moscow State University, Geological Faculty, Crystallography Department).

Ferrocolumbites from the Maykul'sky massif are the most ordered (relation of the unit cell parameters b_0/c_0 varies from 2.817 to 2.818). Col-Ta specimens from the Aetykinsky massif are disordered in different degree (b_0/c_0 varies from 2.780 to 2.827). Manganocolumbites from the Orlovsky massif are the most variable in degree of ordering: from the ordered normal rhombic to completely disordered rhombic ixiolites and more rare monoclinic wodgenites.

Col-Ta specimens from the investigated massifs differ greatly in their anatomy. This feature has been studied on the crystallographically oriented and powdered with gold sections of crystals. Ferrocolumbites from the Maykul'sky massif do not reveal visual zonal – sectorial picture of inner structure: its crystals are evenly well polished without crumbling and evenly powdered. Three different types of zonal-sectorial picture are distinguished for the Col-Ta from the Aetykinsky massif: 1) nonvisualized zonality (could be revealed only during point-to-point microprobe analysing), 2) coarse zonality of the "center – margin" type characteristic, as a rule, to the specimens from the early phases and facia of the massif, and 3) complicated picture of oscillating or hourglass type structure revealed by the presence of different oriented trends of chemical composition change in different sectors of Col-Ta monocrystal characteristic to the later granite massif facia. First type zonal – sectorial picture does not practically occur in the Col-Ta specimens from the Orlovsky massif; crystals with second and more often third type of zonal – sectorial anatomy structure predominate.

In the investigated massifs of rare metal granites, Col-Ta group minerals are paragenetically associated* with the following rock-forming minerals: 1) albite (no. 0–5 polysynthetically

twinned or rarely "chess-like"), 2) lithium micas belonging to the zinnwaldite – lepidolite row (Fig. 2, 3) smoky-gray small-grained quartz or outer zones of coarse-grained "pea-shaped" quartz containing oriented intergrowths of albite (the so called quartz with a structure of a snowball), 4) poikiloblastic topaz', 5) pale violet fluorite, and 6) intensively colored blue-green small-grained idiomorphic microcline (amazonite).

For less autometasomatically altered granites of the Orlovsky massif, the following association of accessory minerals is common: ilmenite, monazite, zircon, titanium oxides, and apatite. Within the albitized granites, this association is replaced by the association of ferrocolumbite with cassiterite and monazite. With increase of the albitization intensity, more tantallic members of the Col-Ta mineral group occur, and monazite escapes. Zone of amazonite containing significantly albitized granites with lepidolite is characterized by the presence of substantial amounts of microcline and topaz in association with Col-Ta. According to the data of the researchers of this massif (Zalashkova *et al.*, 1969), the relationship between the amounts of Col-Ta group minerals and microcline accounts there for about 3:1, and reach 7:1 for the underlying muscovite-containing intensively albitized granites with amazonite and lithium mica. Investigations on mineralogical mapping of the Orlovsky massif showed (Matias *et al.*, 1984, Povarennykh, 1988) that the distribution of the Col-Ta group minerals is uneven (lens-shaped and banded) and does not correspond with the known before strict vertical zonality described by the other investigators (Lugovskoy *et al.*, 1972, Alexandrov, 1989).

In the rocks of the Aetykinsky massif, Col-Ta group minerals occur everywhere in contrast to the other ore tantaloniobates. Due to the association with different age facial granite varieties (subphases), they are present here in the form of several generations. Two widespread generations are distinctly determined: early, pre-microcline, and later, post-microcline. First generation Col-Ta is presented by small grains (0.05–0.15 mm along elongation) with composition corresponding to manganiferous ferrocolumbite (Ta_2O_5 5.88–8.78%, FeO 7.89–11.16%, MnO 8.4–10.9%). In quantitative sense, it strongly predominates, and in granites it is distinctly replaced by pyrochlore-microcline containing 8.5–35 mas. % Ta_2O_5 and 41–69 mas. % Nb_2O_5 . Second generation Col-Ta is more coarse-grained (0.25–1.0 mm along elongation), more tantallic

* Paragenetic association was determined visually with a binocular microscope due to the presence of induction surfaces of cooperative growth as well as with the help of a raster electron microscope JSMT-20 under 1000–2000 magnifications.

and manganiferous (can be classified as manganocolumbite), and contains more high concentrations of such admixture elements as titanium, tungsten, tin, and scandium. Col-Ta group minerals are distinctly connected with different age subphases of granites (facia on degree of albitization and greisenization): ferrocolumbite is connected with the early rocks, and manganocolumbite to the later rocks. Coarse-grained Col-Ta crystals (0.5–1.5 cm) of isometric or tabular – columnar habitus close in composition to the second generation Col-Ta occur in pegmatoid quartz – amazonite and Li-mica quartz – amazonite veins intersecting middle-grained and fine-grained amazonite – albite with light Li-mica granites. Within the middle-grained amazonite – albite apical massif part granites of homogeneous and taxitic texture (γ_3^5), incomplete apomanganocolumbite pseudomorphosises of wolframite (huebnerite) occur (Povarennykh, 1991, 1994, Povarennykh *et al.*, 1990). Mutual overgrowths of manganocolumbite and pyrochlore – microlite occur in the later facia.

The Maykul'sky massif is characterized by the occurrence of regular intergrowths of ferrocolumbite with fersmite and samarskite as well as its apopyrochlore pseudomorphosises. Presence of induction surfaces of cooperative growth between ferrocolumbite, amazonite, and lithium-containing biotite (raster electron microscope JSMT-20 under 200-fold magnification) indicates close synchronism of their formation in the granite. According to the presence of replacement products correlation, the following row of the occurrence succession of the main ore tantalum-bearing minerals of the Maykul'sky massif has been established: fersmite – samarskite – ferrocolumbite (Povarennykh, 1994).

Resistant characteristics of Col-Ta have been investigated with the help of PMT–3 device with indenter loading varying from 20 to 100 g. Microhardness of the Col-Ta specimens from the investigated granite massifs varies within the limits 320–970 kg/mm². Relation between the microhardness and Ta content is nonlinear and represents a broken line. Col-Ta specimens with 5–15% Ta₂O₅ content occupy the part of this broken line with a steep incline, and Col-Ta specimens with 15–60% Ta₂O₅ occupy its part with a gentle incline. We have found the inverse proportion between the values of microhardness and microbrittleness of the investigated Col-Ta specimens. Col-Ta from the later granite subphases rather often shows microhardness anisotropy of the I and II types (Povarennykh, 1991, 2008).

Crystal morphology mapping of the Col-Ta group minerals has been conducted at the rare metal granite massifs Orlovsky and Aetykinsky (Transbaikalia). Tantalum deposits are connected with these massifs, and the Col-Ta role in the balance of tantalum in these deposits is predominant in comparison with the pyrochlore-microlite. Col-Ta crystals shape and habitus have been used as elements of mapping (Povarennykh, 1988). We construct histograms of distribution of different habitus type crystals of Col-Ta in series of samples in every borehole and in surface mining workings (quarries, open pits, trenches), series of boreholes in profiles, series of profiles in the block, and in the massif as a whole. With the help of the data of the preceding researchers, we construct block-diagrams showing the correlation between the Col-Ta concentration in the granites and peculiarities of its crystal morphology.

For explanation of the established crystal morphology regularities, the author has used morphogenetic hypothesis (A. Povarennykh, 1966) in addition with the universal principle of Curie on the influence of the environment symmetry onto the individual symmetry. As a result, we could gain an impression of the crystal genesis conditions (if for no other reason than the symmetry of feeding environment) due to the observed natural distribution of the Col-Ta individuals of different habitus type. It also allows reconstructing the former geological conditions and estimating respectively the modern level of erosion shear of granite massif. Thus, according to the distribution in the granite samples of Col-Ta crystals belonging to the different habitus types and members of the evolution row of habitus forms, the minimal erosion shear level occurred in the western apical nose of the Aetykinsky massif roof (in reality does not day outcropping). The values of the erosion shear level have been respectively estimated as negligible (0–50 m) for the Orlovsky massif, moderate (100–200 m) for the main cupola of the Aetykinsky massif, and significant (300 m and more) for the Maykul'sky massif. These estimates of the erosion shear level are in well correspondence with those made in accordance with the geological data by Yu.I. Temnikov for the Orlovsky massif, A.A. Sitnin and V.V. Sunkin for the Aetykinsky massif, and P.V. Koval' for the Maykul'sky massif (Beskin, 2007).

Thus, along with the other typomorphic signs, crystal morphology of the Col-Ta group minerals can be successfully used during the geological prospecting for the survey and estimation of the tantalum ore occurrences in the

massifs of the subalkalic type rare metal amazonite – albite granites. It can be also used at the stage of the detailed and exploitation exploration during conduction of the mineralogical – technological mapping of tantalum deposits in such massifs.

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MINERALOGICAL AND GEOCHEMICAL FEATURES OF DEPOSITS IN THE SOUTHEASTERN TRANSBAIKALIA FOR LOCAL FORECAST OF URANIUM ORE

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A.A. Chernikov discovered the uranium-molybdenum hydrochemical anomaly in the southern Argun region (southeastern Transbaikalia) that had been forcible argument for geological substantiation to renew research and exploration for uranium in this region. This anomaly is important to understand a state of supergene zone of uranium deposits with leached near-surface oxidized zone in the region. The Strel'tsovsk-Antei largest uranium deposits in Russia (Laverov *et al.*, 1991, 1992) are characterized by great vertical extension (2.7 km) of ore mineralization and variation of ore mineralogy, mineralogy of metasomatic and host rocks downward (Ishchukova and Modnikov, 1991; Andreeva *et al.*, 1996; Chernikov, 2006/2007). Chernyshov and Golobev (1996) reported and we confirmed in this study that massive pitchblende ore was deposited within interval 134 – 136 (~150) Ma. Isotopic age of "protore" is 250 – 260 (~300) Ma; age of Th-bearing uraninite is ~500 Ma and older. New data indicated that uranium (IV) oxides and silicates, including coffinite, uranium titanates, and brannerite, in ore of the Antei deposit are young, from zero to few Ma. Exclusively very young uranium (IV) silicates and titanates are observed at lower levels of the Antei deposit. These mineral precipitated from meteoric water infiltrated from surface into deep levels of the deposit. The basic level of karst and fracture rocks can be probable outflow area of meteoric water at the Argun deposit. Distribution of oxygen and carbon isotopes in the Argun and Antei structural clusters confirms the main role of meteoric solution to form various minerals at the uranium deposits; this is important for revealing additional exploration and estimation criteria for these deposits. Large uranium accumulations are predicted to the northward of the Strel'tsovsk structure.

1 table, 7 figures, 22 references.

Keywords: uranium ores, uranium silicates, uranium titanates, oxidized zone of uranium deposits, deep-seated hypergenesis, Argun deposit, Strel'tsovsk-Antei deposits.

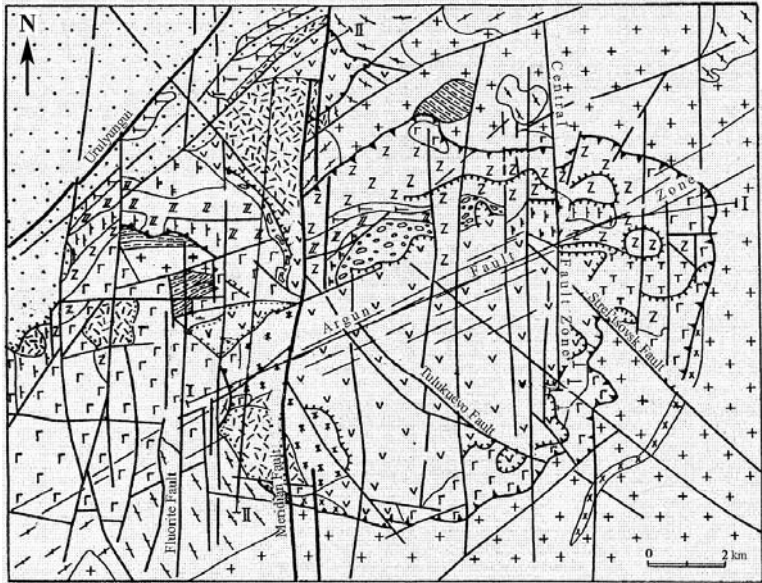
Introduction

Mineralogical and geochemical study of deposits and occurrences carried out by the authors since 1957 in the southern Argun region, the southeastern Transbaikalia have revealed hydrochemical U-Mo anomaly overcapping the Strel'tsovsk volcano-tectonic structure and host basement rocks (Fig. 1) (Chernikov *et al.*, 2007a, 2007b, 2008). At background Mo and U of $n \cdot 10^{-7}$ to $1 \cdot 10^{-6}$ g/l in waters circulating in host rocks, the great anomaly with $1 \cdot 10^{-5}$ – $n \cdot 10^{-4}$ g/l U and Mo was found in subsurface water of the Strel'tsovsk structure, water of the Urulyngui river and Kisly (Acid) spring in the northern side of the East Urulyngui depression. Concentration of uranium in water of the Urulyngui river downstream of settlement Dosatui is not lower than $n \cdot 10^{-5}$ g/l.

These results were forcible argument for substantiation to renew research and geological exploration for uranium in this region in 1962, which had been terminated in 1957. In addition, the results obtained are important to understand a state of supergene zone in the region and contents of uranium and molybdenum in water combined with below new data can be applied to elaboration of research and geological exploration guides of uranium deposits and their local forecast.

Mineralogical and geochemical features of oxidized zone and unoxidized ore of the deposits

The near-surface oxidized zone of uranium deposits in the Southern Argun region is pronounced and highly leached along some well permeable structures down to



Legend to figures 1 and 2:

- sandstone;
- basaltic andesite;
- granite porphyry;
- rhyolite;
- felsite;
- andesite;
- trachybasalt;
- conglomerate;
- syenite porphyry;
- amygdaloid basalt;
- trachydacite, upper cover;
- basaltic andesite, middle cover;
- trachydacite, lower cover;
- basalt, lower cover;
- granite;
- granite gneiss;
- (a) quartz-graphite schist; (b) marbled dolomite limestone;
- metagabbroid;
- ring fault;
- steep fault;
- gentle fault;
- uranium deposit;
- line of geological section.

Fig. 1. Geological scheme of the Strel'tsovsk volcano-tectonic structure, after Ishchukova et al. (2005).

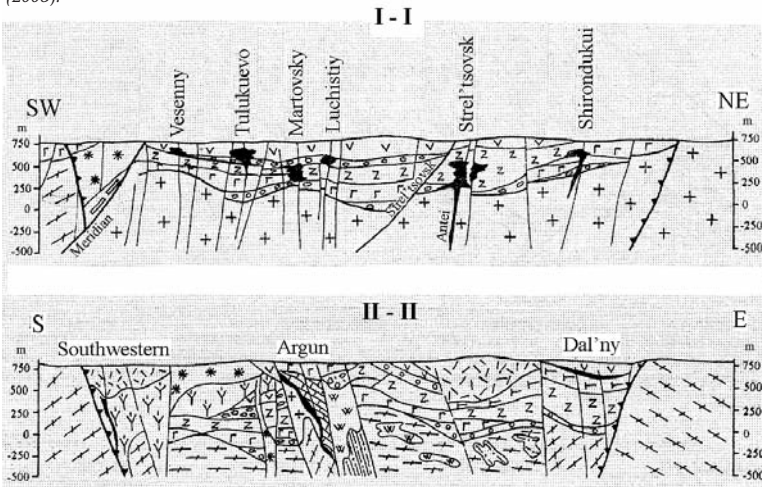


Fig. 2. Geological sections along lines I – I and II – II.

300 – 500 m below surface, where it gradually turns to the deep-seated leached supergene zone. In oxidized zones, uranium was leached from both ore and host rocks. Present uranium content in such zones is hundreds and locally thousand times lower than primary concentration calculated from ²⁰⁶Pb radiogenic additive for age of 150 Ma. As a result of these, all economic orebodies and host rocks enriched in uranium are exposed

at the depth of tens to hundreds meters below surface while ground water form aforementioned large hydrochemical U-Mo anomaly.

Mainly iron and manganese oxides and hydroxides with uranium background $2 \cdot 5 \cdot 10^{-4}\%$, rarely $n \cdot 10^{-3}\%$, sometimes higher occur in the near-surface oxidized zone of most deposits (about 20 deposits have been discovered since 1962). Oxidized

zones with economic uranium content were preserved only at the Tulukuevo, Luchistoe (Fig. 2) and Krasny Kamen' (out of section) deposits. These oxidized zones exposed at the depth of few tens meters below surface are blind and overlain by barren or weakly radioactive rocks.

The largest Russia's uranium deposits (Laverov *et al.*, 1991, 1992) Strel'tsovsk and Antei (the former is hosted in volcanic rocks of the structure, the latter, in basement granites) are characterized by the absence of economic uranium concentration in the near-surface oxidized zone, great vertical extension of orebodies (2.7 km) (Fig. 3), change of the mineralogy of ores, of metamorphic wall-rocks and of host rocks in the vertical geological section (Ishcukova *et al.*, 1991, 2005; Andreeva *et al.*, 1996; Chernikov, 2006/2007). Chernyshov and Golubev (1996) reported and we confirmed that according to U – Pb age of massive nasturan ore hosted in Mesozoic volcanic rocks at the Strel'ovsk deposit ranges from 134 to 136 (or ~150) Ma. Isotopic age of "pro-toores" is 250 – 260 (~300) Ma; age of Th-bearing uraninite is ~500 Ma; and probably, age of disseminated uraninite is more than 500 Ma. However, we documented various intermediate ages and nearly present minerals by dating our samples and samples by I.S. Modnikov and I.V. Sycheva (Table 1).

Hypothetically, disseminated uraninite is not identified. Therefore, the mineral assemblages dated more than 500 Ma can not be characterized and determined only by excess radiogenic lead. U-Mo mineralization of ~500 is found in basement rocks between Argun and Tulukuevo depressions as well as in Tulukuevo depression basement between the Argun and Tulukuevo deposits is of ~500 Ma. Xenoliths of Proterozoic albitized amphibolite and schist containing uraninite-molybdenite mineralization were found in the Paleozoic granitoids at these deposits. Andradite, titanite, allanite, phlogopite, ilmenite, apatite, and zircon are characteristic minerals of these albitized rocks. Previously, uraninite-

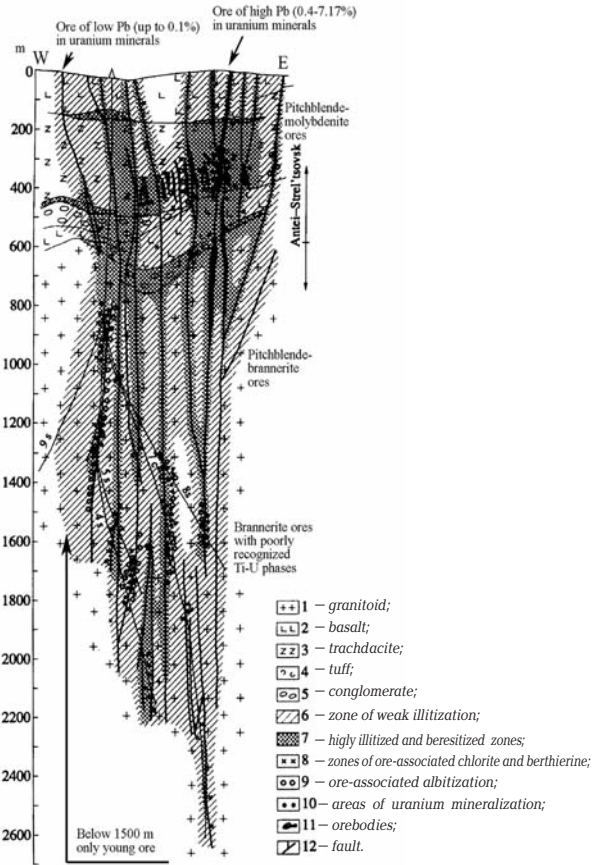


Fig. 3. Sketch geological section of the Strel'tsovsk-Antei deposits with distribution of wall-rock alteration, modified after Andreeva *et al.* (1996), with the authors additions on ore geochemistry and mineralogy.

molybdenite mineralization was studied by K.V. Skvortsova and N.S. Trofimov. Coarse-flake (up to 2 mm) hexagonal (2H) molybdenite is distinguished by low concentration of trace elements (0.0n % Fe, Cu, Pb, Zn; 0.00n % Sb, Bi); the unit-cell dimensions are $a_0 = 0.315$ nm, $c_0 = 1.229$ nm. Th-bearing uraninite occasionally is replaced by coffinite (Fig. 4) that results in Si in composition of the mineral. The composition is as follows, wt. %: 81.33–82.35 UO_2 , 0.0–0.12 Y_2O_3 , 0.36–0.38 ZrO_2 , 10.18–10.68 ThO_2 , 5.38–6.07 PbO , 0.45–0.88 CaO , 0.0–1.81 SiO_2 ; total is 99.65–99.94.

Nasturan from the Dosatui occurrence may be an example of the 300 Ma "pro-toore". Its composition is as follows, wt. %:

Table 1. Chemical composition of uranium silicates and titanates of the Antei uranium deposit, wt. %

No	Dept, m	Major mineral	UO ₂	TiO ₂	CaO	ThO ₂	PbO	ZrO ₂	Fe ₂ O ₃	SiO ₂	Total
1	210	Brannerite	51.13	38.45	4.93	<0.01	1.54	< 0.01	Bdl	2.76	98.81
2	230	Brannerite	58.81	35.44	2.05	<0.01	1.22	0.33	1.02	0.36	99.25
3	230	Si titanate	57.4	13.10	1.0	<0.01	0.00	Bdl	1.06	10.10	82.66
4	230	Si titanate	56.60	13.9	1.9	<0.01	0.60	Bdl	1.22	9.0	83.22
5	230	Si Brannerite	54.60	18.2	2.00	Bdl	0.50	<0.01	2.5	5.29	83.09
6	230	Si Brannerite	57.80	14.00	1.75	Bdl	0.20	<0.01	1.99	10.10	85.84
7	230	Coffinite	55.40	Bdl	3.0	Bdl	0.00	Bdl	3.56	21.6	83.56
8	298	Brannerite	54.1	32.4	1.53	<0.01 –	0.8	2.2	1.1	1.49	93.62
9	298	Brannerite	53.4	33.3	1.79	Bdl	0.4	2.4	1.1	1.16	93.55
10	448	Silicate U	54.46	0.11	1.86	Bdl	<0.15	0.15	0.87	10.39	77.84
11	448	Silicate U	55.65	0.12	1.73	Bdl	<0.15	9.28	0.58	9.44	76.80
12	448	Coffinite	65.42	0.46	2.10	Bdl	<0.15	0.43	0.47	18.66	87.54
13	448	Coffinite	58.24	1.63	1.68	Bdl	<0.15	1.78	1.63	18.99	83.95
14	558	Silicate U	74.54	0.31	2.39	Bdl	<0.15	1.15	0.48	12.10	90.97
15	558	Ti-Silicate U	54.80	25.47	2.04	Bdl	<0.15	2.03	0.83	10.82	95.99
16	558	Ti-Silicate U	47.63	23.93	2.02	Bdl	<0.15	2.47	0.81	10.55	87.48
17	558	U oxide Ti	14.02	64.72	0.87	Bdl	<0.15	1.58	5.78	3.77	90.74
18	910	Si-Zr titanate	60.7 –	21.99 –	0.98 –	Bdl	0.00 –	2.51 –	1.58 –	6.02 –	91.35 –
		U. 7 analyses	17.28	50.94	1.83		0.83	8.41	4.57	11.91	93.74
19	910	Si oxide U.	69.23 –	0.00 –	1.22 –	Bdl	0.00 –	0.35 –	0.10 –	11.43 –	92.30 –
		6 analyses	74.71	0.45	2.50		0.39	1.79	0.57	14.75	95.17
20	1260	Si titanate	36.49	46.55	1.46	2.08	0.78	0.89	0.35	7.21	95.81
21	1573	Silicate U	59.2	0.1	1.8	<0.5	<0.1	1.4	0.3	13.0	91.80
22	1590	Brannerite	50.1	35.3	1.57	Bdl	0.03	1.1	1.8	2.5	94.80
23	1590	Brannerite	54.8	33.4	2.18	Bdl	0.03	1.4	2.5	2.5	97.01
24	1700	Si Brannerite	41.48	32.6	2.7	0.34	0.2	Bdl	Bdl	6.88	86.25
25	1700	Brannerite	45.65	35.1	3.5	<0.3	0.1	Bdl	Bdl	2.22	89.36
26	1718	Coffinite	61.4	<0.1	1.5	0.5	<0.1	0.5	Bdl	16.7	91.20
27	1718	Si Brannerite	43.64	33.0	2.94	1.12	<0.15	0.6	Bdl	5.85	89.92
28	1718	Brannerite	49.75	35.2	3.01	1.2	0.15	0.4	Bdl	0.3	92.45
29	1979	Coffinite	50.3	0.1	1.4	Bdl	<0.1	1.4	1.0	19.7	82.40
30	2020	Brannerite	42.5	33.4	2.3	Bdl	0.03	0.7	Bdl	6.6	86.75
31	2509	Coffinite	61.5	<0.1	0.5	<0.5	<0.1	Bdl	Bdl	18.4	95.40
32	2509	Brannerite	48.28	32.9	2.3	Bdl	<0.1	Bdl	Bdl	0.7 – 4.5	90.04

Notes: An JXA-8100 Jeol electron microprobe operating at 20 kV and current 2 nA. The following analytical lines were used ULa, TiKa, CaKa, ThLa, PbLa, ZrLa, FeKa, u SiKa. Standards were: UO₂, TiO₂, diopside (Ca and Si), ThO₂ (Th), PbTe (Pb), ZrO₂ (Zr), almandine (Fe).

Samples 1 and 2 characterize the lower levels of the Strel'tsovsk deposit. In addition to oxides listed in the Table, the following species were detected, wt. %: 0.0n–2.5 Al₂O₃, up to 3 P₂O₅, up to 0.65 V₂O₅, up to 1.4 WO₃; 0.1–8.9 Y₂O₃ in samples 21, 23, 25, 26, 27, 28, and 31; 0.7 Nb₂O₃ in sample 29. The major mineral phases were named according to relation of oxides.

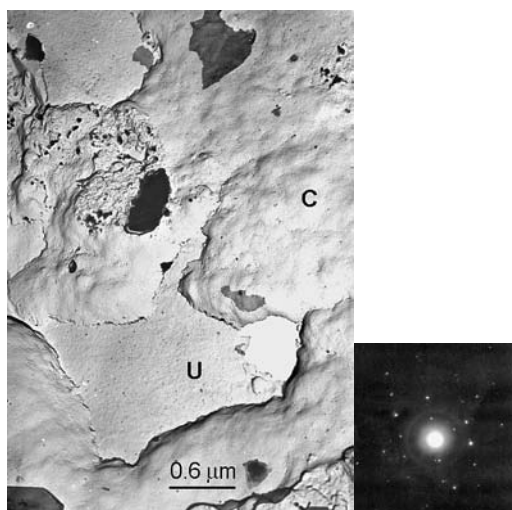


Fig. 4. Replica extraction. Colloform coffinite (C) replaces uraninite (U). Inset: Microdiffraction pattern of coffinite.

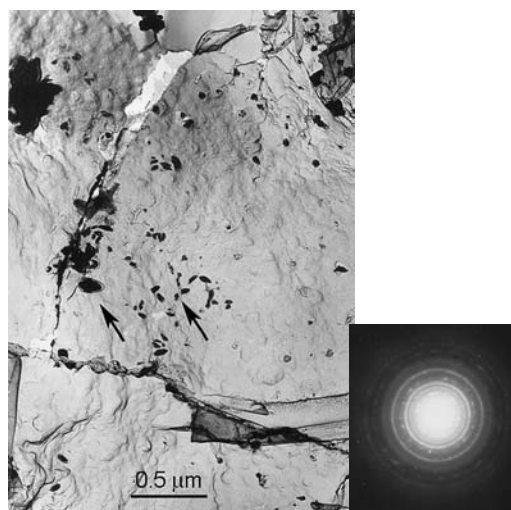


Fig. 5. Replica extraction. Pitchblende fills the whole visible field. Extracted particles are coffinite (arrows). Inset: Microdiffraction pattern of coffinite.

— 92.10–94.02 U_3O_8 , 0.25–0.32 SiO_2 , 0.38–0.76 CaO , 0.41–0.68 Fe_2O_3 , 3.36–3.45 PbO , 1.32–1.35 Y_2O_3 ; total is 98.52–98.54. Sufficiently high Pb, Y, and absence of Th are characteristic features of the mineral.

Massive rich ores of the Strel'tsovsk deposit with age of ~150 Ma are mainly pitchblende with insignificant coffinite (Fig. 5) and brannerite, as well as nasturan with molybdenite (+femolite) and coffinite. Previously, many mineralogists and in the first place, I.V. Mel'nikov, V.P. Rogova, M.V. Vampilov, K.V. Skvortsova, Yu.M. Dymkov, and N.S. Trofimov examined pitchblende. At least four reniform generations of the mineral are recognized. These generations differ in reflectance (from 14 to 16%), size (course-, medium-, and fine-reniform), and associated minerals (coffinite, brannerite, quartz, pyrite, molybdenite, illite, montmorillonite, and Fe-rich chlorite and other minerals).

In addition to uranium, Ti, Zr, Fe, Pb, Ca, Si, occasional Mg, Al, Y, and S rarely other chemical elements were detected by numerous electron microprobe analyses.

Twenty analyses show variable composition of the mineral, wt. %: 73.10–94.82 UO_2 , 0.10–4.03 TiO_2 , 0.48–5.20 Zr_2O_3 , trace–1.91 Fe_2O_3 , 0.42–7.17 PbO , 1.10–3.32 CaO ,

0.15–3.46 SiO_2 , locally up to 1.58 SO_3 , 0.21 ThO_2 , 0.11 Y_2O_3 , up to 0.04 Sb_2O_3 ; total is 91.34–99.63.

According to X-ray diffraction data, molybdenite from these ores is a mixture of hexagonal and rhombic modifications (2H + 3R). Semiquantitative spectral analyses of this molybdenite revealed admixture of Fe (0.2–2.0 %), Pb, Sb, As, Tl (0.001–0.1 %), and locally Ag (0.000n %). These ores also contain Fe-rich molybdenite (femolite) and rare jordisite, X-ray amorphous molybdenum disulfide. Number of molybdenum minerals in the ores decreases downward, whereas content of coffinite and transitional uranium silicate phases increases.

Significant amount of coffinite and transitional silicate mineral phases occurs at the lower levels of the Strel'tsovsk deposit, in the margins of vein pitchblende-molybdenite ore and in stratiform ore of the Dal'nee and Yubeleinoe deposits (Fig. 2, section along line II – II). These phases, as rule, are hydrated, poor crystallized or X-ray amorphous, and recently are called uranium-bearing gels (Dymkov *et al.*, 2003; Aleshin *et al.*, 2006). In most cases, these are nanoscale segregations of coffinite and complex silicate phases transitional from titanates simi-

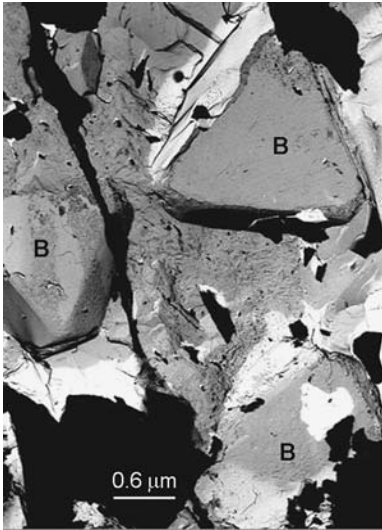


Fig. 6. Replica extraction. Metamict crystals of brannerite (B) in pitchblende (gray field).

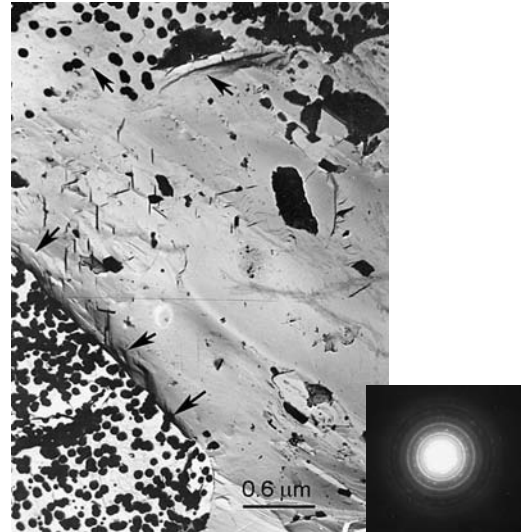


Fig. 7. Replica extraction. Rounded segregations of uranium oxide (arrows) on the surface of quartz grain. Inset: Microdiffraction pattern of uranium oxide.

lar to rutile, ilmenite or titanomagnetite (?) to brannerite (Fig. 6) or uranium oxides (Fig. 7). In addition to U and Si, their formation is accompanied with introduction of zirconium and calcium in deposition areas. In this case, content of PbO in many these phases is lower than hundredths percent indicating their young (near present) geological age. We have composition one of such phases determined with an electron microprobe, wt. %: 61.4 UO_2 , 16.7 SiO_2 , 0.7 Al_2O_3 , 1.5 CaO , 0.5 ThO_2 , 0.5 ZrO_2 , 1.5 P_2O_5 , and 1.4 Y_2O_3 that corresponds to formula of coffinite $\text{U}(\text{SiO}_4)_{1-x}(\text{OH})_{4x}$. The mineral is sufficiently well crystallized and its unit-cell dimensions are: $a_0 = 0.6960$ nm, $c_0 = 0.6288$ nm (± 0.0002 nm) that is consistent with reference data of coffinite. X-ray powder diffraction study of the other uranium silicate was failed.

Many researchers studied in detail brannerite from the Strel'tsovsk deposit. According to analytical electron microscopy (Ivanova *et al.*, 1982), natural unheated brannerite from this deposit is identical to its synthetic analogue $\text{U}[\text{TiO}_3]_2$. However, we identified various transitional varieties from brannerite to coffinite and

nasturan in the ore of the Strel'tsovsk deposit.

At the Antei deposit, amount of uranium silicates and titanates in the ore exposed in the basement granite significantly increases. Uranium titanates (more precise determination is impossible) and less abundant brannerite mainly occur at the lower levels; according to PbO content, identified uranium silicate and titanate minerals at the deep levels (below 1500 m) are of young geological age (Table 1) indicating their recent precipitation from meteoric water infiltrated from the surface to deep levels of the deposit. Basic level of karsting and fracturing at the Argun deposit can be outflow area of meteoric solution in this district (Fig. 2). Distribution of oxygen and carbon isotopes confirms the major role of meteoric water to form gangue minerals (calcite and dolomite) of ore zones in the Antei and Argun structural clusters. Mean $\gamma^{13}\text{C}$ and $\gamma^{18}\text{O}$ values of gangue minerals in the Argun cluster are -0.68‰ and $+3.25\text{‰}$, respectively; these values in the Antei cluster are -1.46‰ and $+10.0\text{‰}$, respectively. These values show minor role of organic matter to form gangue minerals in both

clusters. According to carbon and oxygen isotopic study, in the Antei cluster, minerals were probably formed at decreasing temperature when ore structures pinched out.

Conclusion on meteoric source of mineralizing fluids is consistent with previous determined oxygen and hydrogen isotopic composition of sericite and illite from altered wall rocks (Andreeva and Golovin, 1998). As previously suggested, alkali thermal present deep water (40–40.5°C) interacts with granite of tectonic zones of neighboring Dauriya crest uprising to form zeolites and clay minerals (Chernikov, 2001). The same minerals are observed in some ores of the Strel'tsovsk structure, therefore they can be formed under the similar conditions. Oxygen and hydrogen isotopic study of waters (thermal up to 80–100°C and cold) in Baikal hydromineral area indicated that δD and $\delta^{18}O$ of thermal water of Transbaikalia correspond to meteoric values. As previously reported (Chernikov *et al.*, 2007), all these data testify to important role of meteoric supergene as well as thermal or hydrothermal, as usually they are called, water to form variable minerals and ores. This allows supplementing exploration and prospecting criteria for large deposits (Chernikov, 2006/2007). The major predicted criteria (Ishchukova *et al.*, 2005) allowing to determine the scale of deposits in volcano-tectonic structures, basement rocks, and sedimentary cover should be added by: (1) near-surface zones of leached uranium in the rocks of predicted area; (2) high concentration of uranium and accompanied elements in streams and underground water of this area; (3) occurrence of uranium ore in stratified sediments of volcano-tectonic structures; (4) karst-forming rocks (limestone, marble); (5) oxidation zones of occurrences in basement and volcanic cover are significantly leached and depleted in uranium; and (6) polygene uranium mineralization of variable age.

Conclusion

Strongly leached oxidized zones, significant concentration of uranium minerals precipitated from meteoric water, high uranium content in mineral springs and water of the Urulyngui river downstream, and presents of stratiform deposits, for example Dalnee allow to predict the formation of large uranium mineralization first of all northward of the Strel'tsovsk structure, where these aforementioned prospected criteria are pronounced: 1) in the basement rocks along the Uryulungui fault zone on splotting and cut structures; 2) in basement rocks of the northern side of the East Uryulungui depression; 3) in sediments of the East Uryulungui depression especially in water-permeable beds enriched in organic matter.

Considering the perspective of increasing uranium development in Transbaikalia, B.N. Khomentovsky *et al.* (2000) indicated that stratiform deposits hosted in the Jurassic to Cretaceous sediments of the Olovsky and Urulyngui districts and deposits hosted in the Cenozoic sediments of the Vitim, South Vitim, and Eravneny district with the Shilka and Dzhida promising areas are the major ore objects of the region. It also follows from the data reported by L.P. Ishchukova (2000) and studies of economic types of uranium deposits as well as performed by G.A. Mashkovtsev *et al.* (1998).

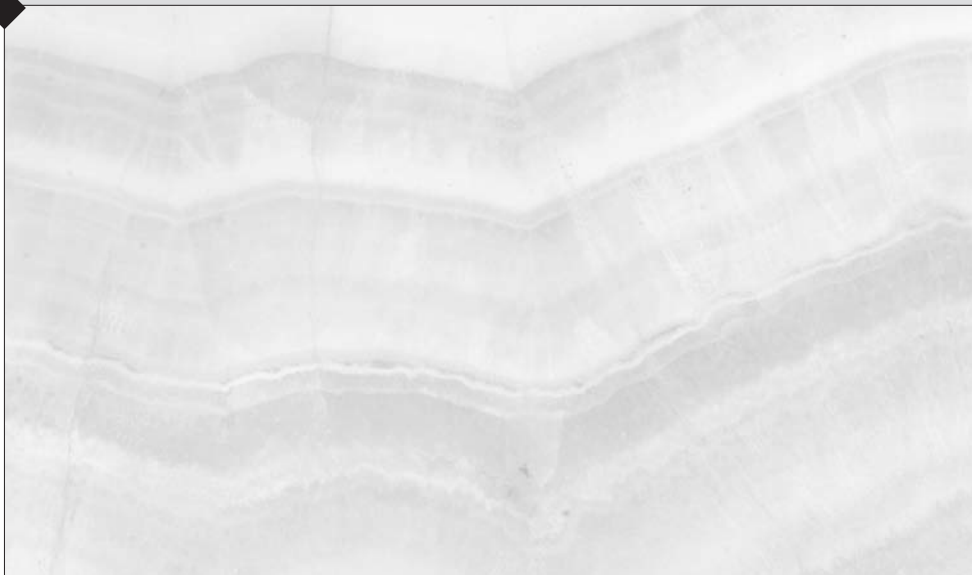
And finally, it should be noted that the notion "deep-seated hypergenesis" was completely revealed by F.V. Chukhrov (1955), who called it "deep-seated weathering". From that time on and as follows from this study, understanding of deep-seated hypergenesis has been broadened. In addition to preparation of weathering profile as reported by F.V. Chukhrov, it was established that deep-seated hypergenesis plays important role to form various types of ores, among which there are large and superlarge mineral deposits. Mineralogical and geochemical features

of such deposits are important to elaborate their new prospective and appraisal criteria, local predicted ore, and increasing reserves of strategic raw.

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**Crystal Chemistry,
Minerals
as Prototypes
of New Materials,
Physical and Chemical
Properties of Minerals**



NEW DATA ON POLYMORPHS OF ANHYDROUS DICALCIUM ORTHOSILICATE

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This article describes new data on polymorphous modifications (α , α'_L , α'_H , β , γ) of Ca_2SiO_4 . Structural features and mechanisms of phase transition between Ca_2SiO_4 polymorphs interrelated to modifications of K-Na sulfate apthitalite (glaserite) $\text{K}_3\text{Na}[\text{SO}_4]_2$ have been analyzed with regard to modular theory and theory of the closest packing. The major structural module $^{[12]}M(1)^{[6]}M(1')^{[10]}M(2)_2[\text{TO}_4]_2$ ($M = \text{K}, \text{Na}, \text{Ca}, \text{Mg}; T = \text{S}, \text{Si}$) has been revealed for the Ca_2SiO_4 modifications and relative natural "glaserite-type" silicate minerals, bredigite $\text{Ca}_7\text{Mg}[\text{SiO}_4]_4$ and merwinite $\text{Ca}_3\text{Mg}[\text{SiO}_4]_2$, and calcio-olivine (γ - Ca_2SiO_4) examined by the authors. The structural glaserite modules similar in symmetry and composition in the structures of described compounds account for topotactic character and reversible phase transition between the Ca_2SiO_4 polymorphs on the one hand and abundant assemblages of the mineral series on the other.

5 tables, 15 figures, 26 references.

Keywords: calcium orthosilicate, new mineral, polymorphous modifications, phase transitions.

Calcio-olivine (γ - Ca_2SiO_4)¹ (Zadov *et al.*, 2008; Gobechiya *et al.*, 2008) pertains to a series of polymorphous modifications of Ca_2SiO_4 (α , α'_L , α'_H , β , γ), based on the running order of decreasing temperature at which these phases are stable (Taylor, 1996):

1425°C 1160°C 630–680°C < 500°C

$\alpha \rightleftharpoons \alpha'_H \rightleftharpoons \alpha'_L \rightleftharpoons \beta \rightarrow \gamma$

690°C
↑
780–860°C

The first four modifications are close to the structural type of K-Na sulfate apthitalite (glaserite) $\text{K}_3\text{Na}[\text{SO}_4]_2$ that causes reversible transitions between them. High-temperature and low-temperature modifications related by phase transitions are known among the "glaserite-type" sulfates. Belonging to the same structural type suggests similar structural transformations between apthitalite (glaserite) polymorphs on the one hand and dicalcium orthosilicate on the other. However, in studies concerned with crystal chemistry of the Ca_2SiO_4 polymorphs (Eysel and Hahn, 1970; Barbier and Hyde, 1985; Il'inets and Bikbau, 1990), such comparison is absent, despite reference of their affinity to the

glaserite structural type. In addition, these studies are based on ambiguous investigation results of single crystals of solid solutions Ca_2SiO_4 – Ca_2GeO_4 , Ca_2SiO_4 – Sr_2SiO_4 , Ca_2SiO_4 – Ba_2SiO_4 , which are structural analogues of high-temperature Ca_2SiO_4 modifications and contain Sr and Ba admixtures used as stabilizers (along with additives V_2O_5 , Al_2O_3 , Cr_2O_3 , and $\text{Na}_2\text{P}_4\text{O}_7$) to synthesize qualitative single crystals.

In this study, we examined features of structure and mechanisms of phase transitions between the Ca_2SiO_4 polymorphs interrelated with modifications of apthitalite (glaserite) using results of structure refinement of pure calcium compounds by Rietveld method on the basis of X-ray powder diffraction: at high temperature using neutron radiation (Mumme *et al.*, 1996) and under ambient conditions using X-ray radiation (Gobechiya *et al.*, 2008). The review has been supplemented with comparison of the structures of bredigite $\text{Ca}_7\text{Mg}[\text{SiO}_4]_4$ and merwinite $\text{Ca}_3\text{Mg}[\text{SiO}_4]_2$, which are natural glaserite-type silicate minerals similar to synthetic modifications of dicalcium orthosilicate (Table 1).

This is the last crystal chemical review prepared with participation by Yuriy K.

¹The mineral species was approved by the Commission on New Minerals, Nomenclature and Classification of the International Mineralogical Association in September 06, 2007.

Table 1. Crystallography of some natural and synthetic glaserite-type compounds

Compound, formula	Unit-cell dimensions (Å, degree)			Space group	Z	V(Å ³)	ρ_{calc} (g/cm ³)	Source
	a	b	c					
	α	β	γ					
Aphthitalite (glaserite) K ₃ Na[SO ₄] ₂	5.680	7.309		$\bar{P}3m1$	1	204.2	2.66	Okada & Ossaka, 1980
α -K ₂ SO ₄ (700°C)	5.947	8.375		$P6_3/mmc$	2	433.9	2.63	Miyake <i>et al.</i> , 1980
Arkanite β -K ₂ SO ₄	7.476	5.763	10.071	$Pnma$	4	194.2	2.91	McGinnety, 1972
α -Ca ₂ SiO ₄ (1545°C)	5.532	7.327		$P6_3/mmc$ $\bar{P}3m1$	2 2	256.5	2.23	Mumme <i>et al.</i> , 1996
α'_{II} -Ca ₂ SiO ₄ (1250°C)	6.871	5.601	9.556	$Pnma$	4	367.8	3.07	Mumme <i>et al.</i> , 1996
α'_I -Ca ₂ SiO ₄ (1060°C)	20.527	5.590	9.496	$Pn2_1a$	12	1089.6	3.11	Mumme <i>et al.</i> , 1996
Larnite β -Ca ₂ SiO ₄ (630–680°C)	6.745 94.59	5.502	9.297	$P2_1/n11$	4	343.9	3.28	Jost <i>et al.</i> , 1977
Calcio-olivine γ -Ca ₂ SiO ₄	5.074	6.754	11.211	$Pcmm$	4	384.2	2.94	Gobechia <i>et al.</i> , 2008
Merwinite Ca ₃ Mg[SiO ₄] ₂	13.254	5.293	9.328	$P12_1/a1$	4	1348.3	3.27	Moore & Araki, 1973
		91.90						
Bredigite Ca ₇ Mg[SiO ₄] ₄	6.739	10.909	18.340	$Pn2n$	2	654.0	3.29	Moore & Araki, 1976

Notes: Orthorhombic and monoclinic compounds are in settings suitable for comparison. Temperatures at which phases are stable are in parentheses.

Egorov-Tismenko (1938–2007), associate professor, Division of Crystallography, Faculty of Geology, Lomonosov Moscow State University, famous teacher and scientist, who made significant contribution to crystallography, crystal chemistry, and structural mineralogy. This article is dedicated to his memory.

Aphthitalite (glaserite) and its polymorphs

Numerous natural and synthetic sulfates, phosphates, silicates, germanates, arsenates, and other compounds whose structures are characterized by certain atom arrangement are attributed to the structural type of aphthitalite (glaserite) K₃Na[SO₄]₂. In space group $\bar{P}3m1$, large cations Na⁺, K⁺, Ca²⁺, Sr²⁺, and Ba²⁺ occupy regular point systems of symmetry $\bar{3}m$ in sites M(1) and M(1') with coordinates (0, 0, 0); (0, 0, 1/2) and on the 3-fold axes in site M(2) (1/3, 2/3, z), where central cations (S⁴⁺, Si⁴⁺, P⁵⁺, Ge⁴⁺) and apical O-vertices of tetrahedra are also arranged. Oxygen vertices of tetrahedron triangular bases are localized in symmetry plane *m* with coordinates (x, -x, z).

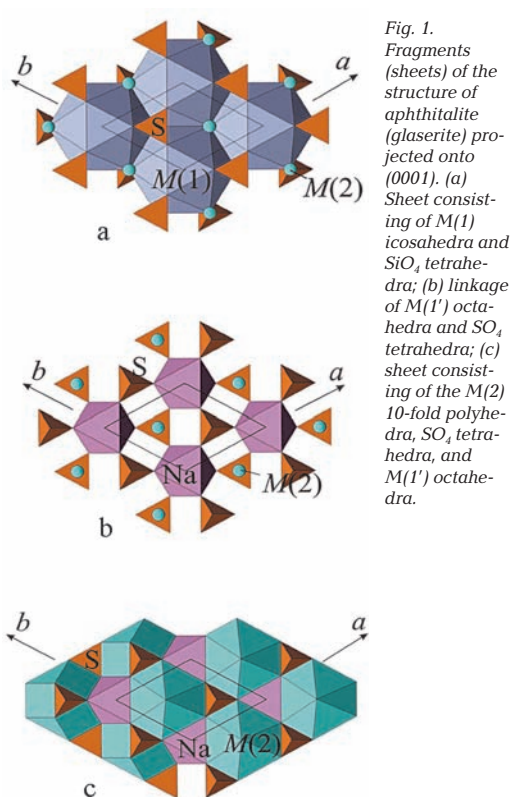


Fig. 1. Fragments (sheets) of the structure of aphthitalite (glaserite) projected onto (0001). (a) Sheet consisting of M(1) icosahedra and SiO₄ tetrahedra; (b) linkage of M(1') octahedra and SO₄ tetrahedra; (c) sheet consisting of the M(2) 10-fold polyhedra, SO₄ tetrahedra, and M(1') octahedra.

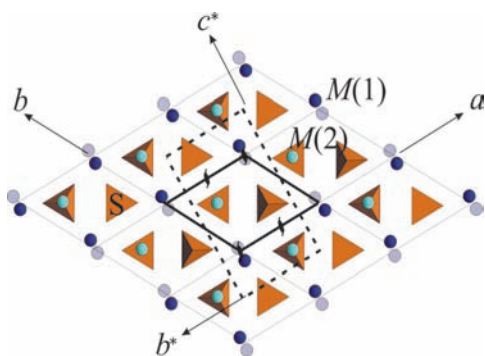


Fig. 2. Relationship of the unit cells of apthitalite (glaserite) $K_3Na[SO_4]_2$ (solid thick line) and arkanite $\beta-K_2SO_4$ (dashed line).

The structure of apthitalite (glaserite) $K_3Na[SO_4]_2$ (Bellanca, 1943; Moore, 1976; Okada and Ossaka, 1980) is sufficiently close framework consisted of large K polyhedra and Na octahedra with isolated $[SO_4]$ tetrahedra in cavities. Two types of sheets parallel to (0001) can be recognized in the framework. The first one (-0.2 to $+0.2$ thick along z) is composed of edge-sharing distorted centrosymmetrical K icosahedra with centres in sites $M(1)$ bonded by shared horizontal edges. Six $[SO_4]$ tetrahedra surrounding $M(1)$ icosahedron, with each of three vertical edges being shared with neighboring $M(1)$ polyhedron and apical vertex being shared of three $M(1)$ polyhedra of the sheet are attributed to the same layer (Fig. 1a). Six oxygen atoms at distance of 2.909 \AA arranged in vertices of two opposite triangular icosahedron faces perpendicular to the 3-fold axis and forming octahedron elongated along axis c compose the first coordination sphere. The second sphere consists of six apical vertices of S tetrahedra arranged in equatorial plane of icosahedron at distance of 3.288 \AA . Another more voluminous sheet ($0.2-0.8$ thick along z) is composed of Na octahedra (Fig. 1b) with centres in sites $M(1')$ shared triangular faces with the $M(1)$ icosahedra and face-sharing K 10-fold polyhedra with centres in sites $M(2)$ (Fig. 1c). Each of two $M(2)$ polyhedra of unit cell bonded by inversion centres is half of Archimedean cuboctahedron covered by hexagonal pyramid instead

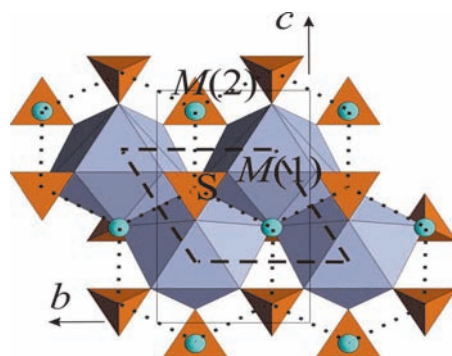


Fig. 3. Zigzag ribbons composed of $M(1)$ 9-fold polyhedra projected onto (100) of the structure of arkanite $\beta-K_2SO_4$. Icosahedra of the primary structure of glaserite are delineated by dotted line and its unit cell, by dashed line. Solid line delineates the unit cell of arkanite.

of the second half. Six of ten ligands around the $M(2)$ atom are located in plane (0001) at distance of 2.854 \AA ; three ligands composing shared face with $[SO_4]$ tetrahedron are distant of 3.112 \AA ; the tenth ligand opposite to this face being apex of hexagonal pyramid is located 2.547 \AA of central atom. This $O(1)$ atom located in equatorial plane of $M(1)$ icosahedron is apical vertex of tetrahedron translational along axis c and located Thus, the second more voluminous sheet of the structure of glaserite consists of $M(1')$ octahedra and $M(2)$ 10-fold polyhedra with vertices of hexagonal pyramids embedded in upper and lower icosahedral sheets. The central Na octahedron called by Moore (1973) as rotator combined with surrounding $[SO_4]$ tetrahedra is the major element of the structures similar to glaserite (Fig. 1b). The lower three tetrahedra ($z \sim 0.2$) of the rotator are shared with the upper three tetrahedra of the first icosahedral layer and upper three tetrahedra ($z \sim 0.8$) of rotator are shared with three tetrahedra of translationally identical sheet along axis c .

Two modifications of K sulfate, low-temperature $\beta-K_2SO_4$ (analogue of arkanite) (McGinnety, 1972) and high-temperature synthetic $\alpha-K_2SO_4$ (Miyake *et al.*, 1980) are assigned to the apthitalite (glaserite) structural type. Egorov-Tismenko *et al.* (1984) showed that the structure of $\beta-K_2SO_4$ can be obtained by rotation of the initial glaserite unit cell (Fig. 2) around axis 2_1 input instead of axis 3 into coordinate origin. Such trans-

formation results in disappearing translations along horizontal axis and appearance of a new vector, which is equal to long diagonal of the glaserite unit cell and perpendicular to preserved translational vector of glaserite along axis x . Transition matrix from the glaserite to arkanite unit cell is $(001/\bar{1}00/120)$. In addition, instead of horizontal 2-fold axes and inversion centres located on the $(01\bar{1}0)$ faces of the glaserite unit cell, apothemal planes c appear as a result of interaction of input axes $2_1(z)$ with preserved mirror symmetry planes m of the glaserite space group $P\bar{3}m1$ perpendicular to axis b of the β - K_2SO_4 unit cell. In the new orthorhombic unit cell, slip vector of plane c is directed along coordinate x that changes the name of this plane to a . Residual half of inversion centres of the glaserite space group preserves in orthorhombic space group $Pnma$ of β - K_2SO_4 and their interaction with input axes 2_1 accounts for appearance of perpendicular clinoplane n localized between inversion centres along vertical axis a of the new cell. In the structure of β - K_2SO_4 within the selected glaserite cell, atoms are arranged similarly to those in the glaserite structure. In duplicate orthorhombic cell, O atoms occupy three regular point systems in contrast to two systems in the glaserite structure. Two varieties of O atoms located on planes $m_{\perp y}$ have two degrees of freedom that allows their displacement from the glaserite sites resulting in liquidation of the 3-fold axes. In addition, reflection of the glaserite cell in apothemal plane c displaces oxygen atoms O(1), which are apical vertices of S tetrahedra arranged in equatorial plane of $M(1)$ icosahedron, to $1/2 Ta$ (coordinate x of the β - K_2SO_4 structure). It is reflected in the shape of coordination polyhedra around $M(1)$ and $M(1')$ cations. Three of six oxygen atoms of the hexagonal section of $M(1)$ icosahedra ($12 - 3 = 9$) transit to coordination sphere of $M(1')$ cations ($6 + 3 = 9$) forming the identical polyhedra bonded by screw 2-fold axis (2_1) on two levels on axis a . In this case, continuous the $M(1)$ icosahedral sheets and $M(1')$ octahedra of the other layer are transformed in the structure of β -modifications into zigzag ribbons consisting of $M(1)$ and $M(1')$ 9-fold polyhedra (Fig. 3) elongated along axis b of orthorhombic cell and arranged on two levels on axis a . As a

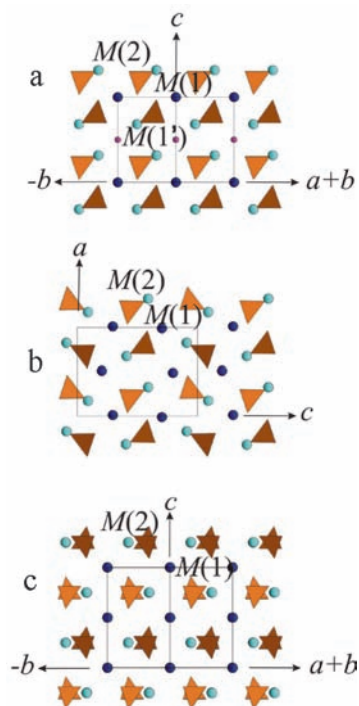


Fig. 4. Projections of the structures: (a) apthitalite (glaserite) K_2NaSO_4 on (1210) ; (b) arkanite β - K_2SO_4 on (100) ; (c) high-temperature modification α - K_2SO_4 on (1210) . Atoms in $M(1)$, $M(1')$, and $M(2)$ sites are shown by circles. Triangles are tetrahedra around S atoms.

result, less close framework composed of $M(1)$ 9-fold polyhedra, $M(2)$ polyhedra, and $[SO_4]$ tetrahedra is formed. Coordination of $M(2)$ atoms is unchangeable; only orientation of hexagonal pyramids of $M(2)$ 10-fold polyhedra changes. Orientation of part of $[SO_4]$ tetrahedra around $M(1)$ polyhedra in the centre of the glaserite rotator also changes (Figs. 4a, 4b).

β - K_2SO_4 modification stable within wide range of temperature (from $-117^\circ C$ to $582^\circ C$) at $800^\circ C$ transits to high-temperature α - K_2SO_4 (Miyake *et al.*, 1980), whose symmetry increases up to space group $P6_3/mmc$ in comparison with the initial glaserite symmetry. In the structure of α - K_2SO_4 (Fig. 4c), K_1 atoms occupy regular point system of symmetry $\bar{3}m$ (coordinates $0,0,0$ and $0,0,1/2$) and K_2 and S atoms occupy system of symmetry $\bar{6}m2$ (coordinates $2/3, 1/3, 1/4$ и $2/3, 1/3,$ and $3/4$, respectively). Two alternative mirror-symmetrical tetrahedra with opposite oriented apical vertices and statistically filled sites $4f$ (regular point system of symmetry $3m$ and coordinates $1/3, 2/3, z$) and sites $12k$ (symmetry m and coordinates $x, 2x, z$) by O(1) atoms (apical vertices of tetrahedra) and O(2) atoms (vertices of tetrahedron bases), respec-

Table 2. Distances (Å) cation-anion in coordination polyhedra around sites $M(1)$ of the glaserite-type compounds

Compound, formula	$M(1)$ -polyhedron			$M(1')$ -octahedron		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Aphthitalite (glaserite)	2.91	3.29	^[12] 3.10	2.39	2.39	2.39
$K_3Na[SO_4]_2$	2.91	2.91	^[6] 2.91			
Arkanite β - K_2SO_4	2.73	3.13	^[9] 2.86	—	—	—
	2.73	2.80	^[6] 2.77			
α - K_2SO_4	2.69	3.52	^[12] 3.28	—	—	—
	2.69	3.41	^[6] 3.05			
α - Ca_2SiO_4	2.60	3.53	^[12] 2.97	2.26	2.26	2.26
space group $P\bar{3}m1$	2.72	2.72	^[6] 2.72			
α - Ca_2SiO_4	2.23	3.54	^[12] 3.08	—	—	—
space group $P6_3/mmc$	2.23	2.75	^[6] 2.49			
α'_H - Ca_2SiO_4	2.26	2.85	^[8] 2.56	—	—	—
	2.26	2.68	^[6] 2.53			
α'_L - Ca_2SiO_4	2.39	2.75	^[8] 2.58	—	—	—
	2.39	2.71	^[6] 2.52			
Larnite β - Ca_2SiO_4	2.38	2.64	^[8] 2.49	—	—	—
	2.38	2.64	^[6] 2.48			
Calcio-olivine	2.32	2.47	^[6] 2.41	—	—	—
γ - Ca_2SiO_4						
Merwinite $Ca_3Mg[SiO_4]_2$	2.31	2.84	^[8] 2.55	1.99	2.16	2.06
Bredigite $Ca_7Mg[SiO_4]_4$	2.39	3.01	^[10] 2.79	2.01	2.22	2.11
	2.28	3.28	^[10] 2.78	2.00	2.12	2.07
	2.31	2.65	^[9] 2.60			
	2.31	2.72	^[8] 2.47			

Notes: Average cation-anion distances of two domains are given for α'_H polymorph and three subcells, for α'_L polymorph. Cation-anion distances for independent sites are given for the structures of merwinite and bredigite.

Fig. 5. The structure of α'_H - Ca_2SiO_4 projected on plane (100) (b) and its left (a) and right (c) mirror-symmetrical domains. Ca atoms in $M(1)$ site at levels $x \sim 0$ (light circles) and $x \sim 0.5$ (dark circles).

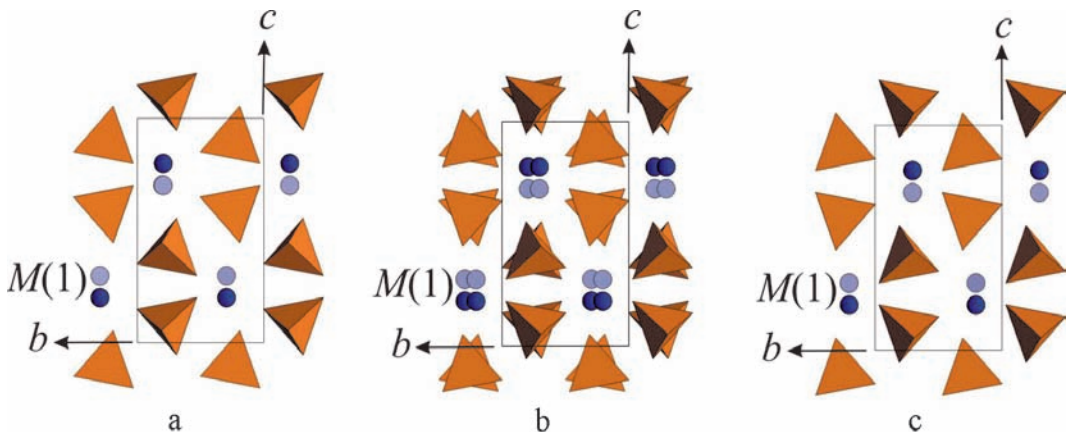


Table 3. Cation-anion distances (Å) in coordination polyhedra around sites *M(2)* and *T* in the structures of glaserite-type compounds

Compound, formula	Minimum	<i>M(2)</i> -polyhedron		Minimum	<i>T</i> -tetrahedron	
		Maximum	Average		Maximum	Average
Aphthitalite (glaserite)						
K ₃ Na[SO ₄] ₂	2.55	3.11	[10]2.90	1.47	1.48	1.47
Arkanite β-K ₂ SO ₄	2.72	3.19	[10]3.00	1.46	1.47	1.47
α-K ₂ SO ₄	2.85	3.87	[10]3.28	1.34	1.35	1.35
α-Ca ₂ SiO ₄	2.06	3.66	[10]2.97	1.58	1.67	1.61
space group $\bar{P}3m1$						
α-Ca ₂ SiO ₄	2.12	3.36	[10]3.03	1.57	1.64	1.58
space group $P6_3/mmc$						
α' _H -Ca ₂ SiO ₄	2.29	3.32	[10]2.82	1.59	1.65	1.63
α' _L -Ca ₂ SiO ₄	2.32	3.36	[10]2.82	1.53	1.67	1.61
Larnite β-Ca ₂ SiO ₄	2.22	2.88	[7]2.51	1.61	1.65	1.63
Calcio-olivine	2.29	2.39	[6]2.35	1.58	1.69	1.62
γ-Ca ₂ SiO ₄						
Merwinite	2.22	2.81	[9]2.58	1.60	1.66	1.63
Ca ₃ Mg[SiO ₄] ₂	2.25	3.10	[9]2.64	1.60	1.64	1.62
Bredigite						
Ca ₇ Mg[SiO ₄] ₄	2.31	3.11	[10]2.67	1.58	1.65	1.61
	2.24		[10]2.69	1.58	1.61	1.61
	2.33	3.15	[10]2.72	1.58	1.66	1.61
	2.33	3.43	[10]2.81	1.60	1.65	1.62

Notes: Average cation-anion distances of two domains are given for α'_H-polymorph and three subcells, for α'_L polymorph. Cation-anion distances for independent sites are given for the structures of merwinite and bredigite.

tively, are formed around sulfur atoms. Two bipolar statistically filled 10-fold polyhedra are formed around K₂ atoms that causes an appearance of horizontal plane *m_z* and increasing symmetry to holohedral. Coexistence of alternative mirror-symmetrical tetrahedra in the structure of α-modification provides orthogonal unit cell in it, where the structure of β-modification of K₂SO₄ is described (Fig. 4b) accounting for topotactic character of β-K₂SO₄ – α-K₂SO₄ transition previously reported in (Miyake *et al.*, 1980). As seen from Tables 2 and 3, this transition is accompanied with increase of average cation-anion distances in coordination polyhedra around large cations at simultaneous their decrease in S tetrahedra.

High-temperature polymorphs of Ca₂SiO₄

The structures of high-temperature polymorphs of Ca₂SiO₄ are similar to the

structures of above glaserite modifications, where the glaserite sites of K and S are replaced by Ca and Si. According to Mumme *et al.* (1996), the structure of α-modification of Ca₂SiO₄ is close to that of high-temperature α-K₂SO₄ (Fig. 4c) but differs from it in greater number of statistically filled atomic sites. In addition to the formation of alternative tetrahedral and 9-fold polyhedra, the displacement of apical O(1) vertices (site 4f) of Si tetrahedra from 3-fold axes to form alternative and arranged in one plane sites (12k) is observed in the structure of α-Ca₂SiO₄. This results in wide range of Ca-O distances (Tables 2, 3) and strong distorted Ca polyhedra. Mumme *et al.* (1996) reported in the examined sample the second component, whose structure is described in the frame of the glaserite model (space group $\bar{P}3m1$) differed from the latter in analogous displacement of O(1) atoms from 3-fold axis.

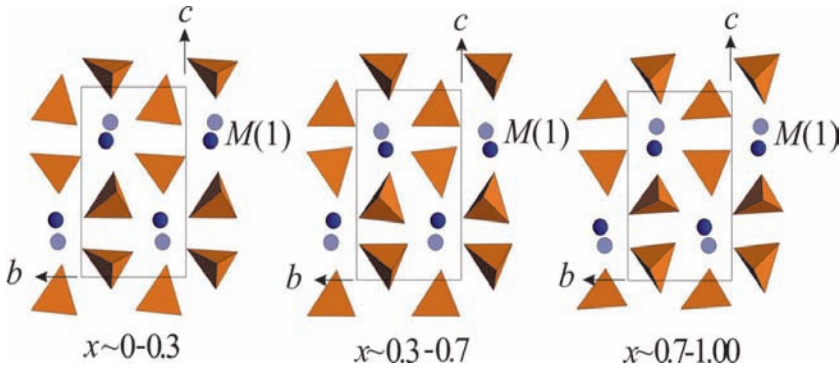


Fig. 6. The structure of α'_L - Ca_2SiO_4 projected onto (100). Subcells at three levels on axis x are shown. Light and dark circles are Ca atoms in sites M(1) with $x \sim 0.17$.

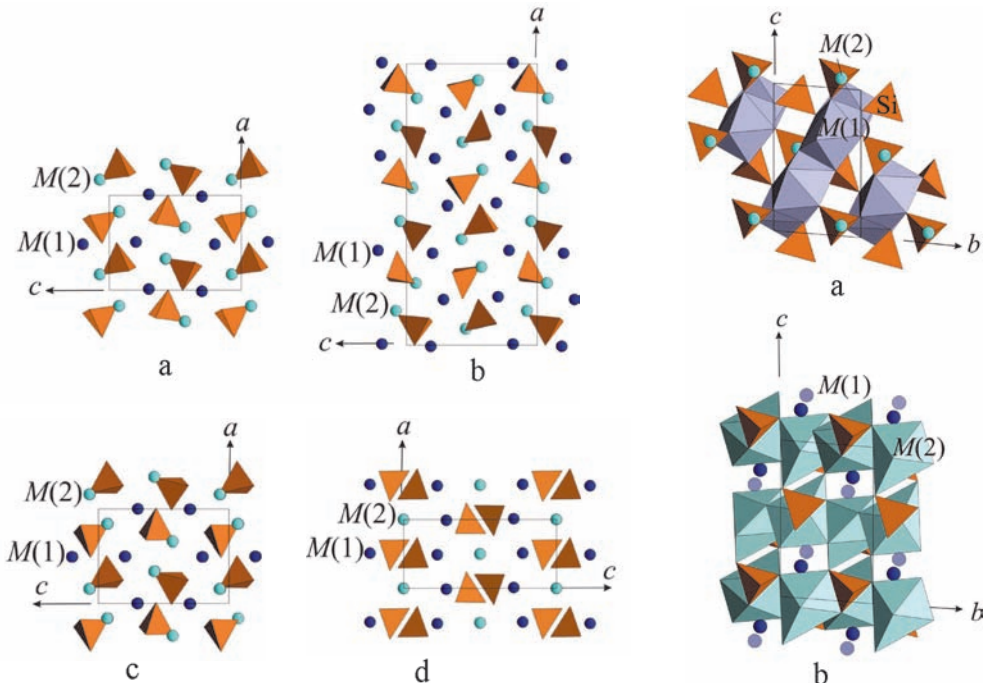


Fig. 7. The structures of polymorphs of dicalcium orthosilicate onto (010): (a) α'_L - Ca_2SiO_4 ; (b) α'_L - Ca_2SiO_4 ; (c) β - Ca_2SiO_4 ; (d) γ - Ca_2SiO_4 .

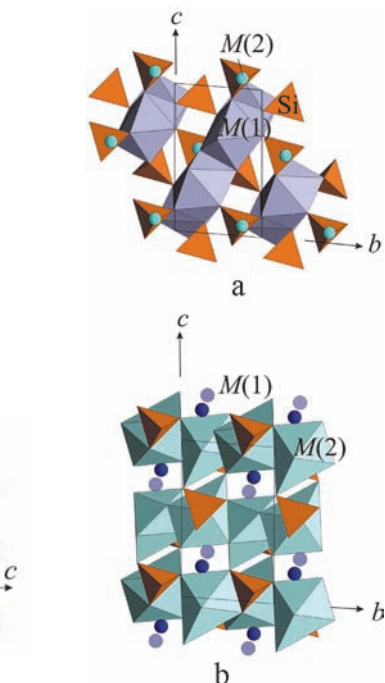


Fig. 8. The structure of β - Ca_2SiO_4 projected on plane (100): (a) sheets consisting of M(1) 8-fold polyhedra; (b) framework composed of M(2) 7-fold polyhedra. Ca atoms in site M(1) at levels $x \sim 0$ (light circles) and $x \sim 0.5$ (dark circles).

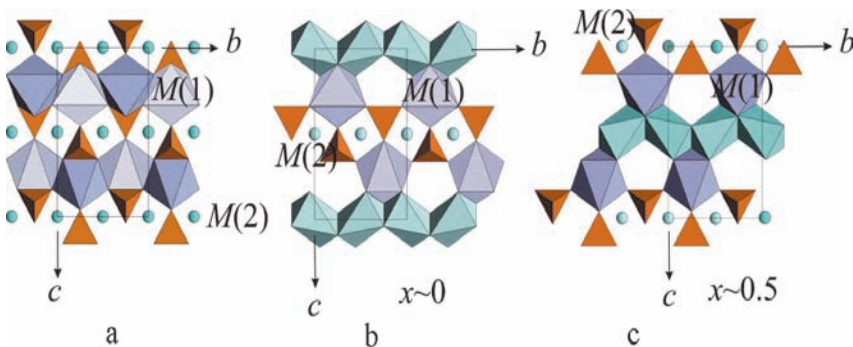


Fig. 9. Fragments of the structure of calcio-olivine γ - Ca_2SiO_4 projected onto (100): (a) wall composed of the M(1) octahedra; (b, c) olivine ribbons consisting of the M(2) octahedra with tooting of the M(1) octahedra at levels $x \sim 0$ and $x \sim 0.5$, respectively.

In the structures of orthorhombic α'_H - and α'_L modifications of Ca_2SiO_4 (Table 1), the model of the $\beta\text{-K}_2\text{SO}_4$ structure is repeated but it is distorted due to atomic atoms displaced from corresponding sites. In the structure of $\alpha'_H\text{-Ca}_2\text{SiO}_4$ (Figs. 5a, 5b, 5c, 7a) this leads to the formation of two mirror-symmetrical (m_{1b}) domains (space group $Pn2_1a$) with statistically filled all sites (with the exception of Si) and in the structure of $\alpha'_L\text{-Ca}_2\text{SiO}_4$, to threefold one of the unit-cell dimensions ($6.84 \times 3 = 20.53 \text{ \AA}$). In the last case, in addition to displaced O and Ca atoms, turn of Si tetrahedra and their distortion are observed in subcells neighboring on axis a (Figs. 6a, 6b, 6c, 7b). Distinctions of hexagonal α - and orthorhombic α'_H - и α'_L - modifications of Ca_2SiO_4 are similar to those described for glaserite and concern with modified orientation of tetrahedra in the glaserite rotator resulting in decreasing number of ligands around Ca in $M(1)$ site. In addition to these distinctions, in the structures of α'_H - and α'_L - modifications, atomic displacement results in distance one of three equatorial vertices of $M(1)$ 9-fold polyhedra from central Ca (3.20 \AA in $\alpha'_H\text{-Ca}_2\text{SiO}_4$; and $3.39, 3.43,$ and 3.56 \AA in three neighboring subcells in $\alpha'_L\text{-Ca}_2\text{SiO}_4$, respectively) and their conversion into 8-fold polyhedra (Table 2), which are edge-shared only with two Si tetrahedra. $M(1)$ 8-fold polyhedra form framework consisting of zigzag columns elongated along axis a of unit cell, rather than bands in the structure of $\beta\text{-K}_2\text{SO}_4$. Each of these columns is formed by edge-sharing polyhedra along $[100]$ and $[001]$, and vertex-sharing, along $[010]$; the latter is true for the averaged $\alpha'_H\text{-Ca}_2\text{SiO}_4$ model. Polyhedra around Ca in $M(2)$ site are close in shape to corresponding polyhedra in the structure of $\alpha\text{-Ca}_2\text{SiO}_4$ (for model with space group $P\bar{3}m_1$) and characterized by the greater distortion degree (Table 3). The Si-O distances in the structure of α'_H -modifications are within usual range, whereas, in the structure of α'_L -modification, their small deviation is observed (Table 3).

Low-temperature polymorphs of Ca_2SiO_4

Synthetic analogue of larnite $\beta\text{-Ca}_2\text{SiO}_4$ is metastable phase that at temperature below 500°C transits into γ -modification (Figs. 7c, 7d).

The structure of $\beta\text{-Ca}_2\text{SiO}_4$ was examined for the first time by Midgley (1952) on the basis of crystals stabilized by 0.5% B_2O_3 . Later, the structure was refined using pure Ca (Jost *et al.*, 1977) and Sr (Catti *et al.*, 1983) crystals synthesized without stabilizers. Crystals of both compounds were twinned by plane (010) corresponding to the mirror symmetry plane linking two domains in the structure of $\alpha'_H\text{-Ca}_2\text{SiO}_4$ at certain arrangement of axes of unit cell (Table 1). The structure of $\beta\text{-Ca}_2\text{SiO}_4$ was also refined by Rietveld method for powder (Mumme *et al.*, 1995). All three models are characterized by the same geometry of atomic arrangement (Fig. 8) and close to the structure of each domain of $\alpha'_H\text{-Ca}_2\text{SiO}_4$. Like the structures of orthorhombic polymorphs, Ca atoms in site $M(1)$ are surrounded by eight ligands, six of which are located in octahedron vertices and the other two – apical vertices of Si tetrahedra – are arranged in equatorial plane; the third apical vertex is distant from central cation for $\sim 3.5 \text{ \AA}$. Atomic displacement in the structure of β -modification results in decrease of the nearest neighbors around Ca in site $M(2)$ to 7 (Table 3) and changing way to form polyhedra. Columns consisting of $M(1)$ 8-fold polyhedra elongated along axis a of unit cell are similar to above described and form sheet parallel to $(0 \ 11)$ (Fig. 8a) rather than linked into framework like structures of orthorhombic polymorphs. These sheets are "broached" along axis b by zigzag columns consisting of $M(2)$ 7-fold polyhedra and linked to each other by shared O vertices into tracery framework (Fig. 8b).

Transition of β -modification to $\gamma\text{-Ca}_2\text{SiO}_4$ is accompanied by substantial transformation of the structure. In the structure of $\beta\text{-Ca}_2\text{SiO}_4$, pairs of Ca atoms in site $M(1)$ are bonded by 2-fold screw axes and arrange along axis a of unit cell practically each below other (at distance of 3.5 \AA , approximately $1/2Ta$). In the structure of $\gamma\text{-Ca}_2\text{SiO}_4$, these pairs are displaced with regard to each other (distance between them is $\sim 4.3 \text{ \AA}$) for a half of translation along two axes (a and b) and centre octahedra linked into tracery walls parallel to (001) (Fig. 9a), where empty and occupied octahedra alternate in staggered rows. In the structure of $\beta\text{-Ca}_2\text{SiO}_4$, Ca atoms in $M(2)$ site arranged over and below Si tetrahedra Ca form centrosymmetrical pairs around sites $2a$

(0,0,0) и $2d$ ($1/2,0,1/2$). In the structure of γ - Ca_2SiO_4 , Ca atoms in sites $M(2)$ occupy fixed position in centres of symmetry (site $4a$, coordinates 0,0,0 и $1/2,0,1/2$) and like Ca in site $M(1)$ are octahedrally coordinated. Edge-sharing $M(2)$ octahedra form olivine-like bands, which are elongated along axis b of the unit cell and arranged on two levels on axes a and c (Fig. 9b, 9c). Change of arrangement of Ca atoms is accompanied with displacement and turn of Si tetrahedra. In the structure of β - Ca_2SiO_4 , the $M(1)$ central cation of the glaserite rotator is surrounded by six Si tetrahedra, whose centres are located by triplets on two levels (approximately $+1/4$ and $-1/4$) on axis a with regard to site $M(1)$. In the structure of olivine-type γ - Ca_2SiO_4 , $M(1)$ octahedron is vertex-shared with five Si tetrahedra, three of which have centres arranged approximately at the same level with site $M(1)$ and two are displaced for $+1/2Ta$ and $-1/2Ta$ with one of which $M(1)$ octahedron is edge-sharing and with the other, is vertex-shared. As a result, each Si tetrahedron in the structure of γ - Ca_2SiO_4 shares 3 horizontal edges with two $M(2)$ octahedra and $M(1)$ octahedron, while vertical edges of Si tetrahedra are free.

Close-packed sheets in the glaserite- and olivine-type structures

In the structure of glaserite, oxygen atoms are not close-packed; however, three types of heterogeneous close-packed sheets composed of O and K atoms parallel to plane (0001) can be recognized. Sheet *I* at level $z \sim 0$ (Fig. 10a) consists of hexagons of oxygen atoms (apical vertices of tetrahedron) around K atoms in site $M(1)$. In ideal closest packing (CP), spheres of the next sheet should be arranged in holes of antecedent one. In the structure of glaserite, distortion of CP is caused by rotation of oxygen triangles around axes 3 by $\sim 30^\circ$ counterclockwise at level $z \sim 1/3$ (sheet *II*) and clockwise, at level $z \sim 2/3$ (sheet *III*). As a result of such turn, vacancies occupied by K atoms (centres of 10-fold polyhedra in $M(2)$ site) arranged over or below oxygen atoms of sheet *I* violating CP of the whole structure are formed in the new sheets. Regard to each other, sheets *II* and *III* are arranged according to principle of CP to

form octahedral "cavities" occupied by Na cations (in site $M(1')$ with coordinates 0,0,1/2). Octahedron elongated along axis z , the first coordination sphere around K cation (site $M(1)$ with coordinates 0,0,0), is formed between three oxygen atoms of sheet *II* (level $z \sim 1/3$) and sheet *III* arranged at level $z \sim -1/3$, i.e., translational to initial layer. Tetrahedral cavities occupied by S atoms are formed between sheets *I* and *II* and *III* and *I*. In the former case, cavity centres are arranged at $z \sim 0.2$, in the latter, at level $z \sim 0.8$. In doing so, tetrahedra of neighboring levels are opposite oriented along axis z . Moore (1976, 1981) noted that turn of oxygen threes of sheets *II* and *III* relative to the first sheet leads to closer occupation of space in comparison with classic homogeneous packing and lesser volume of obtained vacant cavity. In the structure of glaserite, distances between the nearest neighbors in sheets *II* and *III* are 2.85 Å ($M(2) - \text{O}$), 2.40 Å (edge of tetrahedron), and 3.28 Å (edge of octahedron) and shorter comparatively to corresponding distances in sheet *I*, which are 3.29 Å ($M(1) - \text{O}$) and 3.31 Å ($\text{O} - \text{O}$). In sheets *II* and *III*, sum of distances between O atoms corresponding to the edge of octahedron and tetrahedron is the a unit-cell dimension of glaserite ($2.40 + 3.28 = 5.68$ Å), while sum of octahedron heights around Na (2.92 Å) and K (4.39 Å), dimension c (7.31 Å).

In the structure of high-temperature modification α - Ca_2SiO_4 , such glaserite heterogeneous close-packed sheets are only characteristic of model with space group $P\bar{3}m1$. Distinction is wider range of distances between neighboring atoms in sheet *I* caused by displacement of O(1) atoms from fixed position on 3-fold axis: 2.60 – 3.53 Å ($M(1) - \text{O}$) and 1.03 – 3.54 Å ($\text{O} - \text{O}$), herewith, anomalous lower limit of the $\text{O} - \text{O}$ distance is resulted from statistical occupation of three closely spaced sites by O atoms. In sheets *II* and *III*, interatomic distances are 2.78 Å ($M(2) - \text{O}$) and 2.63 – 2.90 Å ($\text{O} - \text{O}$). Due to alternative tetrahedra and 10-fold polyhedra, glaserite packing for model of α - Ca_2SiO_4 with space group $P6_3/mmc$ is violated.

In the structure of orthorhombic arkanite β - K_2SO_4 and its Ca-Si analogues, K(Ca) atoms in site $M(1)$ and apical oxygen vertices form bands arranged at levels $x \sim 0$ and $\sim 1/2$

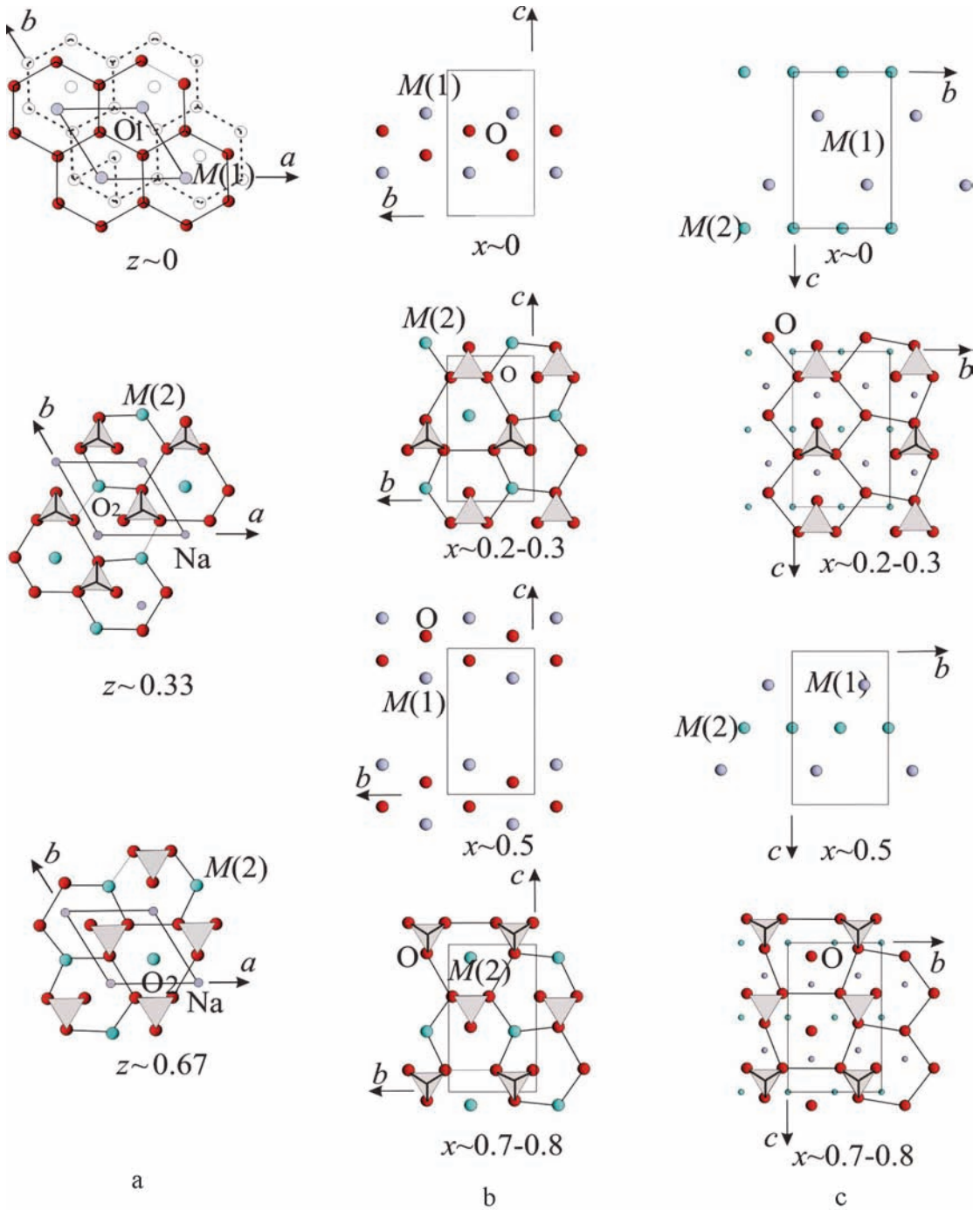


Fig. 10. Close-packed sheets in the structures of: (a) glaserite $K_3Na[SO_4]_2$ (sheets with the ideal closest packing are shown by dashed line); (b) arkanite β - K_2SO_4 , rhombic α'_H , α'_L , and monoclinic modifications of Ca_2SiO_4 ; (c) calcio-olivine γ - Ca_2SiO_4 . Small circles: centres of octahedral sites.

Table 4. Valence forces in anions for various structural models of β - Ca_2SiO_4

O(1)	O(2)	O(3)	O(4)	Source
$2M(1) + M(2) + \text{Si}$	$2M(1) + 2M(2) + \text{Si}$	$2M(1) + 2M(2) + \text{Si}$	$2M(1) + 2M(2) + \text{Si}$	
1.985	1.965	1.944	1.883	Jost <i>et al.</i> , 1977
2.025	1.961	1.948	1.954	Mumme <i>et al.</i> , 1995
1.865	1.939	1.926	2.030	Catti <i>et al.</i> , 1983

(Fig. 10b) and K(Ca) atoms in $M(2)$ site and O vertices of tetrahedron bases are linked into close-packed heterogeneous sheets at levels $x \sim 1/4$ and $\sim 3/4$ similar to sheets *II* and *III* of glaserite but more corrugated. In the structure of glaserite, difference in heights on axis perpendicular to plane of sheet for neighboring atoms of sheets *II* and *III* are 0.22 Å; in the structure of arkanite, 0.97 Å; and in the structures of α' - Ca_2SiO_4 and β - Ca_2SiO_4 , 1.10 Å and 1.21 Å, respectively. Deformation of sheets *II* and *III* is also expressed in increasing range of distances between neighboring atoms of the same sheet; in the structure of arkanite, $M(2) - \text{O}$ distances are within range 2.91 – 3.06 Å, in the structure of α' - Ca_2SiO_4 , 2.64 – 3.32 Å, and in the structure of monoclinic β modification, 2.37 – 3.38 Å. Like the structure of glaserite, sheets *II* and *III* are close-packed and octahedral cavities (the first coordination sphere of 9-fold polyhedra) are occupied by K(Ca) atoms in site $M(1)$. Tetrahedral cavities are between O atoms of sheet *II* (or *III*) and O atoms of neighboring bands, with apical vertices of tetrahedra of the same level being opposite oriented. The unit-cell dimension b of arkanite and its Ca-Si analogues is determined by O – O distances of sheets *II* and *III* corresponded to edge of tetrahedron and octahedron and approximately is their sum and in perpendicular plane of the CP sheets, dimension a is duplicate heights of identical octahedra around site $M(1)$.

As aforementioned, β -modification of Ca_2SiO_4 , that is strongly distorted monoclinic analogue of arkanite β - K_2SO_4 , is metastable phase. Calculation of local balance of valence forces on anions by techniques suggested in (Brese and O'Keeffe, 1991) for variable models of the β -modification structure (Jost *et al.*, 1977; Mumme *et al.*, 1995; Catti *et al.*, 1983) showed certain excess of negative charge for most anions (Table 4) that in turn is caused by the distance of part of O vertices

from centres of M polyhedra. The natural calcio-olivine γ - Ca_2SiO_4 has not similar violation of local valence balance. In the examined structure of the mineral, valence forces in anions occupying crystal-chemical sites close to larnite are 2.056, 2.054, and 1.982 [calculated according to (Gobechiya *et al.*, 2008)]. Metastability of β - Ca_2SiO_4 causes the aforementioned significant spread of $M - \text{O}$ distances in close-packed sheets and high degree of their deformation.

At the transition of β -phase into olivine-type γ -modification, homogeneous sheets (Fig. 10c) consisting of O atoms (at levels on axis $x \sim 0.2$ - 0.3 and ~ 0.7 - 0.8) similar in atom arrangement to heterogeneous sheets *II* and *III* of the β - Ca_2SiO_4 structure and close-packed are formed in the olivine-type structure. At the transition from β - to γ -modification (see previous part), Ca atoms are displaced to the nearest points with coordinates (0,0,0) and (1/2,0,1/2) from sites $M(2)$ of heterogeneous sheets *II* and *III* and O atoms, apical vertices of the β - Ca_2SiO_4 bands arranged at levels on $x \sim 0$ and $\sim 1/2$, respectively, locate in the voided sites. Thus, threes of O atoms, which are bases of Si tetrahedra with apical vertices in neighboring layers, are formed in the homogeneous sheets of γ - Ca_2SiO_4 . As above mentioned, sites $M(1)$ in the structure of γ - Ca_2SiO_4 are displaced comparatively with corresponding sites in the structure of β - Ca_2SiO_4 and like sites $M(2)$, are centres of octahedral cavities whose one half is occupied by Ca atoms. Si atoms center 1/8 of tetrahedral cavities formed between two CP sheets. The unit-cell dimension b (6.75 Å) of γ - Ca_2SiO_4 is sum of edge lengths of $M(1)$ octahedron (4.18 Å) and Si tetrahedron (2.57 Å), and dimension a is sum of heights of $M(1)$ and $M(2)$ octahedra (2.79 + 2.28 = 5.07 Å). Increasing dimensions b and c of γ - Ca_2SiO_4 in comparison with corresponding parameters of the other Ca_2SiO_4 polymorphs is resulted from distortion of

octahedra (elongation along axes b and c) around Ca in sites $M(1)$ and $M(2)$ (Fig. 9). Such distortion, in turn, is caused by mismatch of radius (r) of $^{[6]}Ca^{2+}$ ($r = 1.00 \text{ \AA}$) and size of octahedral cavity of hexagonal closest packing. This discrepancy is lesser in the structure of olivine-type monticellite $CaMgSiO_4$ (Onken, 1965) ($a = 4.822$, $b = 6.382$, $c = 11.108 \text{ \AA}$, space group $Pcmm$), where octahedral site $M(2)$ is occupied by $^{[6]}Mg^{2+}$ ($r = 0.72 \text{ \AA}$) and in the structure of forsterite Mg_2SiO_4 (Fujino *et al.*, 1981) ($a = 4.753$, $b = 5.978$, $c = 10.190 \text{ \AA}$, space group $Pcmm$), dimension b being sum of lengths of edge of $M(2)$ octahedron (3.384 \AA) and edge of tetrahedron (2.594 \AA) is comparable with similar dimensions of the other polymorphs of Ca_2SiO_4 . Shortening of dimension a of γ - Ca_2SiO_4 in comparison with corresponding parameters (perpendicular to plane of CP sheets) of rhombic and monoclinic polymorphs (Table 1) is due to features of atomic layering: in the structure of γ - Ca_2SiO_4 , centres of tetrahedral and octahedral cavities are approximately arranged at the same level on axis a (Fig. 7d) and in the structures of the other modifications, are displaced approximately $1/4$ Ta (Fig. 7a, 7b, 7c).

Features of the merwinite and bredigite structures

In geological objects, γ - Ca_2SiO_4 (calcio-olivine), β - Ca_2SiO_4 (larnite) and bredigite, Ca-Mg orthosilicate with formula $Ca_7Mg[SiO_4]_4$ (Moore and Araki, 1976) are extremely rare, whereas merwinite, Ca-Mg orthosilicate with formula $Ca_3Mg[SiO_4]_2$, is more abundant (Moore and Araki, 1973). The structural affinity of these minerals determines similarity of their optical parameters and morphologies. Above-listed minerals are formed under volcanic or sub-volcanic conditions characterized by high temperature and low fluid pressure (larnite-merwinite facies by Korzhinsky). Larnite and calcio-olivine can be associated with bredigite, whereas merwinite can be associated with bredigite, rather than larnite or calcio-olivine. Merwinite is more frequently associated with monticellite $CaMgSiO_4$ that is Mg-richer compound in the calcio-olivine Ca_2SiO_4 – forsterite Mg_2SiO_4 series.

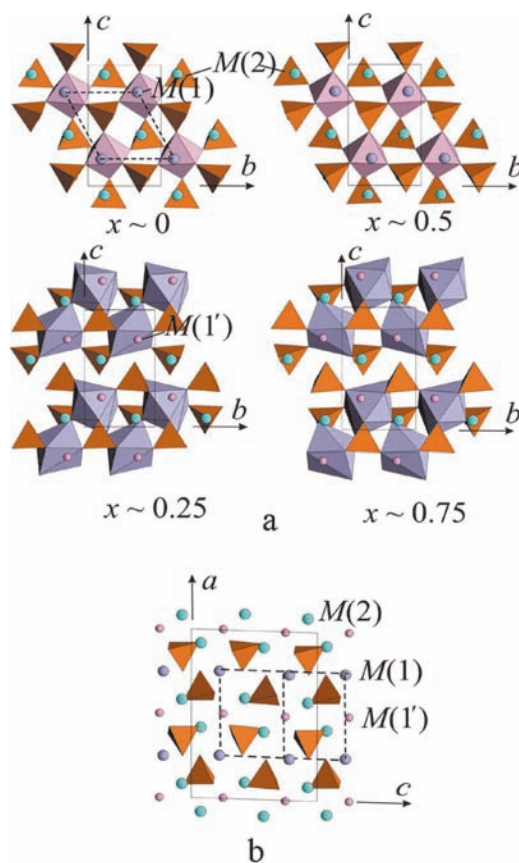


Fig. 11. The structure of merwinite $Ca_3Mg[SiO_4]_2$ projected onto (100) (a) and (010) (b). Mg octahedra with centres in site $M(1')$ (level $x \sim 0$ and $x \sim 0.5$) and Ca 8-fold polyhedra with centres in site $M(1)$ (level $x \sim 0.25$ and $x \sim 0.75$). Dashed line denotes primary glaserite cell.

In the structure of merwinite $Ca_3Mg[SiO_4]_2$ (Fig. 11a, 11b), Ca atoms occupying sites $M(1)$, $M(2)$ and Mg atoms in site $M(1')$ are arranged like K and Na atoms in the structure of glaserite; the arrangement of Si and O atoms and orientation of tetrahedra around octahedron in rotator are also similar. Distinction of the merwinite structure from the glaserite one is little displacement and turn of Si tetrahedra resulting in the symmetry lowering of merwinite to monoclinic (Table 1) and doubling dimension a (Fig. 11c). In the structure of merwinite, atoms form heterogeneous CP sheets composed of Ca and O atoms and analogous to glaserite sheets, while octahedral cavities formed between these sheets are occupied by Mg atoms. The sheets are arranged in pairs at six

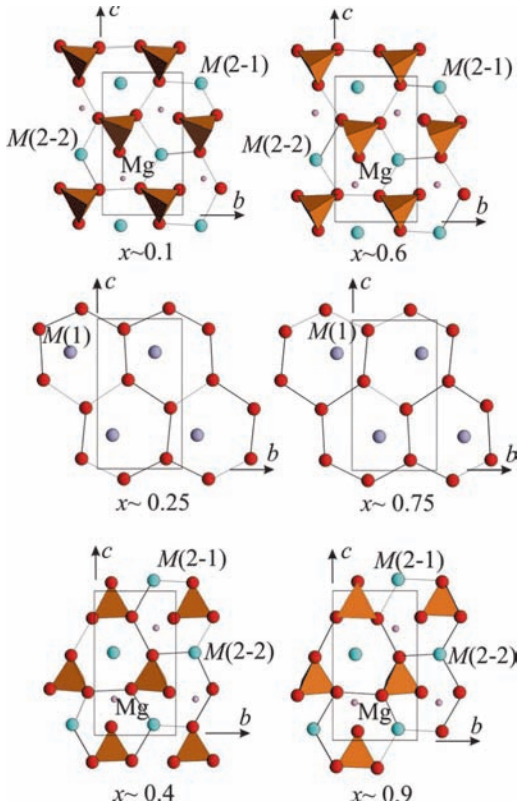


Fig. 12. The close-packed heterogeneous sheets in the structure of merwinite $\text{Ca}_3\text{Mg}[\text{SiO}_4]_2$. Pairs of sheets at levels $x \sim 0.1$ and $x \sim 0.6$; $x \sim 0.25$ and $x \sim 0.75$; $x \sim 0.4$ and $x \sim 0.9$ are bonded by reflection in plane a_{1y} . Small circles: positions of Mg atoms in the centres of octahedra.

levels on axis x , with each pair being linked through reflection in the a plane of glide reflection (Fig. 12). Replacement of Na atoms occupying octahedral cavities (site $M(1')$) in the structure of glaserite by Mg atoms (with smaller ionic radius) in the structure of merwinite leads to the change of the $M(1)$ atom coordination environment. Oxygen atoms at distance of 2.909 \AA compose the first coordination (octahedral) sphere around site $M(1)$ in the structure of glaserite, whereas in the structure of merwinite, one of such atoms is distant from central atoms for 3.28 \AA and the other 3 ligands are out of the radius of 3.5 \AA . As a result, zigzag bands consisting of $M(1)$ 8-fold polyhedra elongated along axis b of the unit cell are formed in the structure of merwinite instead of sheets composed of $M(1)$ icosahedra. These bands linked by turn around screw axis 2_{1y} are arranged at two lev-

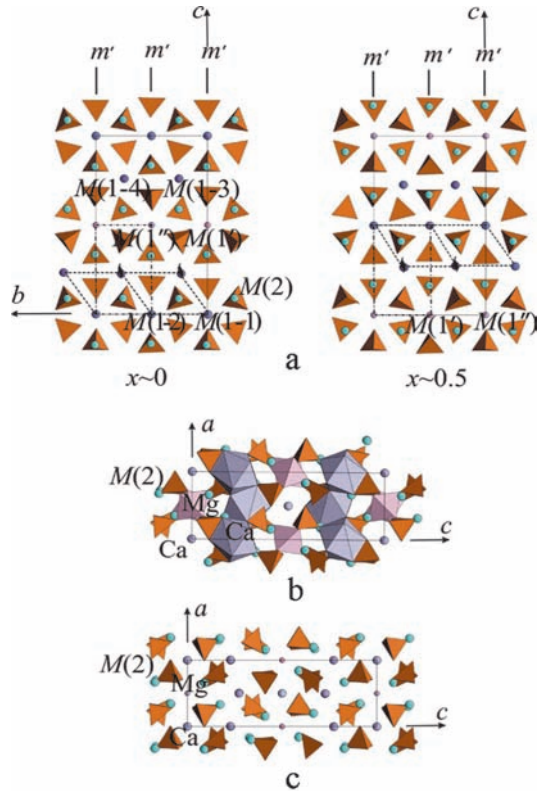


Fig. 13. The structure of bredigite $\text{Ca}_7\text{Mg}[\text{SiO}_4]_4$, projected onto: (a) (100); (b, c) (010). In Fig. a, screw axes 2_{1x} , pseudosymmetry elements bonding primary glaserite cells (dashed line) at levels $x \sim 0$ and $x \sim 0.5$ and planes of mirror reflection m'_{1y} linking arkanite cells (dashed-dot line) are shown.

els along $[100]$ that twice increases the unit-cell parameter of merwinite ($a = 13.254 \text{ \AA}$) (Table 1) in comparison with corresponding unit-cell dimension of glaserite. At the same time, number of ligands around Ca in site $M(2)$ decreases to form 9-fold polyhedra, which are bonded into framework with $M(1)$ 8-fold polyhedra.

At the early stages of study of the dicalcium silicate polymorphs, bredigite was identified with $\alpha\text{-Ca}_2\text{SiO}_4$ (Bridge, 1966; Tilley and Vincent, 1948) that caused certain confusion. In point of fact, despite similar symmetry and comparability of the unit-cell dimensions of bredigite $\text{Ca}_7\text{Mg}[\text{SiO}_4]_4$ and orthorhombic modifications of Ca_2SiO_4 (Table 1), the structure of the latter is original and is complex combination of structural models of both glaserite and orthorhombic arkanite. Part of Ca atoms in sites $M(1-1)$ and $M(1-2)$ (Fig.

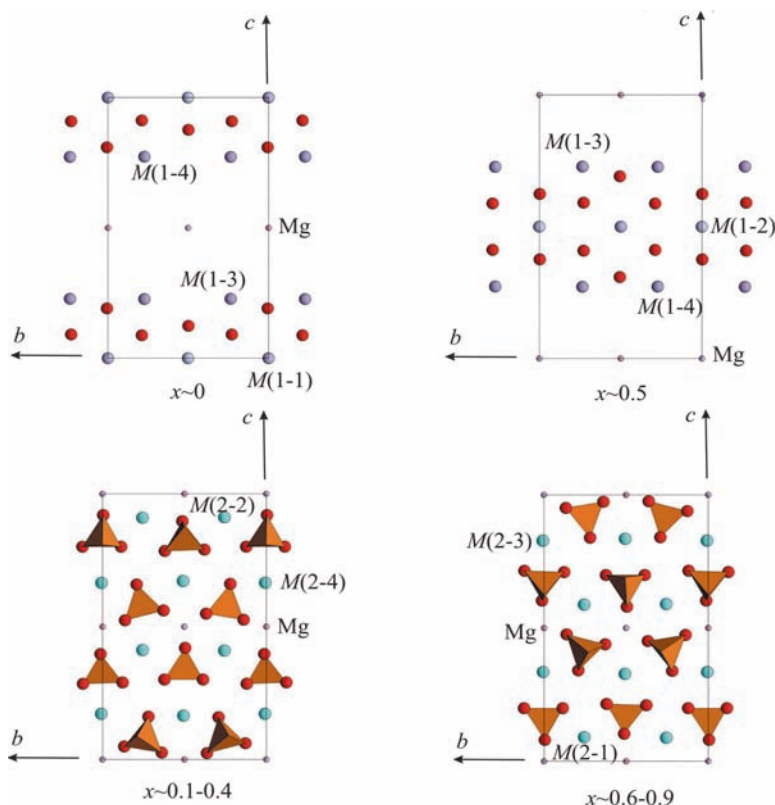


Fig.14. Layering of atoms in the structure of bredigite $\text{Ca}_2\text{Mg}[\text{SiO}_4]_x$: ribbons consisting of Ca atoms in sites $M(1)$ and O atoms (red circles) at levels $x \sim 0$ and $x \sim 0.5$ and heterogeneous sheets at levels $x \sim 0.1-0.4$ and $\sim 0.6-0.9$. Small circles: positions of Mg atoms in the centres of octahedra.

13a, 13b) are arranged similarly to K atoms in the structure of glaserite, i.e., in the centres of large polyhedra (in this case, 10-fold polyhedra) surrounded by six Si tetrahedra with apical vertices oriented like glaserite. Mg atoms in sites $M(1')$ and $M(1'')$, which are centres of octahedra (Fig. 13c) surrounded by six Si tetrahedra, are arranged at the Ta half both over and below sites $M(1-1)$ and $M(1-2)$ like Na in the structure of glaserite. Tetrahedron triplets arranged at two levels on axis x are shared for Mg octahedra and $M(1-1)$ and $M(1-2)$ 10-fold polyhedra. Another part of Ca atoms in sites $M(1-3)$ and $M(1-4)$ centre 9-fold and 8-fold polyhedra surrounded by six Si tetrahedra oriented like in the structures of orthorhombic arkanite $\beta\text{-K}_2\text{SO}_4$, $\alpha'_H\text{-Ca}_2\text{SiO}_4$, and $\alpha'_L\text{-Ca}_2\text{SiO}_4$; and monoclinic $\beta\text{-Ca}_2\text{SiO}_4$. The residual Ca atoms are arranged both below and over Si tetrahedra in four independent sites $M(2)$ in the centres of 10-fold polyhedra close in shape and sizes to corresponding polyhedra of trigonal and orthorhombic polyhedra of Ca_2SiO_4 (Tables 2, 3). Layering of atoms in

the structure of bredigite differs from described above. A pair of ribbons consisting of Ca (site $M(1)$) and apical O vertices of Si tetrahedra linked by turn around horizontal 2-fold axes (2_y) are formed at levels ~ 0 and $\sim 1/2$ on axis x (Fig. 14). In addition, Mg atoms in sites $M(1')$ – centres of octahedral cavities formed by O atoms of heterogeneous CP sheets at levels $\sim 0.1-0.4$ and $\sim 0.6-0.9$ on axis x – are arranged at the same levels. Like the structures of orthorhombic polymorphs, tetrahedral cavities are formed between O atoms of mentioned sheets and apical O vertices arranged at levels ~ 0 and ~ 0.5 on axis x . In this case, tetrahedra belonging to the same sheet-type structures of above described orthorhombic and monoclinic polymorphs of Ca_2SiO_4 have the opposite oriented apical vertices, but alternation of polar tetrahedra in the sheet is different.

Conclusion

Examination of atomic layering in the structures of Ca_2SiO_4 polymorphs indicated

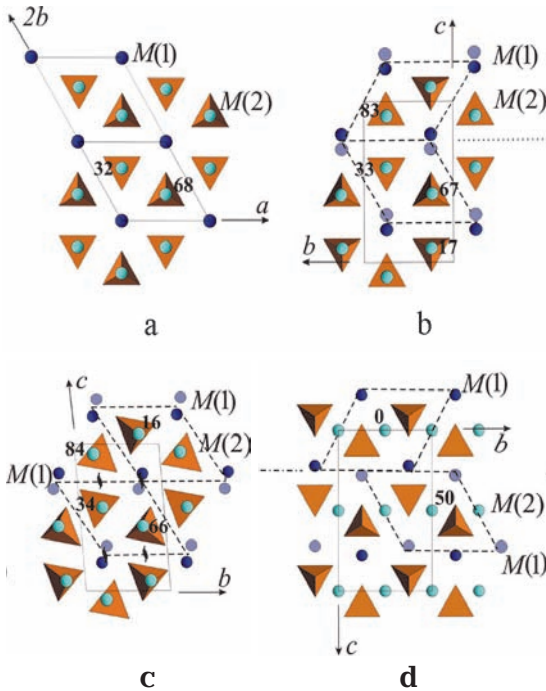


Fig. 15. Idealized projections of the structures: (a) glaserite $K_3Na[SO_4]_2$ and merwinite $Ca_3Mg[SiO_4]_2$; (b) arkanite $\beta\text{-}K_2SO_4$, $\alpha'_H\text{-}Ca_2SiO_4$ and $\alpha'_L\text{-}Ca_2SiO_4$; (c) $\text{-}Ca_2SiO_4$; (d) calcio-olivine $\gamma\text{-}Ca_2SiO_4$, $K(Ca)$ atoms in sites $M(1)$ at levels $z(x) = 0$ (light circles), $z(x) = 0.5$ (dark circles) and in sites $M(2)$ at figured levels on axes $z(x)$. Dashed line: primary glaserite cells bonded through translations (a) and symmetry elements (b – d).

that types of sheets of the apthitalite (glaserite) structure are realized for merwinite and high-temperature α -modification of Ca_2SiO_4 (model of space group $P\bar{3}m1$) and arkanite $\beta\text{-}K_2SO_4$, in the structures of high-temperature modifications $\alpha'_H\text{-}Ca_2SiO_4$, $\alpha'_L\text{-}Ca_2SiO_4$, $\beta\text{-}Ca_2SiO_4$. Significant spread of distances between Ca and O atoms belonging to the same sheet and neighboring sheets caused by the lesser commensurability (in comparison with K) of their ionic radii necessary to form heterogeneous layers is characteristic of Ca modifications of both layering types. Such structure can be stable only at great thermal vibration of atoms that is probable only at high temperature, therefore pure calcium natural analogues of high-temperature (α , α'_H , and α'_L) Ca_2SiO_4 modifications can be most probably observable in quenching environment. It provides split atomic sites in their structures; therefore, the model of α

modification (space group $P6_3/mmc$) used by Mumme *et al.* (1996) to refine the structure is the most probable. In the structure of $\alpha\text{-}Ca_2SiO_4$ whose symmetry is described by space group $P\bar{3}m1$ the volume of octahedral cavities (distance $M(1') - O = 2.26 \text{ \AA}$) is insufficient for relatively large ($r^{[6]}Ca^{2+} = 1.00 \text{ \AA}$) cation, whereas in the structure of natural merwinite, the similar site is occupied by Mg ($r^{[6]}Mg^{2+} = 0.72 \text{ \AA}$) that operates as stabilizer whose presence provides stable compounds under ambient conditions. Magnesium centering octahedral cavities formed between heterogeneous CP sheets in the structure of bredigite is also stabilizer at the formation of the compound, which is closest in metric characteristics and symmetry to high-temperature $\alpha'_H\text{-}Ca_2SiO_4$. The substitution of Mg for Ca in the centres of octahedral cavities in the structures of merwinite and bredigite is accompanied by distortion of heterogeneous CP sheets: differences in heights on axis x (Δx) of O atoms forming horizontal bases of tetrahedra are 0.93 \AA and 1.15 \AA for merwinite and bredigite, respectively. Such deviation causes turn of Si tetrahedra that is also characteristic of transition from α to β modifications of Ca_2SiO_4 : for $\alpha\text{-}Ca_2SiO_4$ $\Delta x = 0$; $\alpha'_H\text{-}Ca_2SiO_4 - 0.48 \text{ \AA}$; $\beta\text{-}Ca_2SiO_4 - 0.54 \text{ \AA}$.

At the transition from high-temperature to low-temperature polymorphs of apthitalite (glaserite) and Ca_2SiO_4 , number of the nearest ligands around cations M and distances cation-anion also decrease (Tables 2, 3). At the same time, decreasing number of shared edges of $M(1)$ polyhedra and Si tetrahedra on the one hand, and $M(1)$ and $M(2)$ polyhedra on the other leads to decrease of the density of the structure. In the metastable β -modification of Ca_2SiO_4 , that is transitional species between the glaserite and olivine structural types, sizes of M polyhedra are the smallest, whereas degree of the CP sheet distortion and turn of SiO_4 tetrahedra are the greatest in comparison with the high-temperature polymorphs of Ca_2SiO_4 . In the structure of olivine-type γ -modification of Ca_2SiO_4 and its natural analogue calcio-olivine, anions are hexagonal close-packed, while cations centre octahedral cavities. Aforementioned mismatch of cation radius to size of octahedral cavity at phase transition $\beta \rightarrow \gamma$ results in

strong deformation of Ca polyhedra, which causes frequently observable cracking of the β -Ca₂SiO₄ crystals (larnite) at cooling along with the minimal density and the largest volume of the γ -Ca₂SiO₄ unit cell. This phenomenon is known in technology of silicates as "dusting of larnite".

It is generally known that all aforementioned modifications of Ca₂SiO₄, bredigite, and merwinite are not stable under effect of fluid at decreasing temperature and are broken down to form wide range of calcium hydrosilicates. It is accepted (Taylor, 1996) that this property is predetermined by distortion of their real structures in comparison with initial ideal models. Larnite is also accepted to react with water at temperature slightly below 0°C in contrast to aforesaid minerals. Particularly, it is known that calcio-olivine can intensely react with water at > 200°C (Taylor, 1996). Such distinction in behavior of relative minerals appears to be caused by violated local valence balance on anions in the structure of larnite (Table 4). Features of the larnite structure are characterized by extremely rapid (avalanche-like) attack by hydroxyls of the areas with excess negative charge and the structure of larnite is transformed (breaking down) to compensate local charge unbalance. Probably, these factors favor the reaction between larnite and haloids. The water-larnite reaction is practically important. Just high speed of reaction between water and larnite and large volume of newly formed species provide strength of pastematrix in contrast to the other aforementioned calcium silicates.

Taylor (1996) noted that products of phase transformation of Ca₂SiO₄ including olivine-type γ -Ca₂SiO₄, are topotactic formed, i.e., in strict crystallographic orientation with respect to initial matter indicating their structural affinity. Comparative crystal-chemical examination of the structures similar to apthitalite (glaserite) allowed to reveal for all examined compounds the major structural module, glaserite block $^{[12]}M(1)^{[6]}M(1')^{[10]}M(2)_2[TO_4]_2$ with pseudo-hexagonal symmetry and atom arrangement close to glaserite. The dimensions of transformed glaserite blocks and transition matrix from unit cells of described poly-

Table 5. Transition matrixes from unit cells of glaserite-type compounds to the unit cell of apthitalite and dimensions of transformed "glaserite" unit cells

Compound, formula	Transition matrixes			Dimensions of the "glaserite" unit cell (Å, degree)		
				<i>a</i>	<i>b</i>	<i>c</i>
				α	β	γ
Arkanite β -K ₂ SO ₄	0	-1	0	5.763	5.820	7.476
	0	0.5	0.5	90	90	119.78
	1	0	0			
α' _{H'} -Ca ₂ SiO ₄	0	-1	0	5.601	5.538	6.871
	0	0.5	0.5	90	90	120.38
	1	0	0			
α' _{L'} -Ca ₂ SiO ₄	0	-1	0	5.590	5.510	6.842
	0	0.5	0.5	90	90	120.48
	0.33	0	0			
Larnite	0	1	0	5.502	5.558	6.745
β -Ca ₂ SiO ₄	0	-0.5	0.5	90	90	123.98
	1	0	0			
Merwinite	0	-1	0	5.293	5.363	6.627
Ca ₃ Mg[SiO ₄] ₂	0	0.5	-0.5	88.35	90	119.57
	0.5	0	0			
Bredigite	0	-0.5	0	5.455	5.335	6.739
Ca ₇ Mg[SiO ₄] ₄	0	0.25	0.25	90	90	120.75
	1	0	0			
Calcio-olivine	0	-1	0	6.754	6.544	5.074
γ -Ca ₂ SiO ₄	0	0.5	0.5	90	90	121.07
	1	0	0			

morphs are given in Table 5. Each of above described structures (Fig. 15) is distinguished by the linkage mode of neighboring blocks that causes difference in size in symmetry of unit cells.

In the structures of glaserite K₃Na[SO₄]₂, high-temperature modification α -Ca₂SiO₄ (space group *P* 3*m*1), and merwinite Ca₃Mg[SiO₄]₂, separated blocks are bonded by translations (Fig. 15a) with the exception of insignificant displacement of atoms in sub-cells neighboring on axis *a* in case of merwinite (Fig. 11c). Neighboring along [010] and [0 $\bar{1}$ 1] glaserite blocks, from which the structure of merwinite can be constructed (Fig. 11a, 11b), are linked by translations, while

along [100], by reflection in plane of glide reflection a_{1y} . Character of combination of the glaserite blocks in the structure of merwinite and close metrics of transformed unit cell (Table 5) and α -Ca₂SiO₄ (Table 1) allow considering merwinite as distorted Ca-Mg silicate analogue of apthitalite (glaserite) K₃Na[SO₄]₂, on the one hand, and as natural distorted Ca-Mg analogue of high-temperature α -modification of Ca₂SiO₄ (its model with space group $P\bar{3}m1$) in whose structure Mg atoms substitutes Ca atoms in site $M(1')$, on the other.

In the structures of orthorhombic arkanite β -K₂SO₄ and its silicate Ca analogues (high-temperature modifications α'_H -Ca₂SiO₄ and α'_L -Ca₂SiO₄), neighboring glaserite blocks (Fig. 15b) are bonded by reflection in plane a_{1z} and tripling unit-cell parameter a of α'_L -Ca₂SiO₄ is caused by small displacement of atoms in neighboring subcells. In the structure of β -Ca₂SiO₄, neighboring glaserite blocks are linked by rotation around 2-fold screw axis 2_x. The structure of calcio-olivine, γ -Ca₂SiO₄, can be considered as product of the structure of glaserite, where neighboring on axis c glaserite-type blocks (Fig. 15d) are linked by the reflection in clinoplane n_{1z} , i.e., they are displaced to each other for $1/2Ta$ и $1/2Tb$ and in the selected glaserite cell, atoms $M(1)$ and Si tetrahedra (without regard for differences in x coordinates) are arranged identically to those in the structure of glaserite (Fig. 15a).

The structure of bredigite Ca₇Mg[SiO₄]₄ can be also constructed from the glaserite cells (shown in Figs. 13a, 13b as dash lines) under the assumption that atoms of the same variety are arranged in its vertices. The neighboring cells are linked by translations along [100] and [010] and by reflection in clinoplanes n_{1z} along [001]. Pairs of blocks arranged at level z from 0 to 1/2 are linked with neighboring similar pair along [001] by the rotation around horizontal 2-fold axis 2_y. Furthermore, additional elements of pseudosymmetry bonding neighboring blocks appear in the structure of bredigite (without regard for small displacements of atoms): screw axes 2_{1(x)} parallel to [100] and arranged in points with coordinates y and z corresponded to sites $M(1-3)$ and $M(1-4)$;

and mirror planes of symmetry m_{1y} at levels $y = 0$ and $y = 1/2$ bonding blocks along [010]. The neighboring arkanite blocks, from which the structure of bredigite can be also constructed under the assumption of identical occupation by atoms of points of selected cell and displacement of its top to site $M(1)$, can be integrated by the latter operation. Along [001], neighboring arkanite blocks are bonded by axis 2_y. The dimensions of arkanite block (a' , b' , c') shown in Figs. 13, 13b as chain line are multiple to relevant unit-cell dimensions of bredigite: $a' = a$, $b' = b/2$, $c' = c/2$ (Table 1). In the interior of the blocks, atoms are arranged in the same manner as in the structures of apthitalite (glaserite) and arkanite, respectively and symmetry lowering and simultaneous increasing unit-cell dimensions of bredigite are determined by the character of layering of selected cells, Mg for Ca substitution, and displacement of atoms.

In all described cases, glaserite blocks are bonded by the symmetry elements of space groups to which arrangement of atoms of the whole structure follows. The additional pseudosymmetry elements also integrate glaserite and arkanite blocks in the structure of bredigite. Topotaxy that is characteristic of the Ca₂SiO₄ polymorphs is caused by close sizes and symmetry of the glaserite blocks (only inversion centres form all symmetry elements are preserved in the selected glaserite cell of each compound) and the same orientation of separated blocks in their structures.

The glaserite modules in the structures of described compounds close in symmetry and composition account for the reversibility of phase transitions between Ca₂SiO₄ polymorphs on the one hand and abundant mineral assemblages of this series on the other. Transition from high-temperature polymorphs α'_H - and α'_L -Ca₂SiO₄ to β -Ca₂SiO₄ can be attributed to deformation without substantial transformation of the structure. Transitions from high-temperature hexagonal α to orthorhombic α'_H modification and from metastable β modification to olivine-type γ -modification are reconstructive when structural type changes. In this case, the structure of γ -Ca₂SiO₄ (calcio-olivine) can

also consists of glaserite-type blocks. Strong drop of density and optical parameters of calcio-olivine in comparison with the other polymorphs emphasizes the structural distinction of this Ca_2SiO_4 modification.

Acknowledgments

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NEW DATA ON TITANIUM-RICH BIOTITE: A PROBLEM OF "WODANITE"

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Titanium-rich mica of the biotite series ("wodanite") was found in tefrite of paleovolcano Rothenberg, Eifel, Germany, and studied by combining of electron microprobe analysis, IR spectroscopy and single-crystal structure analysis. The mineral is monoclinic, space group $C2/m$; unit-cell parameters are: $a = 5.3165(1)$, $b = 9.2000(2)$, $c = 10.0602(2)$ Å, $\beta = 100.354(2)$. The presence of Ti results in strong distortion of the octahedron $M(2)$. IR spectrum demonstrates the absence of detectable amounts of OH groups. The empirical formula of Ti-rich biotite is: $(K_{0.74}Na_{0.15}Ca_{0.05})_{\Sigma 0.94}(Mg_{1.60}Ti_{0.74}Fe^{2+}_{0.62}Cr_{0.04})_{\Sigma 3.00}[(Si_{2.61}Al_{1.29}Fe^{3+}_{0.10})_{\Sigma 4.00}O_{10}](O_{1.17}F_{0.71})$. Regularities of isomorphous substitutions, as well as genesis of Ti-rich micas of the biotite series are discussed. The idealized formula of the magnesium-titanium end member of this series is: $K(Mg_2Ti)(Si_3AlO_{10})O_2$. 5 tables, 4 figures, 26 references.

Keywords: wodanite, titanium biotite, oxybiotite, paleovolcano Rothenberg.

Introduction

The name "wodanite" was first mentioned in a manuscript by G. Lattermann as applied to titanium-bearing biotite-type mica from syenite dykes of the paleovolcano Katzenbuckel located near Odenwald, Baden-Württemberg, Germany. Later Lattermann's original manuscript was lost, but it is referred in the book (Rosenbusch, 1910). The mineral is named from the Teutonic deity Wodan (variants: Wotan, Woden, Odin). The rock with "wodanite" was uncovered by the basalt quarry Michelsberg that functioned up to 1974. The content of TiO_2 in "wodanite" from Katzenbuckel reaches 12.56 wt. % (Rosenbusch, 1910; Hallimond, 1927; see also Freudenberg, 1920).

Later high-titanium trioctahedral micas have been repeatedly detected in different magmatic and metamorphic rocks including phlogopite-leucite lamproite from Western Australia (phlogopite with 8.97 wt. % TiO_2 ; Prider, 1939), lamprophyric dyke from Ilha da Trindade, Brazil (mica with TiO_2 up to 12.71 wt. % and BaO up to 7.11 wt. %; Greenwood, 1998), gabbro from Ontario, Canada (mica with TiO_2 up to 7.11 wt. % and BaO up to 6.1 wt. %; Shaw, Penczak, 1996), basaltoid rocks of

Mongolia (mica with TiO_2 up to 12.49 wt. %; Koval *et al.*, 1988), nephelinites from Oahu, Hawaii (barian biotite with TiO_2 up to 14 wt. %; Mansker *et al.*, 1979), carbonatites from Anti-Atlas, Morocco (mica with TiO_2 up to 13.85 wt. % and BaO up to 21.46 wt. %; Ibhi *et al.*, 2005), high-grade gneisses from West Greenland (biotite with Ti content up to 0.3 atoms per formula unit; Dymek, 1983), corundum-bearing gneisses from Kyushu Island, Japan (TiO_2 up to 17 wt. %; Ushakova, 1971).

In first publications concerning "wodanite" (Rosenbusch, 1910; Hallimond, 1927), it was noted that this mineral is remarkable for very low water content of 0.76 wt. % (for comparison: theoretical content of H_2O is 4.32 wt. % for phlogopite and 3.52 wt. % for annite). In most cases, the calculation of empirical formulae of titanium-rich micas indicates the presence of additional O atoms substituting OH groups in free vertices of octahedral (the site X). The composition of this site is: $(OH)_{1.25}O_{0.65}F_{0.10}$ in a phlogopite sample investigated in detail and containing 3 wt. % TiO_2 (Scordari *et al.*, 2006); $(OH)_{0.93}O_{0.92}F_{0.15}$ in mica with 8.97 wt. % TiO_2 (Prider, 1939); $O_{1.20}(OH)_{0.41}F_{0.39}$ in phlogopite containing 10.85 wt. % TiO_2 (Cruciani, Zanazzi, 1994).



Fig. 1. Crystals of titaniferous biotite in nepheline tephrite. Photo: A.V. Kasatkin.

For trioctahedral mica with 12.57 wt. % TiO_2 , charge-balance empirical formula shows the prevalence of O over OH and F in the X site (even under assumption that all iron is Fe^{2+} , the composition of this site is $\text{O}_{1.04}(\text{OH},\text{F})_{0.96}$; Greenwood, 1998).

These examples demonstrate the existence of O-dominant micas belonging to the biotite series (i. e. trioctahedral micas with potassium as the main interlayer cation). It should be noted that the names like "oxybiotite", "oxyannite", "ferrixyannite" have been used rather widely though in different sense (see Ohta *et al.*, 1982; Koval *et al.*, 1988; Rancourt *et al.*, 2001). Owing to the uncertainty of the term "oxybiotite", this name was descredited with the comment "oxybiotite = oxidized biotite?" (Burke, 2006). However recently Ba-dominant and Ti-rich oxy-mica oxykinoshitalite, $\text{Ba}(\text{Mg}_2\text{Ti})(\text{Si}_2\text{Al}_2\text{O}_{10})\text{O}_2$, was approved by the IMA CNMNC as new mineral species (Kogarko *et al.*, 2005). At the same time, O-dominant analogues of phlogopite-annite series minerals are absent in the accepted nomenclature of micas (Rieder *et al.*, 1998).

The present work is devoted to the mineralogical and the structural investigation of Ti-rich trioctahedral oxy-mica from the paleovolcano Rothenberg located in the effusive complex Eifel.

Occurrence, properties and chemical composition

Specimens of cavernous tephrite with high-titanium mica have been collected in the basalt quarry on the Mt. Rothenberg. Nepheline, plagioclase and augite are the main rock-forming minerals. Among accessory minerals, titanium-rich magnetite is most abundant. Mica forms dark brown to black scales and prismatic crystals up to 1 mm length crowing on the walls of cavities (Fig. 1) and in the rock near the vugs. Twins of feldspars (sanidine and plagioclase), crystals of diopside and magnetite are present in close association with mica.

Although mica was obviously formed later than the main minerals of tephrite, the temperatures of its crystallization were probably rather high: experimental data for lherzolite demonstrate the growth of the ratio $\text{Ti} : \text{K}$ in phlogopite with growing temperature (up to $\text{Ti} : \text{K} = 0.4$ at 1150-1250°C – Thibault *et al.*, 1992). High activity of oxygen also promotes the formation of oxy-micas. For example, unusually high oxygen fugacity (0.5 – 1.9 logarithmic units above the FMQ buffer) was recorded for the rocks of Katzenbuckel, where "wodanite" was first described (Mann *et al.*, 2006), autometasomatic stage being characterized by even higher oxygen fugacity.

As compared with common biotite, high-titanium mica is more brittle. IR

Table 1. Chemical composition of Ti-rich biotite

Component	Content, wt. %	Ranges	Probe Standard
Na ₂ O	1.05	0.97–1.15	Albite
K ₂ O	7.69	7.60–7.84	Microcline
CaO	0.64	0.52–0.70	Wollastinite
MgO	14.21	14.12–14.26	Diopside
FeO	11.47	11.35–11.61	Fe
Al ₂ O ₃	14.48	14.35–14.66	Al ₂ O ₃
Cr ₂ O ₃	0.71	0.67–0.75	Cr
TiO ₂	13.08	12.95–13.28	Ti
SiO ₂	34.62	34.49–34.71	SiO ₂
F	2.99	2.64–3.16	CaF ₂
-O=F ₂	-1.26		
Total	99.68		

Table 2. Atomic coordinates, equivalent atom displacements, site multiplicities (Q) and site occupancy factors (q)

Atom	x/a	y/b	z/c	Q	q	B _{eq} , Å ²
M(1)	0	0	0.5	2	1	1.20(1)
M(2)	0	0.3441(1)	0.5	4	1	1.03(1)
T	0.742(1)	0.1675(1)	0.2218(1)	8	1	0.80(1)
K	0	0.5	0	2	1	1.11(2)
O(1)	0.0181(5)	0	0.1653(2)	4	1	1.60(8)
O(2)	0.3218(3)	0.2320(2)	0.1621(1)	8	1	1.59(6)
O(3)	0.1325(2)	0.1702(1)	0.3902(2)	8	1	1.02(6)
X	0.1285(3)	0.5	0.4009(1)	4	1	1.11(7)

Table 3. Characteristics of coordination polyhedra

Site	Composition (Z=2)	Coordination			
		number	Minimum	Maximum	Mean
M(1)	0.60Mg+0.40Fe	6	2.046(1)	2.109(1)	2.088
M(2)	1.0Mg+0.74Ti+0.22Fe+0.04Cr	6	1.939(1)	2.133(1)	2.047
T	2.6Si+0.33Al+0.1Fe ³⁺	4	1.6509(9)	1.666(1)	1.655
K	0.7K+0.3Na	12	2.944(1)	3.295(2)	3.110

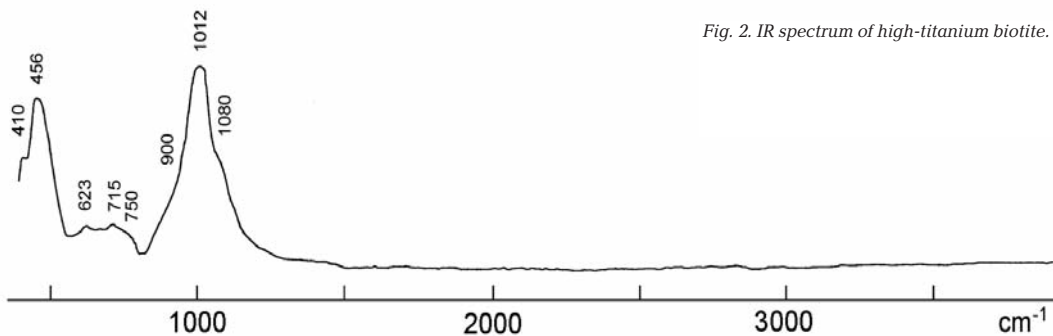


Fig. 2. IR spectrum of high-titanium biotite.

spectrum of the sample from Rothenberg differs from the spectra of other biotite-series micas by the absence of the bands of O-H stretching vibrations (the range 3300–3750 cm⁻¹, Fig. 2). The absence of hydroxyl groups can be connected with the combined influence of different genetic and crystal-chemical factors including magma outgassing, high temperature of crystallization, high activity of oxygen, as well as the presence of Ti⁴⁺ that favours the compensation of high positive charge of octahedral cations by a mechanism like (Mg,Fe) + (OH,F) Ti + O.

The chemical composition of high-titanium biotite from Rothenberg was investigated by the EDS-mode electron microprobe (Table 1). The empirical formula calculated on 7 layer cations (including octahedral and tetrahedral ones) is: (K_{0.74}Na_{0.15}Ca_{0.05})_{Σ0.94}(Mg_{1.60}Ti_{0.74}Fe²⁺_{0.62}Cr_{0.04})_{Σ3.00}[(Si_{2.61}Al_{1.29}Fe³⁺_{0.10})_{Σ4.00}O₁₀](O_{1.17}F_{0.71}). The basis of the formula calculation was chosen taking into account that structural data show the absence of vacancies in the TOT layer. Some deficiency of X-anions (1.88 instead of 2) can result from the assumption that all iron in octahedral sites is Fe²⁺. Taking into account oxidative conditions of mineral formation, the presence of Fe³⁺ in octahedral sites seems very likely. Full occupancy of the X site (i. e. O_{1.29}F_{0.71}) would correspond the following

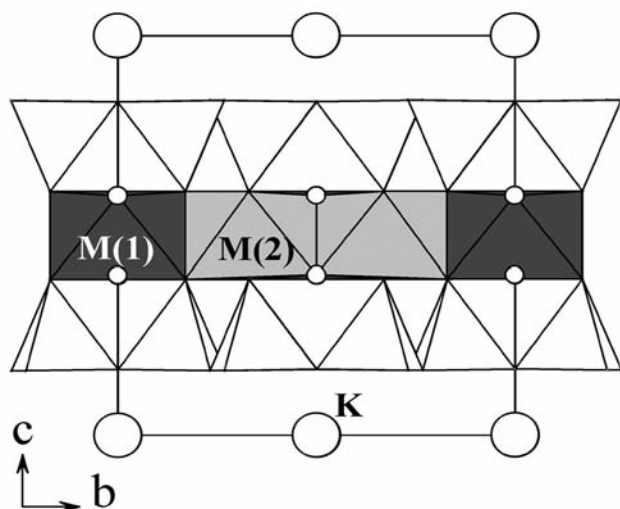


Fig. 3. Crystal structure of high-titanium biotite: *bc*-projection. The X site is denoted by small rings.

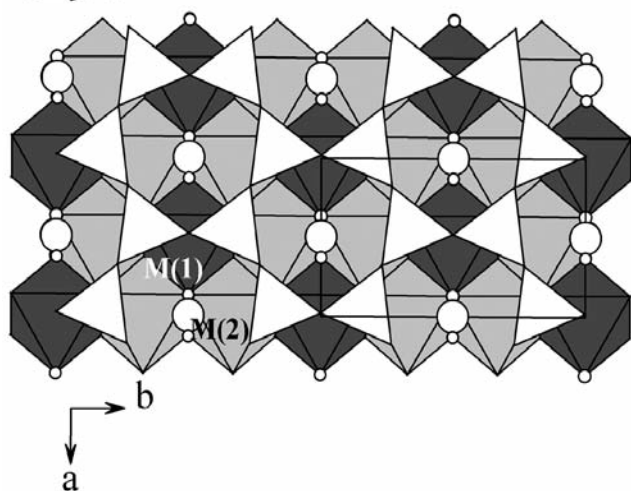


Fig. 4. Crystal structure of high-titanium biotite: *ab*-projection.

composition of the octahedral sheet:
 $\text{Mg}_{1.60}\text{Ti}_{0.74}\text{Fe}^{2+}_{0.38}\text{Fe}^{3+}_{0.24}\text{Cr}_{0.04}$.

Crystal structure

For the structural investigation of Ti-rich biotite, a crystal with the dimensions 0.1 0.2 0.3 mm was used. Single-crystal diffraction data have been obtained using the Xcalibur CCD diffractometer with MoK radiation. In the range with $\max = 54$ ($-10 < h < 12$, $-20 < k < 20$, $-22 < l < 20$) 1642 independent reflections were obtained with $F > 5(F)$. R-factor of averaging of the equivalent reflections is 0.025; R-factor of anisotropic refinement is 0.047; the structure refinement was carried out using the program AREN (Andrianov, 1988); the program DIFABS (Walker, Stuart, 1983) was used for the absorption correction.

The mineral is monoclinic, space group $C2/m$, unit cell parameters are: $a = 5.3165(1)$, $b = 9.2000(2)$, $c = 10.0602(2)$ Å, $\beta = 100.354(2)$, $V = 484.05$ Å³, $Z = 2$.

Atomic coordinates, equivalent atom displacements, site multiplicities and site occupancy factors are given in Table 2; for the characteristics of coordination polyhedra see Table 3.

The crystal structure of high-titanium biotite (Figs. 3, 4), as well as that of other trioctahedral micas, contains triple TOT layers where T is the sheet of the tetrahedra $(\text{Si,Al,Fe}^{3+})\text{O}_4$ sharing common edges, and O is the sheet of the octahedra $(\text{Mg,Ti,Fe,Cr})(\text{O,F})_6$ sharing common vertices. The TOT layers are connected to each other via interlayer cations (K, Na, Ca).

Table 4. Variants of the distribution of cations over octahedral sites M(1) and M(2)

№	Composition of the M(1) site	The number of electrons - in M(1)	Composition of the M(2) site	The number of electrons - in M(2)
1	Mg _{0.6} Fe _{0.4}	17.6	Mg _{1.0} Ti _{0.74} Fe _{0.22} Cr _{0.04}	17.48
2	Ti _{0.55} Mg _{0.45}	17.5	Mg _{1.15} Fe _{0.62} Ti _{0.19} Cr _{0.04}	17.53
3	Mg _{0.6} Fe _{0.2} Ti _{0.2}	16.8	Mg _{1.0} Fe _{0.42} Ti _{0.54} Cr _{0.04}	17.88

Table 5. Local valence balance for the X anion

Site	Composition	Валентное усилие	Total
M(1)	Mg _{0.6} Fe _{0.4}	0.41	1.61
M(2)	Mg _{1.0} Ti _{0.74} Fe _{0.22} Cr _{0.04}	1.20=0.6 x 2	
M(1)	Fe ₁ ²⁺	0.57	1.59
M(2)	Mg ₂	1.02=0.51 x 2	
M(1)	Fe ₁ ²⁺	0.43	1.87
M(2)	Ti ₂	1.44=0.72 x 2	
M(1)	Mg ₁	0.39	1.53
M(2)	Fe ₂ ³⁺	1.14=0.57 x 2	
M(1)	Ti ₁	0.54	1.98
M(2)	Ti ₂	1.44=0.72 x 2	
M(1)	Mg ₁	0.39	1.41
M(2)	Mg ₂	1.02=0.51 x 2	
M(1)	Fe ₁ ³⁺	0.46	1.68
M(2)	Fe ₂ ³⁺	1.22=0.61 x 2	
M(1)	Fe ₁ ²⁺	0.43	1.57
M(2)	Fe ₂ ³⁺	1.14=0.57 x 2	

The site partitioning of Mg, Fe, Ti and Cr was determined taking into account the sizes of octahedral, the values of thermal parameters and R factor. The octahedral sheet of high-titanium biotite contains two types of octahedral, M(1)(O,F)₆ and M(2)(O,F)₆ (Table 3). The latter is smaller and more distorted than the M(1)-centered octahedron. For this reason, the presence of titanium in the site M(2) is more probable than in the site M(1). The refinement of the crystal structure of Ti-rich biotite under the assumption that titanium is present only in the site M(2) results in the following crystal-chemical formula: (K_{0.7}Na_{0.3})_{Σ=1}(Mg_{0.6}Fe_{0.4})_{Σ=1}(Mg_{1.0}Ti_{0.74}Fe_{0.22}Cr_{0.04})_{Σ=2}[(Si_{2.6}Al_{1.3}Fe_{0.1})_{Σ=4}O₁₀](O,F)₂. The refined numbers of electrons in the sites M(1) and M(2) are respectively 17.60 and 17.48 that corresponds to the full (without vacancies) occupancy of both sites. This site population is in good agreement with the values of equivalent atom displacements (Table 2). The dependence of the R-factor on the site partitioning of Mg, Fe, Ti and Cr is weak.

The mechanisms of isomorphous substitution and cation ordering in biotite-series micas have been discussed in numerous publications. According to M.F. Brigatti with coauthors (Brigatti *et al.*, 1991; Brigatti, Poppi, 1993), the cations Mg, Fe and Ti can be present simultaneously in both M(1) and M(2) sites, although in different proportions. However it was shown (Hazen, Burnham, 1973) that of eight possible cation configurations involving Ti and Fe in trioctahedral micas, only three (Fe₃Si, TiFe₂Al and TiFe Si) are close to the ideal net charge contribution of ²⁺ for oxygen. The supposition that the presence of Ti in octahedral sites of micas can be accompanied by the formation of vacancies in octahedral (in accordance with the scheme of isomorphism Ti⁴⁺ + 2R²⁺) was adduced in some other publications (Dymek, 1983; Mineraly, 1992).

In the basic work (Cruciani, Zanazzi, 1994), crystal structures of 24 phlogopite samples (space group C2/m) were investigated. It was shown that the cations Ti⁴⁺, Al³⁺, Fe³⁺ and Cr³⁺ concentrate in the site M(2). The preferential partitioning of high-charge cations in M(2) results in the distortion of the M(2)-centered octahedron. In particular, the off-center shift of the cation within the M(2) site correlates with the total content of titanium in mica and changes from a practically zero shift for low-titanium samples to 0.08 – 0.09 Å for the samples with Ti_{0.59–0.65}. In the sample investigated in the present work, off-center shift of the M(2) cation is (2.133 – 1.939):2 = 0.097 Å where 1.939 Å is the distance between M(2) and X. According to (Cruciani, Zanazzi, 1994), the shortening of the bond M(2)-X can be due to the substitution of OH for O.

The results of bond valence calculations for different statistical combinations of octahedral cations coordinating the site X are given in Table 5. The value of 1.61 valence units calculated for X with average compositions of the octahedra M(1) and M(2) indicates that the affinity of the site X with respect to O is better than that with respect to OH of F. Among different local situations around X, only the variant M²⁺M₂²⁺ (M = Mg or Fe) agrees with a monovalent anion (F⁻ or OH⁻) whereas other variants, especially MTi₂ and TiTi₂, agree better with O.

On the basis of available chemical and structural data, it was concluded (Cruciani, Zanazzi, 1994) that in Ti-bearing phlogopite

the following scheme of isomorphic substitutions is realized: ${}^{[6]}R^{2+} + 2OH^{-} \rightarrow {}^{[6]}Ti^{4+} + 2O^{2-}$. Thus the idealized formula of Ti-rich "oxyphlogopite" can be written as follows: $K(Mg_2Ti)(Si_3AlO_{10})O_2$.

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Mineralogical Museums and Collections



COLLECTION OF MINING ENGINEER I.N. KRYZHANOVSKY

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Collection of mining engineer I.N. Kryzhanovsky was purchased for the Mineralogical museum of the Academy of Science by the efforts of academician V.I. Vernadsky, A.E. Fersman and V.I. Kryzhanovsky in 1912. The collection accounts more than 4500 mineral specimens mainly from the Urals and Siberia and had an exceptional scientific significance for the studies of mineralogy of Russia. It was gathered and professionally formatted by the father and the sons Kryzhanovsky. There is a full catalog with precise designation of a mineral, its original locality and comments on the collection gathering and brief description of the minerals by groups. Overview of the collection material held at the Mineralogical Museum of the Russian Academy of Science is provided.

15 photos, 15 references.

Keywords: Mineralogical Museum of the RAS, collection of minerals, mining engineer I.N. Kryzhanovsky.

Funds of the Mineralogical Museum of the Academy of Science had risen to the new level of quality in 1912 and the museum was ranked among the best mineralogical collections of the world. This jump was connected to the purchase of the famous collection of count Kochubey, financed from the government funds (Proceedings..., 1914). However, the Academy of Science had purchased for the museum also another wonderful collection, the collection of mining engineer I.N. Kryzhanovsky, in the same year. (Proceedings..., 1913, Matvienko, 2007). Academician V.I. Vernadsky, addressed to the department with the request to purchase "about 4500 numbers of exceptionally Russian minerals" on September 5, 1912 and emphasized: "The collection is very rich in material that is new for mineralogy of Russia and not scientifically studied and well gathered. It presents a significant scientific value especially in respect to crystallography and paragenetic associations. It is absolutely exceptional in this respect representing number of deposits in the Urals which were not described, very old and sometimes depleted ones with fine samples from old collections from the Urals, which were purchased during thirty years... This collection has an exceptionally rich scientific material that not only our museum has lack of but also all scientific collections that I know. From the scientific point of view this collection is more valuable than the one of Kochubey... Purchase of this collection is extremely important for executing the task that the Academy of Science has to accomplish, which is to comprise a mineralogical data from all territory of Russia, that we do not have yet" (Minutes of the meeting..., 1912). The description of the collection of engineer

I.N. Kryzhanovsky was composed by academician V.I. Vernadsky and A.E. Fersman, the senior scientific custodian of the museum from 1912 (Barsanov, 1989), and was included in the note to the following meeting department of Physics and Mathematics of the Academy of Science (Appendix II ..., 1912).

It is very remarkable that the collection was organized in due form: it had a catalog with notes of the mineral names and localities of their origin and was accompanied with hand written notes by author's sons, mineralogists Vladimir Il'ich and Leonid Il'ich. They worked in the museum on the overview and the history of the collection (V. Kryzhanovsky, 1912; L. Kryzhanovsky, 1912). It was a collection formed by professionals.

The Kryzhanovsky family made an exceptional contribution to the museum to make it an outstanding mineral assembly (Matvienko, 2008). The father and the sons were "the authors" of more than 10 thousands of specimens.

Ilya Nikolaevich Kryzhanovsky (1854 – 1927) (fig. 1) had a solid background (Internet publication). Graduate of Petersburg Mining Institute he denied to stay at the department after graduation and went to Krasnoufims in Perm province with his family to become a teacher in industrial college. Later he transferred to the mining service in Ekaterinburg. He had personal nobility himself and for the merits in mine-rescue service was granted The Cross of Saint Vladimir of second degree which gave the rights of hereditary nobility. Then, in 1920 he became the director of Kolivan' polishing and lapidary factory in Altai. He was transferred to Petersburg polishing and lapidary factory as a director in 1923. Ilya Nikolaevich worked in the Commission of Natural Productive Forces (KEPS in the



Fig. 1. Mining engineer I.N. Kryzhanovsky. Ekaterinburg, early 1900s. N.G. Barsanova's archive.

Fig. 2. The brothers Kryzhanovsky: Vladimir (on the left) and Leonid, Ekaterinburg. 1910. N.G. Barsanova's archive.

Russian abbreviation) with the Academy of Science of the USSR from 1925.

The sons were mineralogists with brilliant education and made all efforts to create and purchase father's collection (fig. 2). The elder son V.I. Kryzhanovsky (1881 – 1947), by the words of V.I. Vernadsky, excelled with a special talent for "museum creativity" (Barsanov, 1949) devoted all his life to the museum. He started working there in 1907 and later headed the museum from 1932 to 1947 (Godovikov, 1989). Apart from everything else Vladimir Il'ich studied way of handling mineral specimens in biggest foreign mineralogical museums and mineral firms in Europe. It was him who received the famous Kochubey collection in Austria. His brother Leonid Il'ich (1884 – 1925) had a mineralogical firm himself (Internet publication...). He specialized mainly in precious stones and in association with A.E. Fersman organized business organization "Russkie Samotsveti" (Russian Colored stones) and became its commercial director and gem specialist.

Manuscripts that remained after the sons (V. Kryzhanovsky, 1912; L. Kryzhanovsky, 1912) have information on the history of the father's collection gathering. Ilya Nikolaevich started collecting minerals being a student in 1880s. He lead field trips to various mines and processing plants of the Urals almost every year during those 16 years when he headed mining department in Krasnoufimsk College.

I.N. Kryzhanovsky's collecting passion grew to a larger scale from 1890s due to taking a position in mining service and moving to Ekaterinburg. Also it was due to his older sons became interested in minerals. Vladimir and Leonid Il'ich described in details their trips ("excursions") to Urals and Siberia in those years. The brothers lived up to several months in some places getting a local job, for example, in the Asbestos mines in the Urals.

Their reviews specify mineralogical collections including very old ones which were purchased and kept, describe people, who favored gathering the collection: miners, officials, stone lovers. We wanted to distinguish some collections purchased from people, who played "important role in educational-industrial life of the Urals" (L.I. Kryzhanovsky):

- Famous collection of D.P. Shorin, the valet of the prince San-Donato Demidov, the owner of Tagil plants, who became close to him and got him interested in stones;

- Gathering of famous Ural collector O.E. Kler, which contained minerals from collection of mining engineer Akhmatov;

- Rich collection of P.O. Korevo, the owner of the Asbestos mines, former gold miner and manager of Emerald mines.

L.I. Kryzhanovsky wrote: "All the best, all the most valuable and scientifically interesting from those collections, from personal gathering during field excursions and samples

bought separately formed the mineralogical assembly of I.N. Kryzhanovsky... Our motto was to present mineralogy of Russia and gather all the rare, the interesting as complete, and as beautiful as possible".

L.I. Kryzhanovsky emphasized presence of extraordinary specimens in every section of the collection, occurrence of minerals first discovered in a deposit and yet absent in other collections. He noted that "the vast majority of minerals known in the Urals is presented here with sufficient and sometimes with comprehensive number of samples".

Collection of I.N. Kryzhanovsky perfectly describes many deposits: the Asbestos mines, the Emerald mines, Murzinka, Mednorudnyanskoe, Beryozovsky zavod (Urals), Adun-Chilon, Sherlovaya Gora (Transbaikalia), Zolotushinsky and Zmeinogorsky mines (Altai) and others.

Almost literary reproduction of the brief description of the collection made by V.I. Vernadsky and A.E. Fersman for the Academy of Science was published in the Proceedings of the museum in the section "List of collections acquired by the museum" in subsection "Collections purchased by the museum". It was "absolutely exceptional position" of the collection of mining engineer I.N. Kryzhanovsky "transferred to the possession of the museum on October 10" (Proceedings..., 1913). The introduction stressed that "the possibility to organize crystallographic studies at the museum on scientific approach occurred due to the presence of the collection, because crystals of Russian minerals composed the main value of the collection. Moreover, the collection significantly replenished gaps in the academic collection...". Registering the specimens to the main funds of the museum started immediately.

L.I. Kryzhanovsky especially emphasized existence of "full catalog of the collection with exact notes on the very mineral and its original locality". He wrote: "our multiple excursions in the Urals and Siberia, acquaintance with the very deposits and locations of minerals played a great role in composing the present catalog and made it possible to reconstruct deposits of some minerals which were purchased to the collection and had not been described before". Absence of catalog or its incompleteness significantly decreases a value of any collection. Even the famous collection of P.A. Kochubey did not have a catalog, whereas "this collection has an ideal order as in the catalog recordings, as in mode of

enumeration of the sample by numbering with enamel paint".

The catalog kept in our archives is comprised of two similar volumes (fig. 3). They resemble the books which were kept for recording of the museum collection starting from 1912. Apparently, the data was recorded gradually using the original catalog: the recording started in 1913 and ended in 1916. Minerals were recorded by groups, according to Dana classification with numeration within the groups. The most part of the recordings was made by Leonid Il'ich by hand with black China-ink: the names, descriptions ("the state of occurrence"), deposits. Prices were put in pencil. Vladimir Il'ich, then a custodian of the mineralogical museum, made additions, corrections, notes, proved the accuracy of the data, signed and put a date with black and red China-ink or a colored pencil. He marked samples to allocate them to collection of deposits or rarely to collections of crystals or pseudomorphs and united recorded specimens "under one number". The through numeration is absent as well as numbers attached during the recording to the catalog of the main museum's collections. It makes difficult to compare data and sample search, because the collection was dissolved in the mass of the main museum collection. To compare the data is especially hard if there is no enamel number on the sample. It is impossible to find all the samples. Number of the specimens insignificantly declined because of recording "under one number". Also samples could be recorded with names of people who gave the specimen to the author of the collection. Unfortunately, such a "diffusion" of collections is a common practice in remaking ca-

Fig. 3. The catalog of the collection of mining engineer I.N. Kryzhanovsky.

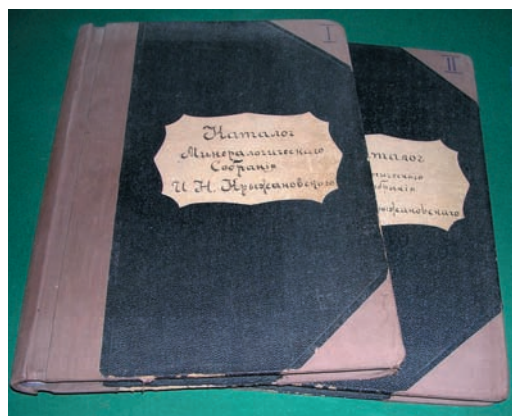




Fig. 4. Ilmenite with Vladimir I. Kryzhanovskiy's label. 9 cm. Ilmeny Mts, South Urals. FMM No 23287. Photo by Elena Matvienko.

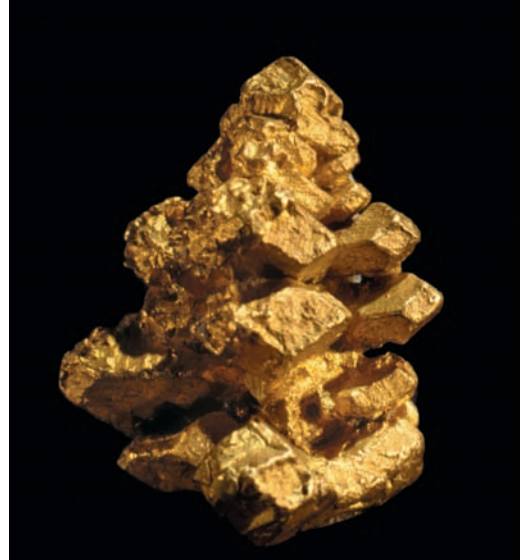


Fig. 5. Native gold. 13 gram. Nev'yanskaya dacha, Middle Urals. FMM No 23097. Photo by Michael Leybov.



Fig. 6. Amethyst. 9 cm. Lipovka, Middle Urals. FMM No 22248. Photo by Michael Moiseev.

Fig. 7. Heliodor and aquamarine. 5 cm and 9 cm accordingly. Murzinka, Middle Urals. Adun-Chilon, E. Transbaikalia. FMM No 23975 and FMM No 24020.

Fig. 8. Spessartine. 3 cm. Krasnobolotsky mine, the Emerald Mines, Middle Urals. FMM No 24443.

Fig. 9. Rubellite. 3 cm. Lipovka, Middle Urals. FMM No 23581. Photo by Michael Moiseev.

Fig. 10. Topaz. 3 cm. Kamenka river, South Urals. FMM No 22608.



Photo by Elena Matvienko.

talogs. The labels for the samples neatly written by Vladimir Il'ich by hand (fig. 4) provide a lot of help by having on the other side a stamp mark "coll. min. eng. I.N. Kryzhanovsky", author's number and some commentaries, for example, a person's name that the sample was acquired from.

The brothers Kryzhanovsky placed minerals by the groups in their manuscripts (V. Kryzhanovsky, 1912; L. Kryzhanovsky, 1912), mentioning quantity, some commentaries and the estimated value. Leonid Il'ich made the most detailed notes also with prices mentioned. Data on the quantity and the quality of the specimens is summarized in the brief review by academician V.I. Vernadsky and A.E. Fersman (Appendix II..., 1912). Appraisal and emphasis on the most interesting objects are similar in all the reviews. All the mentioned papers are cited below.

"A whole series of specimens which have a big value for crystallographic studies and study of some specific problems of gold occurrence in the Urals" is emphasized by V.I. Vernadsky for the **group of native gold** (total 132 specimens, native gold – 115 samples). Leonid Il'ich especially allocated samples where gold occurs in mineral or rock and also its "magnificent crystalline intergrowth" (fig. 5).

Group of quartz (377 samples) "gives a rich and various material of every variety of SiO₂ encountered in the Urals and Siberia" (L.I. Kryzhanovsky). It "presents an excellent set of curious crystallographic forms" and complex resorption patterns noted V.I. Vernadsky. V.I. Kryzhanovsky noticed a "very good and interesting collection of the Urals's quartz" (fig. 6).

Group of beryl (476 samples) contains magnificent collection of emerald and beryl specimens from the Emerald mines, beautiful beryl from Murzinka village and Aduy creek (the Middle Urals), vorobievite, roosterite and aquamarine from Transbaikalia (fig. 7) and "has without doubt one of the most valuable groups in the assemblage" (V.I. Vernadsky).

Garnet group (194 sample numbers) "presented... with appropriate to the group beauty and variety" (L.I. Kryzhanovsky). It contains among the other specimens crystals of "andradite with perfect faces of such a rare crystal forms for garnet as cub and pyramidal cub from Nikolae-Maximilianovskaya mine" (ibid); antique almandine from Ahmatovskaya mine (V.I. Kryzhanovsky), collection of big well formed spessartine crystals from, then newly discovered, Krasnobolotsky deposit, in the field of the Emerald mines in the Urals

(fig. 8); transparent garnet and "superior material on demantoid garnets and which is very interesting by the novelty of the deposit of the Asbestos mines" (V.I. Vernadsky).

Tourmaline group (404 specimen numbers), by V.I. Vernadsky words, is "the outstanding gathering of crystals": "...this material, organized by the deposits and crystallographic types, has a big scientific value". The classic deposits near villages Murzinka, Alabashka, Sarapulka, Shaitanka and Lipovka (Middle Urals) are represented here with hundreds of samples (fig. 9). The collection is also rich with samples from Borchshovochniy Range, from localities near Nerchinsk (Transbaikalia). The Kryzhanovsky brothers stressed the high value of the collection, which also was noticed by V.I. Vorob'ev, a well known expert in minerals.

"**Minerals of topaz group** (215 specimen numbers) also have a distinguished place in the collection and have some rare crystallographic forms" (V.I. Vernadsky). "Borchshovochniy range, Adun-Chilon, Murzinka, Ilmen Mountains and river Kamenka (fig. 10) have their best representative samples" (L.I. Kryzhanovsky). The brother, Vladimir Il'ich, pointed out the topaz "from old workings from Mokrusha mountain" (near Murzinka village, Middle Urals).

Leonid Il'ich wrote about the collection of serpentine (121 samples) and stresses that it was gathered as a material for V.I. Kryzhanovsky's work "Deposit of serpentine-asbestos in Kamenskaya and Monetnaya dacha in the Urals" (Proceedings..., 1907) with later additions to it. Together with minerals of other groups the collection "in assembly gives the most comprehensive picture of the whole deposit". Vladimir Il'ich himself mentioned "the very good collection of serpentine-asbestos".

V.I. Vernadsky characterized samples of **copper minerals from oxidation zone** as exceptional. There were libethenite, ehrlite (pseudomalachite) (fig. 15), olivenite, lettsonite (cyanotrichite) and others among them. L.I. Kryzhanovsky underlined the beauty, the rarity, the difficulty to identify all those interesting minerals and "usual absence of them in private mineral collections". Almost all of them originate from Mednorudnyanskoe mine (Nizhniy Tagil, Middle Urals).

V.I. Vernadsky reported: "the group of malachite definitely has a big value because of beauty of hand samples and variety of the material". The group was comprised of malachite and azurite then. L.I. Kryzhanovsky wrote about the **malachite** collection (74 spe-

Fig. 11. Malachite. 30 cm. Gumeshevsky mine, Middle Urals. FMM No 24622.

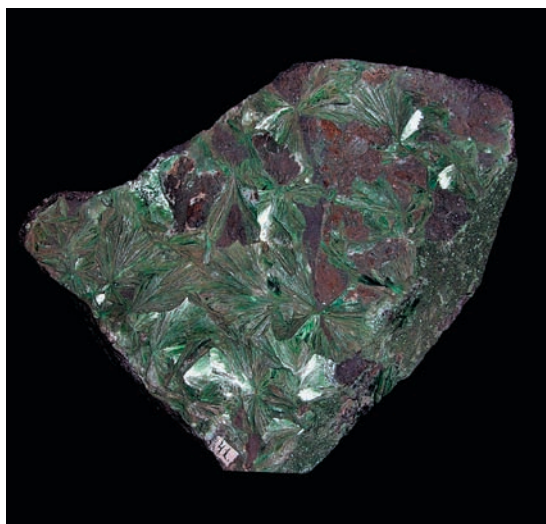
Fig. 12. Cuprite. 4.5 cm and 10 cm. Gumeshevsky mine, Mednorudyansky mine, Middle Urals. FMM No 22786 and FMM No 22812.

Fig. 13. Fuchsite. 23 cm. Bairamgulovo, South Urals. FMM No 23537.

Fig. 14. Rutile. 3.5 cm. Kosoi Brod, Middle Urals. FMM No 22365.

Fig. 15. Pseudomalachite. 5 cm. Mednorudyansky mine, Middle Urals. FMM No 24828.

Photo
by Elena Matvienko



cimens): "There is as much beauty as originality. Graceful and original sinters, bright and subdued colors and shades of solid lapidary malachite make the gathering very interesting..." We want to mention samples from Gumeshevskoe deposit, which had being depleted a long time ago (fig. 11). The authors also marked azurite from Altai.

Gathering of hand samples of platinum, osmiridium, native copper, pyrite and marcasite, molybdenite, cuprite (fig. 12), crystals of chalcocite, corundum, hematite, alexandrite, zircon, rutile (fig. 14), perovskite and pyrochlore, rare niobates and tantalates, ilmenite (fig. 4), gibbsite, limonite, vesuvianite, phenacite, epidote and fuchsite (fig. 13) catch particular attention as well as crystals of feldspars, chromium chlorites, clintonite, minerals of the group of apatite, libethenite, crocoite and wulfenite.

L.I. Kryzhanovsky wrote, finalizing his overview, that his father "had to place the collection for sale" nevertheless he asked the minimum price for it "taking in consideration financial difficulties of his highest purchaser" and "had brought to the altar of the national science all our work carried out for many years". The father suggested "that this collection has big both scientific and national interest... Because of this he passionately desired that the collection would stay in Russia and not flew abroad, as it usually happened with Russian national treasures".

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FABERGÉ EGGS FOR EVERYONE. POINT OF VALUE

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This article describes a set of Fabergé keychain eggs from the collection of the Fersman Mineralogical Museum of the RAS. The weight, size, and manufacturing material were compared to the original labels on the boxes, which helped to decode their original price range.

5 photos, 1 reference.

Keywords: Fabergé, Easter keychain eggs, precious and semi-precious stones.

For the more than one and a half century since the time when the Fabergé jewelry firm was founded, this name became one of the most famous brands, a synonym of tsar luxury and the highest-level jewelry art. The most famous pieces from the Fabergé heritage are the Easter eggs made for the members of the Russian Emperor's family from 1885 to 1917. Other relatively inexpensive Easter eggs also manufactured by Fabergé for decorating key chains are much less known. Tatiana Muntyan, curator of the Fabergé collection of the Armoury of the Moscow Kremlin Museum wrote about these: "There was a tradition in old Russia: a girl was presented with a little egg for every Easter (Paskha) since her birth. The keychain eggs were very diverse: golden, silver, sprinkled with gems, or coated with transparent enamel over Guilloché surface. The Empress gave such key chains to maids, house servants, and relatives for Easter. She drew these eggs in a special notebook and marked the price under each: five, seven, ten rubles — Alexandra Fedorovna was not too generous. One of such notebooks is kept in the Moscow Kremlin Museum. Almost none of those keychain eggs remained in Russia: people who left the country after the Revolution took them along as the most precious belongings. The prices for those key chains rose enormously at the antique market: a tiny egg could cost up to 10–12 thousand dollars (Muntyan, 2000).

A set of such key chains made out of rock crystal, jade, lazurite, rhodonite, and purpurine (brownish-red glass, very characteristic of the Fabergé works) is a part of the collection of the Mineralogical Museum (Fig. 1). The eggs have attached golden rings (millesimal fineness 583). One of the rhodonite eggs has a silver fringe (millesimal fineness 800). The keychain eggs are contained in the original box, which has cells of various size carved in a

soft wood and covered with fleece. The cells were obviously shaped for the individual eggs, many of which are placed where they belong. Under each row of cells, iron pins (brands "Original" and "Комите № 2" can probably be used as clues to proper dating) fix the paper labels with ink-written symbols, which probably indicate the price of a particular piece in some coded form. Such coding was evidently used to guide a sales person in Fabergé stores towards a certain price range.

For decoding the prices indicated under the eggs in the box, the following assumptions were made:

1. Letters and letter combinations denote numbers;
2. For the eggs made of the same material, the price is generally proportional to their weight/size.
3. The prices are linked to the Russian monetary system as of the end of the 19th — beginning of the 20th century.

Among the letters used in the codes, there are symbols d, e, m, p, r, z, e.dy, r.dy, to some of which the fractions 1/4, 1/2, or 3/4 are added.

The comparison of the cell sizes for pieces made of the same material results in the following quantitative relations in symbols: $z > r > p$, $m > d > e$, $e > r$, $m > z$, $e.dy > e$. Thus, the all the symbols used can be ranked in the ascending series: p, r, z, e, d, m, e.dy. The jade eggs gradually decreasing in size were marked "p3/4", "p1/2", and "p1/4", which suggests that the fractions are non-coded parts of a monetary unit (probably ruble).

The rhodonite egg marked "e.dy" significantly exceeds others in weight (for example, its mass is 3 times greater than that of the egg marked "e"), therefore, its price should be proportionally higher. As we have already concluded, the symbol "e" corresponds to a single-digit number somewhere in the middle



Fig. 1. A set of keychain eggs from jade, rhodonite, rock crystal, lazurite, and purpurine. FMM, No PDK 2376, 2451–2454, 2475, 2504, 2548, 4082. Photo: Michael Leybov



Fig. 2. Emerald keychain egg. FMM, No PDK-2756.



Fig. 3. Raw materials for chalcedony keychain eggs. FMM, No PDK-2245-2248, 2187.

Fig. 4. Raw materials for bowenite keychain eggs. FMM, No PDK-2402, 2415, 2416, 3899, 3900.

Fig. 5. Raw materials for purpurine keychain eggs. FMM, No PDK-3728.

Photo by Mikhail Generalov



of the 1–9 interval. Hence the price of the egg that is three times larger should be greater than 10. Then, the symbol "dy" means "+ 10".

In the standard "Arabic" numeric system, placing the higher order numbers on the right side is uncommon; so this approach of placing symbols was obviously used to further conceal the relation between the symbols and the actual price value.

The main currency in Russia in the beginning of the 20th century was ruble, which was equivalent to 0.7742 g of pure gold and, before 1914, was one of the most stable currencies in the world. The monetary exchange involved golden coins of 15 rubles (imperial), 10 rubles, 7 rubles and 50 kopecks (half-imperial), and 5 rubles. Commonly used silver coins (millesimal fineness 900) were 1 ruble, 50 kopecks, and 25 kopecks; silver coins (millesimal fineness 500) were 20, 15, 10, and 5 kopecks. Copper coins had the value of 5, 3, 2, 1, 1/2, and 1/4 kopecks. Also credit bills with the value of 500, 100, 25, 10, 5, 3, and 1 rubles were in use.

The only payment amount that could be equivalent to the symbol "e.dy" was imperial. Then the symbol "e" should denote "5". Therefore, the maximum price among the eggs in the set was assigned to the large rhodonite egg with a silver fringe 7.71 g in weight.

Now we can also decode other letter symbols. The row of numbers (prices) less than 5, judging by the mass ratios of the purpurine eggs, is continuous. Then "z" should denote "4", "r" is "3", and "p" is "2".

The symbols following "e" in the ascending order are "d" and "m". The mass ratios of the rock crystal eggs are consistent with the assumption that "d" corresponds to the number "6". The next symbol "m" could be presumed to be "7", but the mass ratios of the rock crystal eggs suggest that if $e = 5$, and $d = 6$, the "proportional" price of the largest egg should be around 7.60–7.80. It is also possible that "m" means not a number, but rather a price equivalent to the half-imperial value – 7 rubles and 50 kopecks.

The attempt to relate the letter symbols to the first letters of numerals in other languages that use Latin alphabet was not successful. It seems that for making decoding more complicated, the symbols were not associated with any abbreviations. The characteristics of the eggs from this set and their preliminarily decoded prices are listed in Table 1.

The stone material used in this set of the egg key chains has a diverse origin. The dark green jade was brought from the Onot River (Eastern Sayan). Judging by the deep blue uniform coloration of the lazurite, it was brought from the famous Badakhshan mines (Afghanistan). The translucent bright pink rhodonite could only be mined from the Sidelnikov deposit in the Urals. The rock crystal was probably also delivered from the Urals. The synthetic jewelry material purpurine (glass with a substantial admixture of copper), very typical of the Fabergé works, was also used in this set. Brockhous and Efron Great Encyclopedic Dictionary says the following about this glass: "... at 8% [Cu] and higher, the glass is opaque red, and the copper monoxide can be present in it as red crystals clearly visible at high magnification; such opaque glass of bright red-purple color is called purpurine (hemation of the ancient)". This glass was manufactured at the Petersburg Emperor's Glass Factory.

Comparing the decoded prices of the eggs that are close in weight but are made from different minerals, one can obtain the relative costs of those materials. The row with ascending cost is as follows: jade – lazurite – purpurine – rhodonite – rock crystal.

However, the egg set in the box is not the only key-chain heritage present in the collection of the Mineralogical Museum. There are about a hundred small eggs made out of various materials among the large volume of art stock – inserts, cut stones, and gems that were handed over to the Museum by the Russian Committee on Natural Manufacturing Resources (KEPS) in 1924. In addition to the eggs similar to those present in the set, there are some made out of agate, sapphirine, and other varieties of chalcedony, beryl, jasper, marble, and noble serpentine (bowenite) (Figures 2–5). Some of those pieces are finished works and have some golden or silver rings on them. But most of them evidently are just stock items, some having drilled holes for fixing the metal parts. The holes for fixing brackets are usually located on the narrow end of an egg, but there are cases when the fixtures and rings are attached on a side. Obviously, one of the cells in the box was prepared for such egg type, although it now contains a rhodonite egg (probably misplaced) marked with the symbol "e".

Table 1. Characteristics of the keychain eggs in the set and their presumable decoded prices

Material	Total mass, g	Dimensions, length . max diameter, mm	Price symbol on the box	Price (rubles) as the beginning of the 20 th century.	Notes
Jade	8.61	20.7 x 15.8	r ^{1/2}	3.50	
Jade	4.31	15.7 x 12.9	r	3	
Jade	3.03	14.8 x 10.7	p ^{3/4}	2.75	
Jade	2.02	11.7 x 9.4	p ^{1/2}	2.50	
Jade	1.25	10.4 x 7.6	p ^{1/4}	2.25	
Jade	0.69	8.0 x 5.9	r.dy	13	Misplaced; the cell is much larger than the egg
Rhodonite	7.71	19.6 x 13.9	e.dy	15	
Rhodonite	2.62	12.5 x 9.6	e	5	Probably misplaced; the cell is designed for a keychain egg with side fixture
Rhodonite	1.90	11.5 x 8.4	r	3	
Rhodonite	1.03	8.9 x 6.5	p ^{3/4}	2.75	
Lazurite	2.03	12.6 x 9.6	p ^{3/4}	2.75	
Lazurite	3.09	15.2 x 11.0	r	3	
Lazurite	1.34	11.4 x 8.0	p ^{1/2}	2.50	
Lazurite	0.63	7.8 x 5.5	p ^{1/2}	2.50	Misplaced; the cell is larger than the egg
Rock crystal	2.59	14.4 x 11.6	m	7	
Rock crystal	1.96	13.4 x 8.9	d	6	
Rock crystal	1.72	12.2 x 9.2	e	5	
Purpurine	9.49	18.4 x 14.4	z ^{1/2}	4.50	
Purpurine	5.00	14.4 x 11.8	z	4	
Purpurine	3.58	13.1 x 10.4	r ^{1/2}	3.50	
Purpurine	2.33	11.0 x 8.8	r	3	
Purpurine	1.24	8.5 x 6.8	p ^{1/2}	2.50	
Purpurine	0.84	7.4 x 5.8	p ^{1/4}	2.25	
Purpurine	12.53	20.4 x 16.0	m	7	
Purpurine	7.85	18.0 x 13.2	z	4	
Purpurine	1.79	10.6 x 7.9	r	3	
Empty cell			d	6	
Empty cell			e	5	

It is very probable that these eggs, as well as a number of other stone works that arrived to the Museum during that period of time, were acquired from the stocks of the Fabergé shops as a result of collaboration of A.E. Fersman and A.K. Fabergé, whose firm stopped its business in Russia in 1918. In this case, the eggs without fixtures cannot be unambiguously attributed to the products of the famous firm, since such "half-fabricated" materials were often bought by Fabergé from other manufacturers. As for the "complete"

eggs, we can now estimate at what price the customers could buy them in the beginning of the 20th century; although those estimates have certainly little to do with the present-day prices for the products produced by Fabergé or even assumingly associated with the name of the famous firm.

Reference

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TO THE HISTORY OF DISCOVERY OF SOME NATIONAL DEPOSITS BY COLLECTION'S SPECIMENS

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The history of geological discoveries has many bright examples of deposits found by the sample material from the field works of previous years or as a result of thorough looking through a museum collection. Several such finds have significantly increased the country's mineral resources base and are described in the article. In particular this article will detail in the main role of plentiful gathering of the Fedorov museum in the Urals in the discovery of the major bauxite deposits; reclamation of Chorukh-Dairon sheelite deposit which was found by N.A. Smolyaninov by museum's specimens; the epic history of search for kimberlites in Siberia using "pyrope path" method invented by A.A. Kukhareno based on his collection of South African kimberlites; the Zheltaya Reka (Zheltorechenskoe) deposit, the first uranium deposit in the USSR, and several other deposits is also described. The data provided will show the importance of careful keeping and practical use of mineral collections and using previous geological works for continuation and success of the later studies.

3 color photos, 12 references.

Keywords: deposit discovery, bauxite, optical fluorite, sheelite, pyrop, diamonds, uranium ores, boron ores, mineral collections.

World experience shows that in past centuries mineral deposits were discovered almost accidentally by ore outcrops or other obvious signs of shallow ore presence. Nowadays, due to the depleting of easy-to-find mineral deposits, mineral deposit discovery is usually the last link in the chain of complex planned and focused geological investigations, that include geological surveying of various scales, revelation of geophysical and geochemical anomalies, detailed mineralogical and analytical research of revealed mineralization and their processing and economical assessment. Nevertheless, there are examples of deposit discoveries without the complex and multistage geological investigation, or with significant reduction of it.

This article will talk about deposit discovery made at the work desk while looking through material gathered during previous field expeditions. Occasionally it was possible to encounter the material signs of valuable mineralization, which were proven by checking in the field. This is a difficult approach, it requires a deep knowledge of mineralogy, a clear understanding of the geology and mineralogy of the regions where the material was gathered, and a hands-on knowledge of mineral identification. The knowledge of the exact location of the gathered samples is espe-

cially important. In the history of the Soviet Russia's geology there have been some stunning examples of discoveries of this type.

Geologists from the Urals know well the history of identification of Krasnaya Shapochka (Red Riding Hood), the biggest Russian bauxite deposits in the NUBR (the North Urals Bauxite-bearing Region). The sources of the discovery lead us to 19th century, when E.S. Fedorov, the prominent Russian geologist and crystallographer (inventor of the universal stage and 230 crystal space symmetry groups. — Translator note), had gone to the Urals from Petersburg in 1885 to carry out a detailed study of the region of Tur'insky mines. A thorough mapping of Bogoslovsky mining district was conducted with creation of a 1:10 000 geological map. It covered 5 thousand km² and had a well described mineral collection which tied samples to points on the topographic map. This collection became fundament of the museum and was named after E.S. Fedorov. Tur'inskaya expedition started investigation work in the region of town of Nadezhdinsk in 1930. Geologist N.A. Karzhavin knew about bauxite occurrences on the Western and Eastern slopes of the North Urals before undertaking the exploration. He studied the collection of Fedorov in the geological museum. He wrote later in his book "Krasnaya



Photo 1. Bauxite. The Krasnaya Shapochka deposit, Urals. The size of the biggest sphere is 33 cm in diameter. VIMS Geological Museum. No 204sh. Photo: N.N. Krivoschekov.

Shapochka" (Red Riding Hood): *"I spend days and nights in the museum. I select 14 samples of suspected bauxite formations to send to chemical analysis out of 50 thousand thoroughly observed samples. Incommunicable joy did I feel when promptly received results of chemical analyses of my "suspected samples". 7 out of 14 turned to be bauxites of the world's best grade... It was easy to learn geographical location and coordinates using maps from the safes."* (Karzhavin, 1975). Follow-up fieldwork to check of the Karzhavin's findings led to the discovery of the best Russian high grade bauxite deposits, which supplied continuous operation of the Urals aluminum plants for many decades (Photo 1).

Material of the vast collection of Fedorov geological museum in the Krasnotur'insk promoted discoveries of Severopeschansky iron deposit, commercial deposits of refractory clays, and many other mineral deposits besides bauxite of the NUBR (Yushkin, 2006). E.S. Fedorov foresaw the important role of the gathering he collected for the future development of the mining industry of the region. He wrote about the visit to the region of his previous works in 1912: *"I suppose that there is no other place on Earth where such detailed work would be done in preparation for solving questions connected to mining activities. Because of it, nowhere else did so deeply into the details of geological structure, which have become a necessity of the mining business in general, and especially for the large field of Tur'insky mines"* (Fedorov, 1912). E.S. Fedorov willed to save the unique in its comprehensiveness and

representative collection gathered by him and his assistants. He knew it was the very important source of information about yet undiscovered resources in the Northern Urals. We know now, his insight was totally proved out.

A museum collection also played the main role in the discovery of the unique deposit of fluorspar with gigantic crystals of optical quality fluorite, on the slope of Zeravshan Range near Panjakent in Tajikistan. V.N. Sobolevsky, the participant of the legendary Tajikistan-Pamir expedition organized by the Academy of Science of the USSR, described it in details. One geological brigade went along the Kulikolon gorge and received a beautiful druse of large colorless crystals as a present from a local habitant. The brigade members did not identify the mineral then and upon arrival at the headquarters in Stalinabad (now Dushanbe), the sample was given to Stalinabad's museum of local lore, history and economy without information on the source locality. V.N. Sobolevsky was one of the other members of the academy expedition, and he was attracted to the sample after observing the museum collection. He identified it as rare optical fluorite of quality and size. They immediately sent an exploration group to the place where the local dweller had presented the magnificent sample to the geologists. Soon, this group with the help of old Tajiks, who were the first to find the great crystals on the mountain side above Kulikulon Lake, discovered mineralized zones with large cubic fluorite crystals of unprecedented quality (Photo 2). It was the first discovery of an optical fluorite deposit in the Soviet Union and there were no similar ones in the world at that time (Sobolevsky, 1945).

A longer, complex, but also very exiting story is about discovery and development of skarn Chorukh-Dairon scheelite deposit. P.S. Nazarov, a businessman who worked in Turkistan, brought a variety of specimens to the Mineralogical museum of Moscow University in 1912. They were described in the catalog by P.E. Alexat, the museum's custodian, as "scheelite samples with manifestation of copper mineralization found on the road from Khujant to Murza-Rabat". Later the greater part of the donation was lost. N.A. Smolyaninov, the famous mineralogist and, later profes-



Photo 2. Druse of large crystals of optical fluorite. Kulikolon deposit, Zeravshan Range, Tajikistan. The size of the sample is 84 x 57 x 32 cm. VIMS Geological Museum. No M 1739.

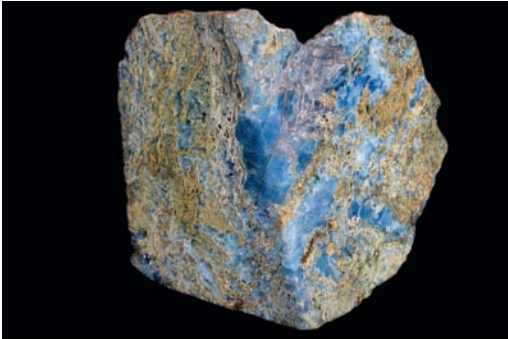


Photo 3. Boron-bearing vesuvianite-pyroxene skarn with blue calcite. Yuliya Svintsovaya deposit, Khakassiya, Krasnoyarsk region. Sample is polished from both sides with size of 15 x 11 cm. From the collection of Vladimir I. Kuzmin.

Photo: N.N. Krivoschekov

sor of the Moscow Institute of Geological Exploration ("MGRI" is the Russian abbreviation), found only two hand specimens left whilst reviewing of the old university collection in 1930. He supposed the Mogol-Tau region, where the samples originated from, to be perspective for *tungsten* mineralization having learned about the conditions of the formation of American scheelite skarn deposits and based on the geological environment of the region. He applied a report note on the subject to the Glavredmet (Main Bureau on Rare Metals) and was commissioned to Karamazar to check his prognosis. F.I. Wolfson, who worked in Turkistan in the period of 1930–1940, described the further development of the story in his memoirs.

"A man of a low stature approached me in Leninabad (Khujand after 1996) around 1930 and represented himself as Professor

N.A. Smolyaninov. After several polite phrases he asked me to give him some ammonal [mining explosive: 80% NH_4NO_3 , 15% TNT, 5% powdered aluminium. — Translator's note]. "What do you need ammonal for?" I asked him. I was convinced that I was talking to a man of science without practical knowledge of mining engineering, who was not capable to carry out exploration mining correctly. He explained me that he found scheelite in samples of supposed copper ore brought by tradesman Nazarov to the MSU museum before the revolution. He discovered the outcrops of the ores on his trip to the original sample locality and he needs to dig an exploring shaft on the outcrop.

I thought that if I gave him ammonal he would blow himself up. So, I decided to better help him with work of specialists. To the request I sent him a team of two colliers and Ilya Arzhanov, the blaster with ammonal. They helped to dig the pit. Later N.A. Smolyaninov characterized the deposit as valuable for further exploration. A geological exploration party was formed to study the deposit in 1931 and cut several trenches on the site of the mineralization.

We were very unfortunate that the German specialist F. Alfred was invited to Karamazar in 1931. He gave negative evaluation of the mineralization and the recently formed party was dissolved. Alfred wrote in his report that "magma in the region is depleted in tungsten and because of that scheelite outcrop at Chorukh-Dayron does not show any prospect". Exploration works on the site were frozen for 10 years.

The business was helped by the fact there was the road by the trenches. We went by the road with Arzhanov in August, 1941. On passing the pit, Arzhanov, who participated in blasting it, said: "Fedor Iosifovich, the "shevelite" was very rich in the pit!" I decided to study Chorukh-Dayron later. To assess the mineralization we dug long trenches. The workings on the site were carried out by a group lead by V.M. Bir'ukov. Bur'ukov came to me when only five or six days had passed since resuming the exploration. With his eyes open wide he said: "The trench had revealed a large tungsten-bearing vein more than 10 meters thick." I went to see the discovery on the site. Indeed the trench laid across the bearing of the

vein opened a magnificent ore body with very rich scheelite ore. The distance from the famous trench to the old Smolyaninov's pit was less than 150–200 m. Naturally, the find got everybody interested. A larger group of trench diggers was organized immediately and they outlined the vein in a month. It was more than 700 m long with an average thickness of 7 meters. Estimation of the reserves of the vein gave 10000–12000 tons of tungsten down to depth of 100 meters.

I went to Dushanbe to visit Protopopov, the first secretary of Central Committee of the Communist Party (of Bolsheviks) in Tajikistan, to tell him about Chorukh-Dayron. He learned from me about the importance of tungsten in production of armor steel, and proposed to prepare a resolution of the Central Party Committee and the Council of Ministers of Tajikistan about opening the mine. The resolution was directed to the Ministry of non-ferrous metals in Moscow. A.A. Amiraslanov, the principal geologist of the Ministry of non-ferrous metals, came for familiarizing with the object on the site soon after. He sent the telegram to P. Lomako, the Minister of non-ferrous metals saying: "Confirm construction Chorukh-Dayron". Necessary goods and machinery started to be delivered to the site in two weeks to begin the construction of the mine and the processing plant. Scheelite concentrate from Chorukh-Dayron began to supply military plants already in the fall of 1942. It was our contribution to the victory on the fascist Germany" (Wolfson, 2000).

Using pyrope as main trace mineral in diamond exploration is the wonderful example of discovering from deposit using samples of a mineral collection. It was the analogy to South African kimberlites that was made. This happened not long ago and it is well known due to memoirs of many participants of the diamond rush in the USSR.

N.N. Sarsadskikh and P.G. Guseva, the members of the Leningrad central exploration expedition, found grains of bright cherry-red mineral in heavy concentrates gathered during field work by exploration parties of the Diamond expedition in several regions of Yakutia. The majority of the mineralogists who worked on diamond exploration in Siberia considered them to be spinel and did not connect "the red grains" to a diamond-

bearing bedrock occurrence. They referred the mineral to A.A. Kukharenko, an assistant professor of the Leningrad state university, for identification. He possessed the only specimen of diamondiferous kimberlite from South Africa that existed in the whole USSR at that time. He saw a similarity in the minerals from the heavy concentrates to pyrope grains from the African diamondiferous kimberlites. A.A. Kukharenko also found picroilmenite which also was identical to one from the South African kimberlites. All those facts, especially presence of pyrope, which is easy to spot during primary observation of heavy concentrate, became a very effective technique in exploration of bedrock diamond deposits.

The common occurrence of pyrope in heavy concentrates was registered by many exploration groups working in the basin of Viluy River in early 1950s. The reliability of A.A. Kukharenko's proposition of pyrope as an indicator mineral urgently needed to be proved. N.N. Sarsadskikh recommended geologist L.A. Popugaeva to carry out this important test work in the region of Daldin river, where pyrope was found in most quantities.

The exploration was simplified to the following procedure: visually or with a hand lens identify and count only pyrope grains in heavy concentrates in the field and move upstream in the direction of increasing abundance; look for kimberlite bedrock outcrops in the area where largest pyrope concentrations were found.

So, the basis of pyrope mapping as an exploration method for diamondiferous pipes was established. "The pyrope trail" helped L.A. Popugaeva to make the outstanding find of the first kimberlite pipe in the region, named Zarnitsa on August 21, 1954. Later a number of kimberlite outcrops were found in the Yakutia diamondiferous province using this method (Lyakhovich, 2000).

Previously collected stone material also played a big role in the period of intensive uranium exploration. It is known that by the early 1940s the USSR had only a few small uranium deposits in Fergana and did not have mineral resources to solve the problem of atomic weapon production. At the same time, the hot-headed in the Pentagon and later NATO were preparing plans for preventative large-scale

nuclear attacks on the Soviet Union. To negate the USA monopoly on nuclear weapons became a matter of life and death for the USSR. Work on the "Uranium Project" started with the lead of I.V. Kurchatov soon after the World War II in very difficult time for the country's economy and with a very strict time frame. A.P. Alexandrov wrote: "... the most important part of the program was a clear but very difficult plan to start extensive uranium exploration and organize uranium production" (Belevtsev, 1992).

The special resolution of the State Defense Committee of the USSR assigned the Committee of Geology of the Council of People's Commissars of the USSR to do exploration for uranium deposits in the territory of the country. All the geological services received the order. Special attention was brought to the necessity of pursuing exploration goals not only by field works but also by revising previously collected material.

Despite of absence of radiometric hardware, geologists actively started exploration for the first time relying on the appearance of uranium minerals. They used the very primitive hardware such as leaf electroscopes, luminoscopes and so on. The research sometimes was successful even in such conditions. Ya.N. Belevtsev who became a principal geologist of Krivorozhsky iron basin in 1944, made a very important discovery in that period (Valter, 1997).

During the World War II the plants and the mines of the basin were ruined, shafts were blocked with loose rock and flooded, shaft houses were blown-up, the ground in many places was covered with drill core fragments. A lot of the core was scattered in the yard of the management building of the mines, where they stored the reference collection of drill core sample from holes across the different parts of the basin. Ya.N. Belevtsev received an order to carry out exploration for uranium deposits in April, 1945. With the help of technician geologist, he began to test fragments of the core spread in the yard. They were equipped with a school electroscope, which Belevtsev took from the physics department of Krivorozhsky mining institute. Fortunately, the core fragments had enamel labels with the drill hole number and sample interval. Hence it was possible to find the source of the core

using archive material. So, they found the place of the origin of the sample, which made the petals of the electroscope move. Ya.N. Belevtsev remembers this event in details.

"We had measured hundreds of core samples and all of them left the petals of the instrument stay motionless. The hope to find something wan and all the work seemed to be pointless and done in vane. Sometimes I thought that I should stop doing this fruitless work. Nevertheless, some force kept me searching.

The question "what to do?" rose when there was nothing else to test, and every drill core brought from the mines and all fragments of the core were extracted from the dirt in the yard and tested showing no signs of radioactivity.

"Let's search in the yard and in the shed one more time", I told Nikolay, "if we might leave something untested". We went to the yard, walked there for a long time. Nikolay dug out fragments of core, I crushed them into pieces and observed but none of them attracted my attention.

Walking around the yard my sight unwillingly came across some samples pressed into hard compressed soil. Some of them were black and stood out with bluish tint of alkaline hornblende. Those samples were dug out, crushed and tested with electroscope. We were so joyful when suddenly the petals of the electroscope went apart. We were rewarded for our hard and as we thought hopeless work. One sample had an enamel label with inscription in China ink that the core originated from the drill hole No 7 of Zheltaya Rechka mine. We found with maps and horizon plans that the drill hole No 7 was drilled through iron ores from the 110 m horizon on the Zheltaya Rechka mine. Later we found several samples on the mine which shown significant radioactivity."

It was the discovery of the first large uranium deposit in the USSR. Ya.N. Belevtsev, its discoverer, wrote in his memoirs: *"There is nothing more exiting for a geologist than finding a deposit. For not every geologist succeeds in it. I had this incomparable feeling I experienced twice in my life! One was the discovery of manganese deposit in Gornaya Shoria during the World War II and another was the discovery of Zheltaya Rechka uranium deposit in Krivorozhsky basin."* It is worth mentioning that the latter uranium deposit was found

using previously mined, almost collectible material.

There is another example of uranium deposit found by checking the radioactivity of previously collected stone material. V.G. Melkov, professor of the VIMS (the All-Union Institute of Raw Mineral Resources) found brightly luminescent uranium-bearing hyalite in the collection of L.P. Vilyunova, the staff of the North Caucasian Geological Survey. It was enough to initiate exploration works for uranium in the region of Caucasian Mineralnye Vodi, which lead to the discovery of commercial mineralization on Besh-Tau mountain followed by construction of Lermontovsky concentrator and metallurgical plant there.

A discussion about deposits found using museum collections need to mention pollucite mineralization discovery in rare metal pegmatites of Kalba Range. A.I. Ginsburg, preparing for field work on pegmatite fields, looked through pollucite-bearing pegmatite samples from Canada and the United States in the collection of Fersman Mineralogical Museum of the Academy of Sciences of the USSR. It helped him to find this valuable cesium mineral, which visually is very similar to quartz and other colorless minerals, in many pegmatite samples from Kalba Range (now in Kazakhstan). Detailed field study of pollucite mineralization in the pegmatites of Kalba field proved its commercial value. It was discovery of the first cesium deposit in the country. A.I. Ginsburg was awarded a state prize for the find.

Museum collections played crucial role in the revelation of Inder borate deposit in the cap rock of the large salt dome structure, one of the biggest boron deposits in the USSR. M.I. Dobrinina-Yakhontova, the head of the department of non-metallic deposits in museum of F.N. Chernyshev TsNIGR Museum (Russian abbreviation for the Central Research Geological Exploration Museum), found a beautiful large specimen of a colorless crystal from Inder Lake in Kazakhstan, in one of the old boxes during reexamination of old collections in 1930s. The mineral was identified as hydroboracite. An expedition was sent to Western Kazakhstan to do reconnaissance work in the original location of the sample. The expedition found enormous reserves of

boron salts in the area of Inder Lake (Inder Mountains..., 1940).

V.P. Petrov wrote in his memoirs a different version of the discovery. He wrote that Volkov, a staff member of the Geolcom (the Geological Committee on Mineral Reserves) (Volkov's initials are missing in his memoirs as long as the ones of Boldireva) collected samples on field studies of the Caspian Sea depression brought to the Geolcom museum as a part of his report in 1920s. A hand sample of unusual crystals had been identified in the field as "gypsum". Mineralogist Boldireva, the museum staff member who received the collection from Volkov, turned her attention to the sample and identified it as hydroboracite. Volkov was sent back to the Caspian Sea depression only a week later with another field group to organize exploration of the boron deposit and its exploitation only a week later. Naturally, a question appears in this case whether the museum staff member is the actual discoverer of the deposit.

Curiously enough the problem of boron deposits gained renewed vigor in the late 1950s despite of existence of the two big boron deposit in the USSR: Inder and the largest Tetukhe deposit in the Primorsky Krai. There was a boron boom in the country. The country's officials made boron the element of strategic importance to the country, due to its use in producing efficiency rocket fuel. Compounds of boron and hydrogen – borans exceed many other rocket fuels in their calorific capacity.

A.E. Sats, the staff member of the First business trust of the Ministry of Geology of the USSR, found a mineral that resembled datolite in the sample from non-ferrous multi-element deposit Yulia Svintsovaya in Khakassiya, whilst looking through the collection of Fersman Mineralogical Museum of the Academy of Sciences of the USSR. Laboratory tests of the mineral proved the initial identification of the mineral as datolite. An exploration reconnaissance group of the First business trust of the Ministry of Geology of the USSR was directed to the Yulia Svintsovaya deposit in the summer of 1959. Simultaneously a similar geological party was organized in VIMS and sent to the Minusinsk depression. The two parties worked in association with each other.

The skarn and adjacent altered rocks contained wide-spread boron mineralization represented with axinite, datolite, danburite and tourmaline. High boron content was also detected in vesuvianite from the deposit (Photo 3). Although, the scale of the mineralization was too small to be economical and the boron-bearing rocks had only scientific interest. Nevertheless, studies done at Yuliya Svintsovaya gave very important scientific data on the mineralogy and geochemistry of boron. Also the first study of supergene alteration of datolite was performed (Vasilkova, Kuzmin, 1961) and a new mineral sibirskite, a calcium borate CaHBO_3 was discovered (Vasilkova, 1962).

We need to mention that the "boron boom" soon came to an end in the country, because it was found that the viscous tar-like products from boron's combustion blocked up turbines and could not be used effectively as a rocket fuel.

The presented stories show the great importance of keeping and wise use of museum geological collections. These collections contain very valuable data on structure of geological bodies that were studied in the past and may have become inaccessible due to deposit depletion or termination of geological work in the area. The material chronicle can be read again, understood from a different point of view and may bring the unexpected joy of a new discovery to an inquisitive investigator. It is appropriate to put here the vivid expression made by N.A. Karzhavin, the discoverer of the Krasnaya Shapochka (Red Riding Hood) deposit, at the end of the article: "*Geological museum or drill core storage systematically ordered as a library, keep magnificent mysteries of the past generations. Drill core storages are centers where new geological ideas are crystallized and are brought to the light. Progress of the science is impossible without them as without fundamental libraries. Drill core storages represent not only forgotten ideas of the past but generate conditions for new daring and scientific deeds!*"

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«AMUSING MINERALOGY» IN STONE: THE EXHIBITION DEVOTED TO ALEXANDER E. FERSMAN'S 125th ANNIVERSARY

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The exhibition in the Fersman Mineralogical Museum, devoted to academician A.E. Fersman's anniversary is described.

1 table, 32 photos, 7 references.

Keywords: mineralogy, collection of minerals, mineralogist, mineralogical museum, academician A.E. Fersman

"I will draw separate isolated pictures, like an artist who pulls out certain separate moments from nature and, before painting a great picture, makes dozens and hundreds of sketches and drawings. The reader's imagination should unite them to make up a general picture of nature".

(A.E. Fersman, "Amusing Mineralogy")

Alexander Evgen'evich Fersman is known to the most rock connoisseurs and amateurs as an outstanding writer of books on mineralogy and geochemistry (Perelman, 1968; Pavlova, 2003). He possessed an extraordinary elocutionary talent, he was a brilliant lecturer able to light the listeners' hearts with an ardent passion for "dead" nature, he shared his energy and desire for exploring the country's mineral resources with young scientists and geologists. Alexander Evgen'evich is the author of a number of popular educational books and articles ("Recollections of Stone", "Geochemistry for Everyone", "Stories about the Gem" etc.). However, his "Amusing Mineralogy" is the most famous and readable book up to now. It was published first 80 years ago in 1928 and went through more than 30 editions in various countries (see Table 1). Many present-day scientists, mineralogists, geochemists, petrographers, geologists of other specializations chose their professions thanks to this engrossing book that they read in their childhood. Surely many its points become out of date today. When writing and republishing the book, A.E. Fersman could not know of the discoveries of rich diamond deposits in Russia, of large iron-manganese concretion accumulations on the ocean bed, of ultradeep drilling and of many others. The ideas of the Earth structure and of the "rocks from the sky", meteorites, have changed too. So, the necessary remarks have been included in the last edition published by the Chelyabinsk "Ural Ltd" under the scientific editing by the Doctor

of Geology and Mineralogy, Professor of the St.-Petersburg University Alexander Alexandrovich Kukharenko (Fersman, 2000). They indicate, for example, that some Fersman's data should be referred to the certain years (e.g., the description of Magnitogorsk metallurgical complex is dated 1937 and the data on the radium crop — 1945), and up-to-date calculations are given referring to this or that item. This is surely reasonable and does not diminish the value of the book in any way as its major charm is in the enthrallment and the passion of scientific searching and foresight that always marked Alexander Evgen'evich's talks and popular works.

To demonstrate minerals and rocks, described in this book, to trace some unexpected ways of prominent scientist's thinking, to reflect arising associations in mineralogical and other exhibits — all these have been the aims of this exhibition using the Mineralogical Museum stock. The exhibition opening was appointed on the 11th of November in 2008 to coincide with the beginning, at the Museum, of the "Fersman Days" — International scientific conference devoted to the Fersman's 125th anniversary.

The first chapter of "Amusing Mineralogy", "Stone in Nature and Town", begins, in the section "My Collection", with the famed sentence: "I became an ardent mineralogist when I was only six. We used to spend each summertime in the Crimea...". Unfortunately, the Museum does not have anything of that first Alexander Evgen'evich's collection that was

Table 1. Editions of the «Amusing Mineralogy» book by Alexander E. Fersman

NoNo	Publishing house	City	Language	Circulation	Year
1	Vremya	Leningrad	Russian	5150	1928
2	Vremya	Leningrad	Russian	8070	1929
3*	Vremya	Leningrad	German	5300	1931
4	Unknown	Kiev	Ukrainian	5000	1931
5	Vremya	Leningrad	Russian	10000	1933
6	Molodaya Gvardiya	Leningrad	Russian	25000	1935
7	Molodyi Bolshevik	Kiev	Ukrainian	10000	1935
8	Jugoslovanska Knjigarna	Lyublyana	Slovenian (?)	7000	1935
9	Dzyarzhin. Vyd. Belarusi	Minsk	Byelorussian	5000	1937
10*	Unknown	Tbilisi	Georgian	3000	1937
11*	Detizdat TsK VLKSM	Moscow–Leningrad	Russian	25000	1937
12	Turkmengosizdat	Ashgabad (?)	Turkmen	3000	1938
13	Detgiz	Moscow–Leningrad	Russian	25000	1945
14*	Novo Pokolenye	Belgrad	Serbian	7000	1947
15	Derzhavne Vydavnytstvo Tekhnichnoy Lyteratury Ukrainy	Kiev–Lvov	Ukrainian	25000	1948
16	Editura de stat (?)	Buharest (?)	Romanian	5200	1949
17	Pedagogicheskoe	Tallinn	Estonian	3000	1949
18	Neues Leben (Новая жизнь)	Berlin	German	?	1949
19	Neues Leben	Berlin	German	10000	1949
20*	Neues Leben	Berlin	German	16–27 000	1949
21	Narodnaya Kultura	Sofia	Bulgarian	5000	1950
22	Muewelt nep koenyvkiado	Budapest	Hungarian	4000	1951
23	Czytelnik	Warsaw	Polish	15350	1951
24*	Derskaya Literature	Moscow–Leningrad	Russian	75000	1953
25	Sverdlovskoe Knizhnoye	Sverdlovsk	Russian	75000	1954
26	Aypetrat	Erevan	Armenian	4000	1954
27*	Akademii Nauk SSSR	Moscow	Russian	25000	1959
28	Latgosizdat	Riga	Lettish	10000	1959
29	Chinese Edition of Literature for Children and Young People	Beijing	Chinese	5000	1960
30	Chinese Edition of Literature for Children and Young People (?)	Beijing	Chinese	9000	1960
31	Gosizdat Uzbekskoy SSR	Tashkent	Uzbek	?	1961
32*	Progress	Moscow	Vietnamese	8100	1968
33*	Detskaya Literatura	Leningrad	Russian	100000	1975
34*	Mokslas	Vilnius	Lithuanian	10000	1977
35	?	?	Japanese	?	?
36	Ural LTD (with the participation of Ural-Kniga)	Chelyabinsk	Russian	7000	2000

Notes

Publications from library and Archive of Fersman Mineralogical Museum RAS are marked by *.

Publications represented on the exhibition «Amusing Mineralogy in Stone» are marked by bold.

The «Amusing Mineralogy» of 1937 (No 11 in the table) like A.E. Fersman's favorite edition was the main source of material for the authors of the exhibition. In the introduction to this (5th) edition Fersman states that the 2nd edition was translated to German, Ukrainian (2 editions), Slovenian and Georgian. The first edition on Russian was published in March 1928, the second – in June 1929, the third – in October 1933. Both 5th and 4th editions (1934) contain differences with the 1st one: nine chapters are cut and six new chapters are included. In the text the role of mineralogy in Socialist economy is put in the forefront. There are more pictures and they are renewed. In the end of the book there is the index of scientific terms. The map of USSR with the main mineral deposits is added.

developing, with the years, from a fun to the really scientific collection: a part of it (including Crimea minerals) "was transferred to the Moscow University, another one became a part of the splendid collection of the First Popular University in Moscow" (Fersman, 1959). Therefore, the two Crimea specimens from the Museum Systematic Collection were presented at the exposition: the pinkish-grey chalcedony from the Karadag Mountain, Khoba-Tepe Range, and the cream-colored, radial laumontite aggregate (Kurtsy) as well as the specimens collected by Fersman (Dusmatov, 2003) at various times (Photo 1): in the Elba Island, Italy, – hematite and quartz crystals, in Czechia – pink natrolite (Marianska Hora) and golden carpholite (Slavkov), in the Northern Caucasus – celestine (Kislovodsk), in the Volga Region – quartz (Fomino-Gorodishche village). Besides, there was one of the two minerals named in the Alexander Evgen'evich's honor here – the fersmanite from the Apatitovaya Mountain (collected by A.N. Labuntsov in 1929 on the Kola Peninsula, Russia).

The same showcase mirrored some other sections of the first chapter: "Stone in Caves" (e.g., the gypsum from the famous Kungur Ice Cave on the Ural Western slope mentioned by A.E. Fersman in this chapter), "Stones on Bottoms of Lakes, Bogs and Seas" (the pyrite with the calcite filling the cracks in a phosphorite septarium from the Volga River banks in the Ulyanovsk vicinities, and the calcite from Imatra, Finland), "Into a Desert for the Sake of Stones" (the sulfur from the sulfur hillocks of the Karakumy Desert in Turkmenia – the specimen collected by A.E. Fersman and D.I. Shcherbakov in 1925).

A special showcase was devoted to the Khibiny and Lovozero Massifs. The Alexander Evgen'evich's description of this "mineralogical paradise" ("To the Mountains for Stones") is full with the romanticism of the North. This is, perhaps, the most poetic part of the book: "Here is menacing nature with its wild gorges

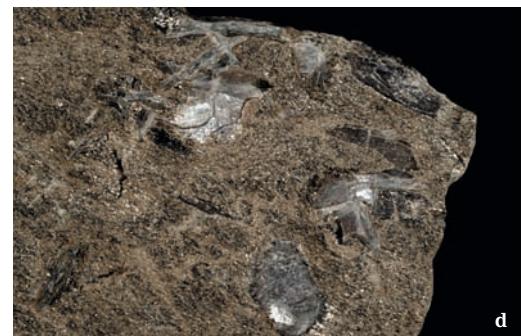
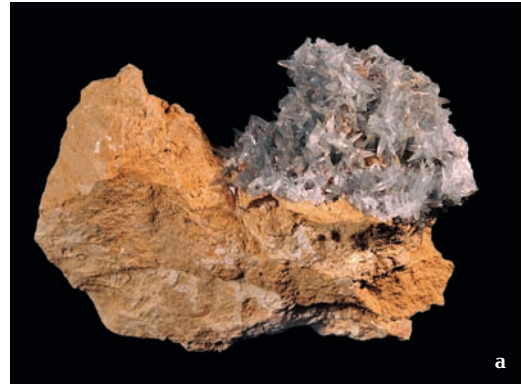


Photo 1. The specimen collected by A.E. Fersman:
a – celestine. Kislovodsk, Northern Caucasus, Russia. 3 x 7 cm. 1938. FMM No 39010;
b – hematite. Elba Island, Italy. 1913. FMM No 11425;
c – natrolite. Marianska Hora, Czechia. 1908 (collected by A.E. Fersman and E.M. Rozhanskaya). FMM No 40215;
d – carpholite. Slavkov, Czechia. 1908 (collected by A.E. Fersman and E.M. Rozhanskaya). FMM No 40206.

Photo: Michael Leybov



Photo 2. Bolshoi Vudayvr near Kirovsk in Khibiny. It is good to visit it, isn't it? (Fersman, 1937, p. 22)

and steep hundreds meters high, and bright midnight sun that lightens the snow fields of high uplands with its long rays. Here, in dark autumn night, the enchanting arctic lights shine the polar landscape of forests, lakes, and mountains with their purplish-red curtains". Besides the photographs of those times (Photos 2 and 3), including ones taken by academician Fersman himself, for example: "The team is evacuating the mineral collection by deers from Khibiny Tundras. A Lapp leads the deers, at the right is the Khibiny Tundras explorer, A.N. Labuntsov", 1925 (Fersman, 1937, p. 20), the "rarest minerals: bloody red or cherry-colored eudialites" (Lyavochorr, Khibiny, collected by the Khibiny Expedition in 1925, and other specimens as well), "lamprophyllite spangles sperkling like gold" (Iidichvumchorr, Khibiny, collected by the Khibiny Expedition of 1922, and Sengischorr, Lovozero) (Photo 4), "deep-green aegirines" (radial aggregate 16 cm in diameter from

Photo 3. The first "skyscraper" in Khibiny built by V.I. Vladavets exploration crew (Vortkeuai River valley at the Kukisvumchorr bottom). 1928.



Malyi Punkaruai, Lovozero), "goldish sphe-nes" (stellar, up to 1.5 cm in diameter, Kukisvumchorr, Khibiny, E.M. Bonshtedt collection of 1934) were flashing in the showcase. Another two specimens of this showcase, not very picturesque, though, depict this region history. One of them, ramsayite, is a mineral which can be considered a Lovozero symbol (brown crystals about 1 cm long in albite from the Flora Mountain, collected by A.N. Labuntsov in 1923). Another one is mentioned by Alexander Evgen'evich "dark red like clotted blood, neptunite", the mineral named in modern nomenclature manganneptunite (small, less than 1 cm in length, prismatic crystals of dark brown, nearly black color with analcime from Mannepakhk, Khibiny, collected by the Khibiny Expedition in 1926) – one of first numerous species discovered after that in the Khibiny Massif.

"...I never experienced such an admiration sense for the nature gorgeousness and beauty as at the Amazonite pits of Ilmeny Mountains", in such a way Alexander Evgen'evich Fersman described his feelings during his visit to the like-named mineralogical preserve in the corresponding section of the book. "The beauty of these pits is not only in the amazonite of fine bluish green color but its combinations with light grayish-smoke quartz which penetrates it in certain directions and intergrows into a beautiful pattern" (Fersman, 1937, p. 61). In the Ilmeny showcase, one could see not only "various and unique" "nature's letters" (Photo 5) but also a schorl on amazonite and microcline from the collection of those times prominent Ural prospectors G.A. Kitaev (Lobachevskaya Pit, 1912) and A.S. Yuzhakov (Mokrusha, Murzinka, 1910), tourmaline collected by V.I. Kryzhanovsky and A.E. Fersman (Mokrusha, Murzinka, 1912), phenakite on amazonite from the mentioned in the book Prince's P.A. Kochubei collection, topaz well-shaped crystals intergrowths with quartz and tourmaline (Photos 6 and 7).

"At the Window with Precious Stones" (the headline of another section of the book's first chapter and the corresponding showcase name) the spectator's attention was primarily attracted with "the fine fantastic pictures" on jasper from the famous native deposits – alike motley feathers and a "chaos of red tints" (Orsk, South Urals), foamy surf at a sand beach (Aushkul Lake, South Urals), a greenery "on the waves of a sleeping pond" (Revnevaya

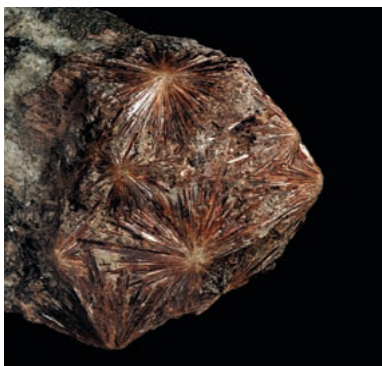


Photo 4. Stellar lamprophyllite. Sengischorr, Lovozero, Russia. 13 x 9 x 6 cm, crystals from 2 to 4 cm. Collected by A.N. Labuntsov and E.E. Kostyleva. 1932. FMM No 44589.
Photo: Michael Leybov
Photo 5. Graphitic granite. Shaitanka, Middle Urals, Russia. 7 cm. FMM No PDK 2919.

Mountain, Altai), a cool sunrise above mountains (Sibai, South Urals), a cinereous thunder cloud (Kalkan Lake, South Urals). Among foreign specimens, the so called oceanic jasper from the Madagascar Island should be marked that resembles the underwater iridescent world of Southern seas with its bright lacy pattern (Photo 8).

Besides the jaspers, various agates fascinated with their fine banding (Photo 9): the delicate whitish-grey one from the Chayachy Cape (North Timan), the chiselled red-grey one from Gusinoe Lake (Transbaikalia), the elegant greenish-white and the transparent honey-yellow ones from the Zeya River banks (Amur oblast'), the patterned pinkish-brown one from Chihuahua (Mexico). Among other decorative and precious stones, malachite, especially the specimen with the beautiful banding on its polished section from A.E. Fersman's collection (Photo 10), rhodonite (Sedel'nokovo Village, Middle Urals), the two labradorite specimens with well visible color reflexes (Volyn', Ukraine, and Karelia, Russia), the "bright blue, glowing with that blue fire that burns your eyes" lazurite (Badakhshan, Afghanistan), the magnificent, large topaz crystals (brown one – 7 cm,

bluish one – 11 cm high) from Ukraine (Volyn') and Transbaikalia (Urulga River, P.A. Kochubei collection, crystal 7 cm high) should be marked. "The lump of precious nephrite" (19 x 13 x 6 cm in size) from the banks of "famous Onot River in Eastern Siberia" and articles made of dark and light varieties of this stone stood out in the showcase bottom. Large amethyst crystals should be mentioned (Adui River, Middle Urals, the specimen 9 x 13 cm in size) as well as the photograph of some Ural prospectors with the freshly extracted amethysts from the Adui mine, which has been published in the A.E. Fersman's book (Photo 13). Like in the Alexander Evgen'evich's book, the section "At the Window with Precious Stones" was crowned with the "Marvelous Map of the Socialism Land" (its color photo) – a unique map of the Soviet Union made up of precious and decorative stones at the Ekaterinburg (then Sverdlovsk) plant in the late 1930s; it is now stored in the St.-Petersburg F.N. Chernyshev TsNIGR Museum.

As illustrations to the second and third chapters of "Amusing Mineralogy" – "How the Dead Nature is Built" and "The History of Stone" – there were the gypsum crystals



Photo 6. Topaz with quartz. Murzinka, Middle Urals, Russia. Topaz crystal syze is 1 cm. From V.A. Iossa collection. 1918. FMM No 10729.
Photo 7. Topaz on tourmaline. Murzinka, Sverdlovskaya oblast', Urals, Russia. Topaz crystal 3 cm. From L.I. Kryzhanovskiy's collection. 1937. FMM No 36197.
Photo: Michael Leybov

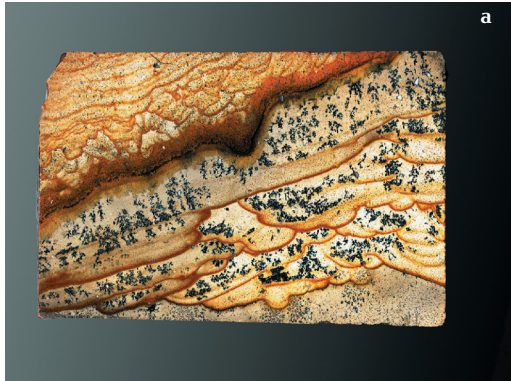


Photo 8. The jaspers from various localities:
 a – Aushkul Lake, South Urals, Russia. 18.5 x 12 cm. From V.I. Kryzhanovsky's collection. 1926. FMM No PDK 2812;
 b – Polkovnik Mountain, Orsk, Southern Urals, Russia. Stroganovs' heritage. 1919. 16 x 5.5 cm. FMM No PDK 926;
 c – "oceanic jasper". Madagascar. 17.5 x 10.5 cm. FMM No PDK 7977.

Photo 9. Agates: a – Chaichy Cape. North Timan, Russia. 13.5 x 9 cm. Collected by T.M. Pavlova. 1970.

FMM No PDK 6972;

b – Gusinoye Lake, Transbaikalia, Russia. 6 x 5 cm.

Stroganovs' heritage. 1919. FMM No PDK 952; c – Zeya River, Amur Region, Russia. 6.5 x 4 cm. FMM No PDK 6886.

Photo 10. Malachite. Nizhny Tagil, Middle Urals, Russia.

9.5 x 6 cm. From A.E. Fersman's collection. 1920.

FMM No PDK 1317.

Photo 11. Amethyst. Adui River, Middle Urals, Russia. 10 cm.

From I.N. Kryzhanovsky's collection. 1912. FMM No 22185.

Photo 12. Aragonite. Karlsbad (now Karlovy Vary), Czechia.

14 x 9 cm. From A.E. Fersman's collection. 1934.

FMM No 34976.

Photo by the authors

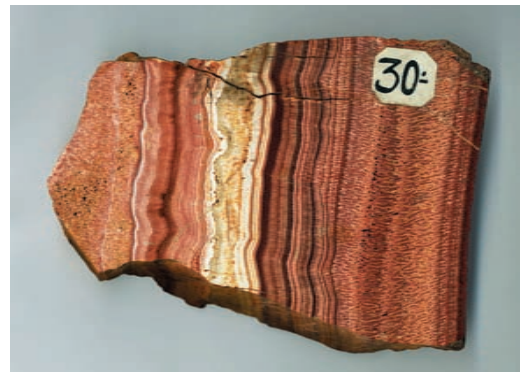
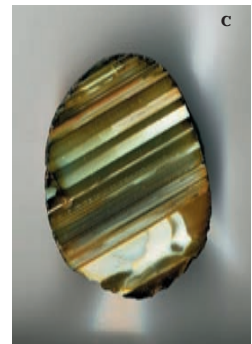




Photo 13. The Ural "gorshchiks" (prospectors) have discovered a giant hollow on the Adui River with amethyst crystals which were transferred afterwards to the Mineralogical Museum of the Academy of Sciences. 1926. (Fersman, 1937, p. 109).

Photo 14. A.N. Labuntsov and A.E. Fersman in Khibiny in 1920s.

(from Polivy Village, Central Volga Region) similar to the ones used by Fersman for the photograph in the section "A Crystal and its Properties", artificial crystals of copper vitriol (having been grown in domestic condition in accordance with the section recommendations) as well as the model of the quartz crystal lattice and splendid crystals of this mineral – the rock crystal druse from Dauphin, France, and the amethyst sceptre from mentioned Adui mine (Photo 11). Another specimen from the Alexander Evgen'evich's collection, aragonite from Czechia (Photo 12), was displayed here too. A few historical photographs from the Mineralogical Museum archive illustrated some of Academician Fersman's expeditions: "Transbaikalia. Waiting for a train. A.E. Fersman is to the right" and others (Photos 14 – 16).

The fourth chapter, "**Precious and Technical Stone**", was presented with quartz in the exhibition: excellent rock crystals to 10 or 13 cm long (Tessin, Switzerland) and specimens of various colored synthetic quartz grown in the All-Russian Research Institute for Synthesis of Mineral Raw Materials (Alexandrov). Another widely used mineral, corundum, was also displayed here: small transparent blue crystals (Sri Lanka, one of the specimens from the G.P. Chernik collection, 1909, see Mokhova and Generalov, 2007), pink and yellow crystals (both Sri Lanka, from P.A. Kochubei collection, 1913) as well as the dark blue, star variety of this mineral from Australia and the bright crimson crystal collected in the South Urals by Academician Fersman (Photo 17). Besides, there were small (up to 1 or 2 mm in size) diamond crystals, which have

Photo 15. Steamer on the Selenga River (Western Transbaikalia, Russia). A.E. Fersman photo (1915–1916).

Photo 16. After the [Karakumy] motor rally of 1929 [in the Charjou airdrome] at the airplane – A.E. Fersman and the rally com-modore B.A. Bogushevsky (Fersman, 1959, p. 271).





Photo 17. Corundum. Kamenka River, Southern Urals, 2 cm. Collected by A.E. Fersman in 1926. FMM No 25379. Photo by the authors.

Photo 18. Quartz. Berezovsky Zavod, Middle Urals, Russia. 11.5 cm. From L.I. Kryzhanovsky's collection, 1912. FMM No 21149. Photo: Michael Leybov.



been made on the high pressure device in the Cologne University (Germany).

The showcase "**The Curiosities in the World of Stone**" (the book fifth chapter) was the most saturated with mineralogical rarities and especially engaging. Here, in the section of "*Giant Crystals*", one could see minerals that occur in nature as crystals "of still more colossal sizes" than those that, according A.E. Fersman, impress with their sizes in great museums: the muscovite (Chupa, Karelia, 25 cm crystal), amazonite (Ilmeny Mountains, Urals) and microcline (Klein Spitzkopie, Namibia) as representatives of feldspars which "crystallize from melted masses as homogenous crystals of so big dimensions that entire quarry works for a single crystal (Fersman, 1937, p. 121), aquamarine crystals (Sherlovaya Gora, Transbaikalia, 9–11 cm long), gypsum (Sicily, Italy, 15 cm long). Another mineral that forms giant crystals – quartz, was presented with unusual twisted individuals (Puiva, Subpolar Urals, and Beryozovsky Zavod, Middle Urals), excellently faceted smoky variety (Tavetsch, Switzerland, crystal 8 by 5 cm in size) and the amazing boxy intergrowth of two crystals (Photo 18).

There were two pictures of aquamarine gigantic crystals in this showcase. One of them weighing 100 kg was found in Brazil. Then it was cut into numerous small pieces which saturated the aquamarine market during three years (Fersman, 1937, p. 120, 122). The other crystal, 1.5 m long, was discovered in the pegmatites of Tigeretskie Belki, Altai, and transferred to the St.-Petersburg Mining Museum. The color images of the quartz giant crystals in the "Earth and Men" Museum (Sophia, Bulgaria), the photograph of a large fluorite druse

from Kuli-Kolon in Fanskie Gory (Zeravshan Range, Tadjikistan), which was later placed in the main show-hall of the Fersman Mineralogical Museum, as well as the famous historical photograph, "Transportation of orletz (47 tons rhodonite lump) into the yard of Ekaterinburg lapidary plant from the deposit at the Shabry Village in the Urals" (Fersman, 1937, p. 123), illustrated this section too.

The next section of "Curiosities", "*Stones and Plants*", included magnificent moss agates (Photo 19) with separate "branches" and entire landscape pictures consisting of manganese and iron oxides and hydroxides (Pstan, Kazakhstan) or with pictures resembling thickets of bluish-green seaweeds (Arizona, USA), the small polished plate of Ural rhodonite with a sole black "arboret" (Photo 20), dendritic jasper (Khair-Kumir, Altai) as well as the "genuine petrified plant" – a part of tree trunk replaced with chalcedony (Kamchatka, specimen 14 cm height, 10 cm in diameter) and the amber, petrified resin "from the sands of Baltic coast". One could see, in the same showcase, the stony roses – gypsum (Doskino, Oka River) and hematite (Fibia, Switzerland) and "iron flowers" – "branchy snow white mass of delicate tangles of thin stemlets" (Fersman, 1937, p. 124–125) – aragonite from Austria (Photo 21), and the asteriated quartz alike white daisies (Straznik, Czechia), and the sceptre quartz resembling a mushroom (Borovoye vicinities, Kazakhstan). Among the illustrations, the Alexander Evgen'evich Fersman's photograph should be mentioned: "A gypsum rose of giant size in the quarry near Krasnovodsk, Caspian Sea" (1929) that was also repro-

duced in according section of his book (Fersman, 1937, p. 126).

"About the Color of Stone" (another section of "Curiosities") a variety of brightly colored minerals narrated: the "azure blue" lazurite "with the fine pattern of grey and white spots (Malaya Bystraya River, Baikal Region), emerald-green smithsonite (Tsumeb, S.-W. Africa), crimson rhodochrosite (Argentina), greenish-blue amazonite (Pikes Peak, Colorado, USA) and the wonderful white and foxy chalcedony with black spots from Yakutia (Photo 22).

The two other sections of "Curiosities", "Platy Stones" and "Fibrous Stones" were presented, with the orpiment (Menkyule, Yakutia) and chrysotile asbestos (Tatford Mine, Quebec, Canada) accordingly; next to the latter, an asbestos cord was also placed as well as photograph original "A vein of dark serpentine with the veinlets of fibrous asbestos from Asbestos mines of Middle Urals" from the book corresponding section (Fersman, 1937, p. 138). Another interesting exhibit of this part was the "fine-fibrous gypsum of delicate pink color from the Kungur vicinities in

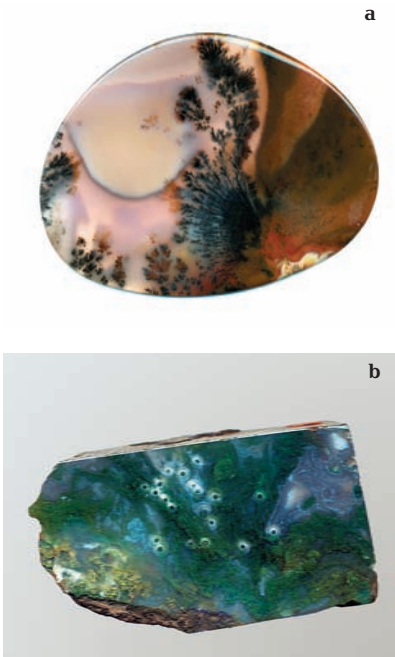


Photo 19. Moss agates:

a – Pstan, Kazakhstan. 10 x 8 cm. FMM No PDK 7968;

b – Arizona, USA. 10 x 5.5 cm. FMM No PDK 4244. Photo by the authors.

Photo 20. Rhodonite. M. Sedel'nikovovo village, Middle Urals, Russia. 4 x 2 cm.

Stroganovs' heritage. 1919. FMM No PDK 1148. Photo by the authors.

Photo 21. Aragonite. Eisenerz, Steiermark, Austria. 9 x 5 cm. From Shenshin's collection. FMM No 6484. Photo: Michael Leybov.

Photo 22. Chalcedony. Muustakh, Yakutia, Russia. 12.5 x 8 cm. FMM No 87926. Photo by the authors.



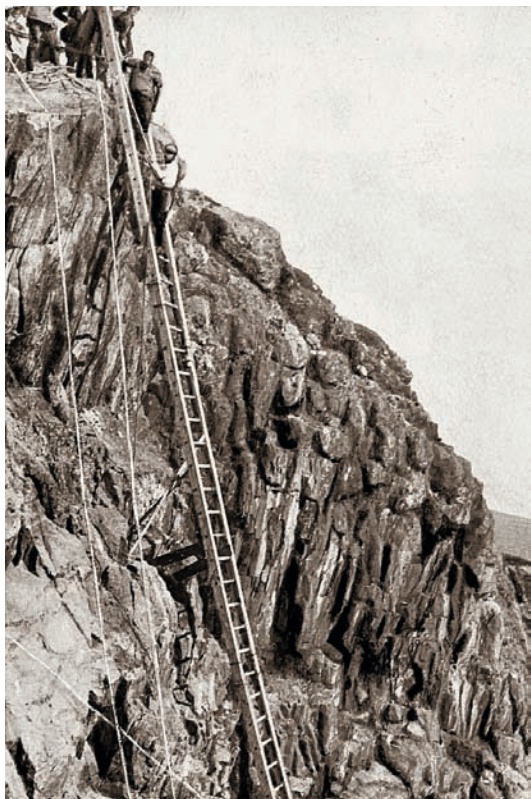


Photo 23. The mining of rare earth valuable ore [lovchorrite] on the Yukspor slopes in Khibiny. The steep height is 300 m. To get the mine working is only possible from above by the ladder. 1935 (Fersman, 1937, p. 202). [A.E. Fersman is on the ladder top.]

Photo 24. A.E. Fersman. Tyuya-Muyun vicinities, South Kirgizia. 1925.

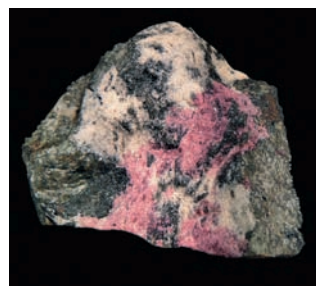
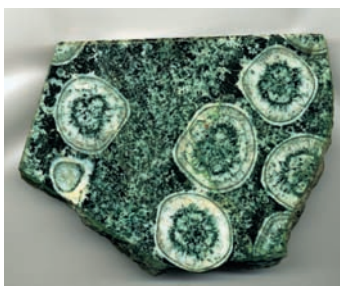
Photo 25. Conglomeratic marble. Knorinskoye Deposit, Primorye. 17 x 13 cm. FMM No PDK 4808. Photo by the authors.

Photo 26. Diorite. Corsica. 13 x 9.5 cm. FMM No 1922. Photo by the authors.

Photo 27. Eudyalite with apatite and nepheline. Kukisvumchorr, Khibiny, Russia. 10 x 9 x 5 cm. FMM No 53292. Photo by the authors.

Photo 28. Barite. Tyuya-Muyun. South Kirghizia. 10 x 9.5 x 4 cm. FMM No 59142. Photo: Michael Leybov.

Photo 29. Magnetite. Kachkanar Mountain, Middle Urals, Russia. 7 x 6 x 5 cm. From I.N. Kryzhanovskiy's collection. 1912. FMM No 23916. Photo: Michael Leybov.



Urals", which was exactly the same specimen that had been photographed as an illustration for the "Amusing Mineralogy" (Fersman, 1937, p. 130) and could be referred both "Fibrous Stones" and the section "About the Color of Stone" (like Alexander Evgen'evich did).

The last section of "Curiosities" at the exhibition (there are more of them in the book), "The Stones in a Living Organism", was presented with the "most remarkable "stone" substance" (Fersman, 1937, p. 142) – a shell with a pearl on its valve and red coral (both from private collections).

"Stone in Human's Service" (the sixth chapter of "Amusing Mineralogy") was shown with a range of historical photographs (including those placed in the book) where various moments of mining, processing and prospection of mineral resources have been imprinted, for instance, "Basalt columns in quarries of N. Bohemia in Czechoslovakia. Photo by acad. A.E. Fersman, 1936" (Fersman, 1937, p. 157), "Granite monoliths processed on the deposit for the columns of St. Isaac Cathedral", "A worker chops up pavement stones from basalt column with a crafty blow of sledge-hammer. Photo by acad. A.E. Fersman, Czechoslovakia, 1936", (Fersman, 1937, p. 158); "Transfer of apatite in Kirovsk (first autotrucks). Winter of 1930", "At the chromite mine of Bol'shoi Boshart during the motor rally in the Southern Urals. August 1935. Above: G.A. Sokolov, A.E. Fers-



Photo 30. The exhibits of showcase "Mineralogist-Amateur": museum labels (upper-wadeite, 1980s, lower – limonite, written by A.E. Fersman in 1908), quartz (Middle Urals, Russia, from I.N. Kryzhanovsky's collection. FMM No 22194). Photo by the authors.

man. Below: V.I. Kryzhanovsky, N.P. Pavlov" etc. (Photos 23, 24).

The color drawing "Moscow Metro. Kom-somol'skaya Station with columns of Crimea and Caucasus mottled marbles", which was in the section "Stone in Big Town" of the book first chapter (Fersman, 1937, p. 58), and the suit of polished plates of marbles from well-known deposits of Italy (in particular, pea green from Verona vicinities and white from Carrara), of Russia (Photo 25), and of China, as well as famous red Altai (Korgon) porphyry and diorite from Corsica with amazing green pattern (Photo 26) were also quite proper in

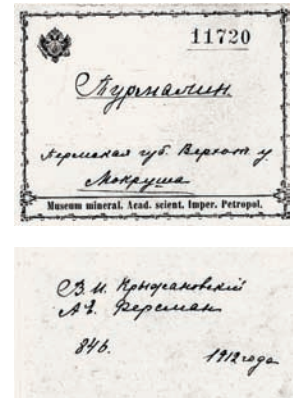
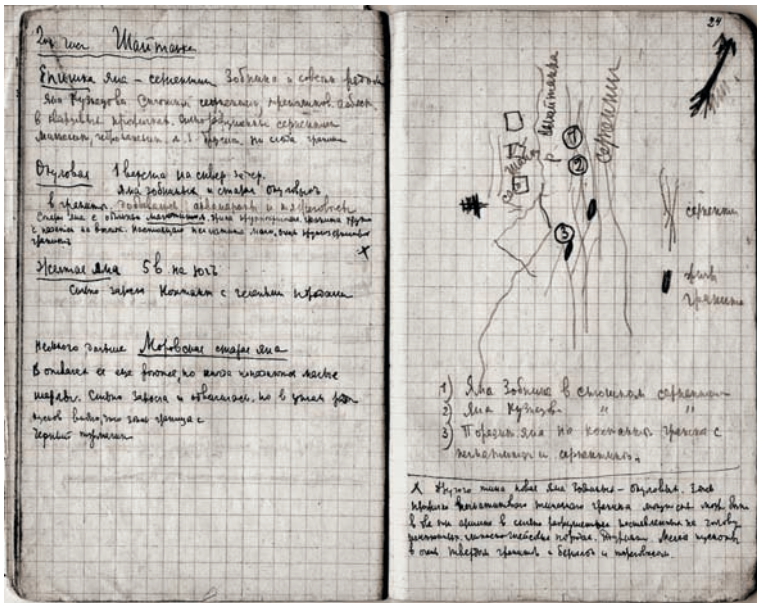


Photo 31. A page from A.E. Fersman's notebook and museum's label of the tourmaline collected by A.E. Fersman and V.I. Kryzhanovsky (right and back sides). Urals, 1912. Photo by the authors.



Photo 32. Different editions of "Amusing Mineralogy".
Photo by the authors.

the showcase "Stone in Human's Service" where they combined with some other minerals of use: Khibiny apatite and eudyalite with nepheline (Photo 27), halite from the Artemovsk Deposit (Ukraine), barite from Tyuya-Muyun (Photo 28), phosphorite from Kamenets-Podol'sky (Ukraine) and magnetite from Kochkanar (Photo 29).

The last showcase was titled, like the book chapter, "**Mineralogist-Amateur**" and included sections "How to collect minerals", "How to identify minerals", "How a mineral collection should be composed and stored". It contained museum labels of various times from the epoch of the Peter the Great Geological Museum of Imperial Academy of Sciences of early 1900s to their contemporary types including ones written with Alexander Evgen'evich Fersman's own hand, his hammer, blowpipe to identify minerals, his log-book and notebook from the Museum archive (Photos 30, 31). Among the specimens there were unusual short-prismatic vesuvianite crystals (Yulia Mine, Khakassia, Siberia, 3–4 cm in size), hematite crystal (Shabry, Middle Urals, 4 cm in size), red with green jasper (Kushkuldinskoye Deposit, South Urals), lilac calcite (Harz, Germany) and perovskite crystals (1–3 cm in size) in valuevite (Yeremeevskaya Pit, South Urals).

The exposition was consummated with "Amusing Mineralogy" different edition (Photo 32) and the two exhibits which photos were in the last chapter of the book. They are the two antipodes: white swan – "Manufactured by the craftsmen of Kungur Region in the Western Urals. Material is massive white, grey or venied gypsum (alabaster) which can be easily processed due to its softness "

(Fersman, 1937, p. 206), and black "Devil of Kasli work in the Urals that decorated automobiles of the first in the Soviet Union scientific motor rally in the Southern Urals in 1935" (ibid, p. 238).

It remains to emphasize that the authors used, to create this exhibition, more than 150 specimens of minerals and decorative stones, more than 50 photographs, drawings, A.E. Fersman's personal items etc.). So, we believe, the described jubilee exhibition for the first time amply demonstrated in stone the contents and basic ideas of academician A.E. Fersman presented in his book "Amusing Mineralogy". This is surely interesting not only for specialists but also to wide range of stone amateurs, students, schoolchildren and other visitors to the Mineralogical Museum.

The authors are thankful to Nina A. Mokhova, Marianna B. Chistyakova, Dar'ya D. Novgorodova, and Oksana L. Sveshnikova for their help in preparation of the exhibition and this article.

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THE REVIEW ON FERSMAN MINERALOGICAL MUSEUM ACQUISITIONS IN 2006–2008

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1337 new mineral specimens were catalogued into main inventory of Fersman Mineralogical Museum RAS in 2006–2008. Those specimens represented by 580 mineral species from 66 countries and from ocean floor and space as well. Among them 200 species are new for Museum collections including 50 species that were discovered during this period. Fifteen of those species were discovered with participation of Museum staff members. Of the species obtained 61 represented by type specimens, cotypes or their fragments. By the end of 2008 the number of valid mineral species in Museum reached 3200. Of the newly acquired items 792 (60%) were donated by 150 persons and by 6 organisations (including about 4.5% obtained as type specimens); 95 specimens (7%) were purchased; 261 (20%) were exchanged and – 157 (about 12%) were collected by Museum staff. Other types of acquisitions are about 1%. A review of new acquisitions classified by mineral species, geography, its types and sources. The list of new species for Museum given in attachment.

2 tables, 18 photos, 1 appendix.

Keywords: mineralogical museum, collection of minerals, new acquisitions, mineral species, type specimen, cotype specimen.

A total of 1337 new specimens were introduced into Museum's inventory between 2006 and 2008 into. The main part – 834 items were catalogued into systematic collection; 240 – into locality collection, 144 – into pseudo-morph collection, 41 – into collection of crystals and 78 became a part of gem collection.

More than 75% of items were both catalogued and acquired during 2006–2008. The rest of them were acquired earlier but were required mineral identification, conservation etc. and since were catalogued during that period.

About 60 % (792) of new items were donated by 150 persons and 6 organizations. Those numbers include also 4,5% specimens provided as type specimens for recently discovered mineral species. Twenty percent (261) of mineral specimens were exchanged with museums and private mineral collectors. Seven percent of new specimens (157) were purchased and about 12% (160) – were collected by Museum staff. Other types of acquisitions were accounted less than 1%. This review only includes the data on items already included into main inventory at indicated period. The specimens that at the end of 2008, had not been completely processed and assigned to the main collections are not included in this review.

New acquisitions classified by mineral species

The mineral specimens catalogued into Museum's main inventory are represented by 580 valid mineral species, 200 of which are new species for Museum (listed in appendix 1). Sixty one of those species are represented by type specimens, cotypes or fragments of type specimens. Fifteen of those species were discovered by Museum staff or in collaboration with Museum staff. Out of about 200 new mineral species approved in 2006–2008 by Commission on New Minerals, Nomenclature and Classification of International Mineralogical Association (CNMNC IMA) Museum was able to acquire 50 species. Thus as of December 31 2008 the number of mineral species at Fersman Mineralogical Museum RAS (counting new and discounting some old species presence of which in collection was not confirmed by scientific study) appeared to be 3200.

Of the 580 recently acquired mineral species the majority (396) are represented by a single specimen. Eighty species represented by 2 specimens. Three to five specimens represent each of 55 mineral species; 33 species represented by 6–10 specimens and 16 – by more the 10 specimens. (Table 1). Two specimens contain a few

Table 1. Mineral species by the number of acquired specimens (for more than 5 specimens)

1. Quartz	95	15. Realgar	10	29. Copper	7
2. Elbaite	26	16. Staurolite	10	30. Forsterite	7
3. Calcite	19	17. Gibbsite	9	31. Chalcopyrite	7
4. Goethite	18	18. Orthoclase	9	32. Wollastonite	6
5. Safflorite	17	19. Baryte	8	33. Gersdorffite	6
6. Skutterudite	17	20. Wulfenite	8	34. Corundum	6
7. Lepidolite	16	21. Hematite	8	35. Lazurite	6
8. Clinocllore	15	22. Kyanite	8	36. Loellingite	6
9. Fluorite	13	23. Magnetite	8	37. Polyolithionite	6
10. Beryl	11	24. Moganite	8	38. Siderite	6
11. Willemite	11	25. Sphalerite	8	39. Fluorapatite	6
12. Gypsum	11	26. Galena	7	40. Spinel	6
13. Zinnwaldite	11	27. Diopside	7	41. Epidote	6
14. Pyrope	10	28. Ilmenite	7		

new species for Museum. The review below given in the order corresponding generally to the Table 1.

Quartz and it's varieties came from 23 different deposits or other locations. A big number of quartz specimens as well as of goethite ones were collected well ago in 1984 by Museum staff (D.V. Abramov, D.A. Romanov, A.B. Nikiforov, T.M. Pavlova) at Tauchik, Mangyshlak Peninsula, West Kazakhstan. Thirty seven specimens were catalogued from that location. They are very diffent by color from colorless to chocolate-brown and red with very contrast color zona-

tion and zonal distributions of **goethite**, hematite and lepidocrocite inclusions. Zonation and inclusions looks very attractive on polished specimens.

Another portion of quartz specimens is from Dashkesan, Azerbaijan. Those are mostly splitted quartz crystals and their intergrowth collected in 2008. Part of them collected by M.M. Moiseev another part donated by A.O. Agafonov. The central parts of crystals have very pale amethyst color. Often crystal intergrowth reminding Japanese twins. The angle very seems to be very close to 90°, however it is impossible to measure



Photo 1. Amethyst druse Size 18 cm. Borosilikatnoe deposit, Dalnegorsk, Primorsky Kray, Russia. Exchange. Cat. No 92728.

Photo 2. Amethyst sceptre. Size 5 cm. Zimmermanovka village, Khabarovskiy Kray, Russia. Purchase. Cat. No OP2422.

Photo N.A. Pekova





Photo 3. Amethyst. «Three head» geode. Height 93 cm. Weight 164 kg. Cristal do Sul, Rio Grande do Sul, Brazil. Donated by D.I. Belakovskiy. Cat. No 92350.

Photo 4. Moganite-chalcedony geode. Size 9 cm. Sierra Madre, Chihuahua, Mexico. Donated by D.I. Belakovskiy. Cat. No OP2397.

Photo N.A. Pekova

it exactly due to crystals splitting. In spite of it is very common case still unclear are they really twins.

Among others it's worth to mention three "heads" amethyst geode from Brazil about 1m tall 164 kg by weight donated by D.I. Belakovskiy (photo 3). We can't say it's a big size for this kind geods but three "head" composition is not too common. Amethyst crystals inside are up to 3 cm and have good dark color.

There were acquired also a few Russian amethyst. One of them is a nice druse of crystals up to 14 cm in size from Borosilikatnoe deposit in Dalnegorsk, Primorsky Krai (photo 1). Another one is a scepter crystal from relatively new location Zimmermanovka in Khabarovsk Krai (photo 2).

Interesting specimen from Ganesh Himal, Nepal – the druse of spindle-like quartz crystals up to 5 cm colored to green by chlorite inclusions was donated by O.A. Lopatkin.

Among quartz varieties represented by different types of chalcedony it's worth to mention big (about 30 cm) attractive lithophyse with agate from Rio Grande do Sul, Brazil donated by

D.V. Abramov and D.A. Ryabukhin. An interesting agate from limestone near Golutvin, Moscow region gifted to Museum by A. Levin. By exchange there were obtained a few big spheres partly hollow inside made out of agate from the same locality. Those were assigned to gem collection along with a few landscape agates from Idzhevan, Armenia. Last ones were donated by A.N. Korobkov and framed by him into a metal to highlight the nature's art. A set of caboshons from mols agate from Pstan in Kazakhstan was also catalogued into gem collection. Very morphologically attractive are the **moganite** containing chalcedony secretions from rhyolites of Sierra Madre, Chihuahua, Mexico (photo 4). They amplify the diversity of similar material earlier obtained by Museum from Mongolia and from New Mexico, USA.

The most and more interesting part of **elbaite** specimens (15 out of 26) represented by polished cross sections of zonal and sectorial elbaite crystals from Malkhan Range, Transbaikal, Russia (photo 5 and 6). Bright-pink splitted elbaite crystals in association with amazonite from new spots at Minh Tien mine, Luc Yen, Vietnam donated

Photo 5. Elbaite. Polished cross sections of zonal crystals. Size 3–5 cm. Malkhan Range, Transbaikal, Russia. Purshase. Cat. No OP2406 – 2416; OP 2419 – 2421. Purshase.

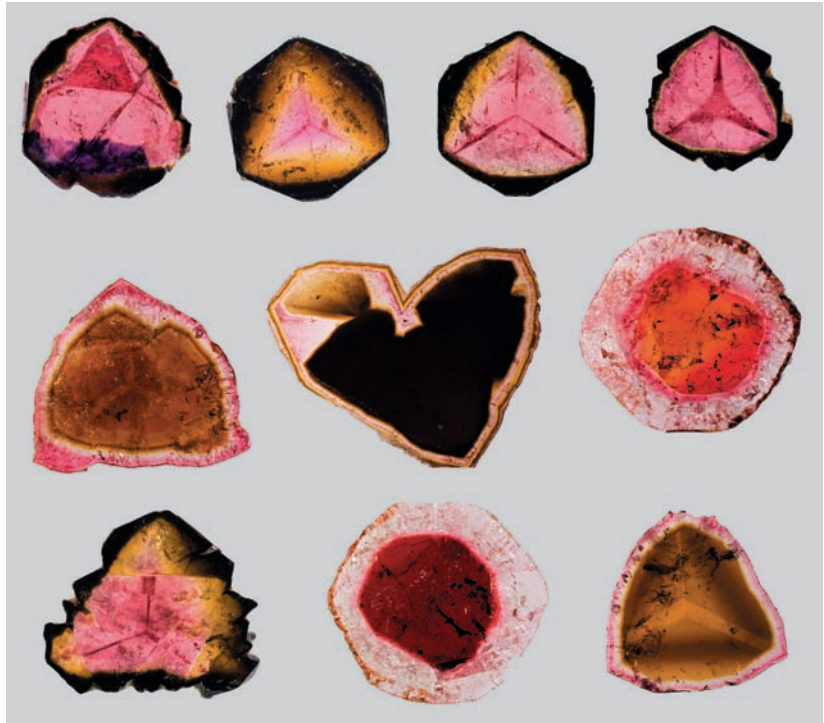


Photo N.A. Pekova

by J.E. Patterson. Pale-pink elbaite from Wama, Pech valley, Nuristan, Afganistan and zonal double terminated floaters from Stak Nala, Afganistan donated by F. Wafi and D.I. Belakovskiy.

Out of 19 **calcite** specimens acquired about one half collected at above mentioned locality at Mangyshlak Peninsula. Those are spherulites and spherulites crusts very interesting by it's morphology. A few calcite twins came from Dashkesan, Azerbaijan. Rather attractive are scalenohedra calcite crystals inside Mercenaria Dermagna shell from Fort Drum, Florida, US (photo 7).

Significant number of new **safflorite**, **skuterudite** as well as **gersdorffite** and **loellingite**

specimens related to extensive collection characterizing mineralogy of Co deposits donated by R.A. Vinogradova. This collection mostly represents Bou Azzer ore field in Morocco but also includes material from Khovu-Aksy deposit in Tuva, from a number of Co deposits in Czech Republic and Slovakia and from some other deposit. The collection accompanied with analytical information on donated minerals and geological data on those deposits and has a significant scientific value.

Lepidolite and **zinnwaldite** (16 and 11 specimens accordingly) are part of collection of mica group minerals donated by T.N. Shuriga. This collection also includes **polyolithionite** and **protolithionite** from different deposits. All speci-

Photo 6. Elbaite. Polished cross sections of zonal and sectorial crystals. Size 4 cm. Malkhan Range, Transbaikal, Russia. Purshase. Cat. No OP2417 and OP2418.



mens of that collection came with detail data on it's composition, polytypes, physical properties. This is a main value of that collection.

The new and very attractive stuff came in the end of 2008 from Korshunovskoe deposit near town Zheleznogorsk, Irkutskaya Oblast', Siberia, Russia. This is complete cross sections of **clinocllore** pseudostalactites and groups of 2, 3 or even 5 pseudostalactites. With a small hollow channels in their centers (photo 8). On a current moment this is probably the best by quality and size material that kind ever mined from that deposit for about 45 years of it's exploration. Specimens are obtained as gift of D.I. Belakovskiy.

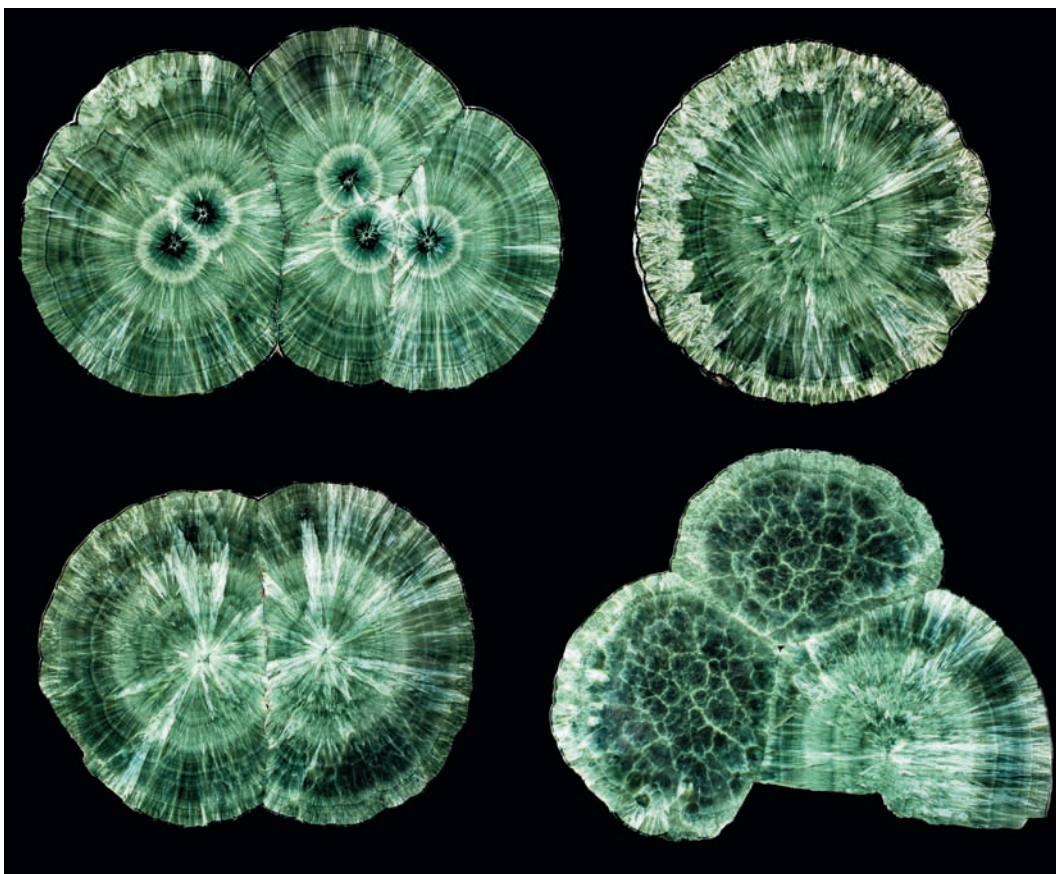
Among **fluorite** specimens (13) most attractive are druses of transparent green cubic crystals and also druse of green fluorite octahedrons with purple coloration near it's edges from



Photo 7. Calcite. Druse inside the shell of Mercenaria Dermagna. Size 9 cm, Ruck's pit, Tamiami formation, Florida, USA. Exchange. Cat. No OP2339.

Photo N.A. Pekova.

Photo 8. Clinocllore. Pseudostalactite's polished cross sections.. Korshunovsky mine near Zheleznogorsk, Angaro-Ilimsky region, Irkutskaya oblast', Siberia, Russia. Donated by D.I. Belakovskiy. Upper left – size 25 cm. Cat. No OP 2475; Upper right – size 15 cm. Cat. No 92736; Bottom left – size 18 cm. Cat. No OP 2473. Bottom right – size 19 cm. Cat. No OP2471.



Shangrao, Jiangxi Province, China. Another decent specimen is unusually blue fluorite spherulite fragment from Dongjiang, Inner Mongolia, China. It's also worth to mention blue zonal cubic fluorite crystals with sphalerite and barite from Elmwood, Smith Co., Tennessee, USA.

Out of 11 catalogued **beryl** specimens decent are prismatic aquamarine about 10 cm in size from Shigar Valley, Pakistan; greenish-yellow partly transparent crystals with very noticeable channels from Kalba Range in East Kazakhstan obtained from V.L. Barsukov through E.L. Sokolova. Besides that a few faceted stones – two aquamarine and one heliodor from Thach Khoan, Vietnam, were donated by J.E. Patterson and directed to gem collection.

As well as a beryl **willemite**, **gypsum** and **zinnwaldite** (see above) obtained by 11 specimens of each. All **willemite** samples came from Sterling Hill Mine, New Jersey, USA. Those and some **wollastonite** specimens from the same location appeared to be a good addition for Museum fluorescent exhibit. Among gypsum specimens recognized are classical "desert rose" from Algeria donated by M. Monzer and fragments of giant transparent crystals with sulphur crystals inclusions from Debar deposit in Macedonia collected by Museum staff in 2007.

All new **pyrope** specimens are from different kimberlite pipes of Yakutia and Arkhangelskaya Oblast', Russia. The biggest are bright red grains up to 3 cm associated with peridot and Cr-diopside. Some specimens are polished plates thin enough to see translucence of those minerals. Those obtained to improve exposition "Minerals of upper mantle". Exemplars of **forsterite**,

ilmenite, **diopside** donated by A.I. Ponomarenko and E.M. Verichev for the same reason and from the same localities.

Massive red aggregates of **realgar** which are hardly recognizable from cinnabar by color were collected by Museum staff from landslide outcrop near Alchar deposit in Macedonia in 2007. The druse of columnar bright red realgar crystals from new location at Baya Sprie, Romania was donated by V. Breckler. None of 10 catalogued staurolites this time came from traditional Museum **staurolite** source at Semiostroviye, Keyvy. V.V. Levitsky donated a few selfcollected specimens from other (new) locations in Keyvy, Kola Peninsula and from Hit-ostrov, Karelia. N. Gospodinov gifted nice typical X-cross twin from muscovite shists near Topolovgrad, Bulgaria. A series of penetrating twins by (031) and (231) (so called X-crosses and right crosses accordingly) from Taos vicinities in New Mexico, USA were exchanged.

The preparation Museum exhibit on hypogenes processes had required obtaining of **gibbsite** specimens. A.D. Slukin and B.A. Bogatyrev provided those from different deposits in Russia, Kazakhstan, India.

New **orthoclase** acquisitions are represented by "noble" amazonite from Minh Tien mine, Luc Yen, Yenbai, Vietnam. There are a few big pieces with amazonite crystals with transparent zones and saturated green color amazonite cabochons and faceted stones donated by J.E. Patterson. Such color and transparency of those stones are rather unusual and could easily get someone confused. From the same locality and source a few specimens with bright red octahedral of **spinel** in marble were obtained.

The new intergrowth of flat nearly colorless **barite** crystals came from Cerro Waihuyn Miraflores, Peru. Most attractive among **wulfenite** specimens are a few from old classic Red Cloud mine, La Paz Co., Arizona, USA with orange-red platy crystals up to 2 cm (photo 9).

A new portion of very attractive **hematite** pseudomorphs after magnetite crystals up to 8 cm from Payun Matru Volcano, Mendoza, Argentine donated by D.I. Belakovskiy were a good addition to previously obtained and show the diversity of hopper crystals. It's good to know finally more exact location for that material which was a secret some time ago.

Kyanite specimens were collected by Museum staff in Kovdor, Kola Peninsula, Russia

Photo 9. Wulfenite. Platy crystal 2 cm in size. Red Cloud mine, Trigo Mts., La Paz Co., Arizona, USA. Exchange. Fragment of specimens. Cat. No 92712. Photo N.A. Pekova.





Photo 10. Corundum. Spindle-like crystal. Size 11 cm. Gwinea. Donated by A.V. Surkov. Cat. No 92288.

Photo 11. Galena with sphalerite. Size 14 cm. Osikovo, Madan, East Rhodopes, Bulgaria. Purchase. Cat. No 92564.

Photo N.A. Pekova.

(M.M. Moiseev) and near Prilep city in Macedonia (N.A. Mokhova, S.N. Nenashveva)

The druses of **magnetite** rhombododecahedrons crystals up to 2 cm in size belongs to above mentioned acquisitions from Dashkesan, Azerbaijan as well as tetrahedrons of **chalcopyrite** up to 4 cm covered with dark blue films of covellite and druses of splitted epidote. Most part of that portion donated by A.O. Agafonov.

The large specimen with **sphalerite** crystals up to 6 cm edged by combination of two tetrahedral from Dalnegorsk was donated by B.Z. Kantor. An interesting sphalerite from Pierrepont, St. Lawrence Co., New York, USA with very bright orange fluorescence both in long and short diapazones of UV waves was obtained as a gift of geologist William deLorraine. An attractive blocky crystals of sphalerite associated with zonal fluorite from Elmwood, Smith Co., Tennessee, USA were exchanged.

There are two nice druses among **galena** from Bulgaria. One – contains flattened by [100] crystals up to 5 cm with cross-like intergrowth from Osikovo, Madan, Estern Rhodopes (photo 11). Another one with penetrated crystals twined by (111) from Angel Yanakiev mine,

Rhodopes. An interesting specimen with galena overgrowing pyrrhotite crystal from Nikolaevsky mine, Dalnegorsk, Far East of Russia was donated by V.V. Ponomarenko.

Two **corundum** specimens are more remarkable among six obtained: greyish-blue crystal more than 9 cm in size from Cape Budun, Olkhon Island, Lake Baikal, Russia (gift of I.A. Tkacheko) and spindle shape crystal of red corundum about 11 cm long (photo 10) from Gwinea donated by A.V. Surkov.

Bright blue and rather big for Malo-Bystyrinskoe deposit (near Lake Baikal, Russia) **lazu-rite** crystals were donated by V.V. Tkachenko.

The most unusual **siderite** acquisitions represented by new material from Nikolaevsky mine, Dalnegorsk, Russia. Those are represented by spheroidal or egg shape aggregates empty inside associated with calcite and pyrite (donated by V.V. Ponomarenko). The genesis of this kind shape remains unclear so far.

At the end of that review part we have to mention a beautiful faceted yellow-green fluoapatite of triangle shape with triangle side about 2 cm. This was faceted for Museum by A.N. Timofeev out of a glass looking splitter found during sorting of an old training material.

Table 2. New acquisitions by countries of the world

1. Russia	457	24. China	12	47. Georgia	2
2. USA	120	25. Brazil	11	48. Denmark	2
3. Kazakhstan	112	26. Sierra-Leone	10	49. Israel	2
4. Morocco	58	27. Austria	9	50. Cape Verde	2
5. Germany	29	28. Slovakia	9	51. Madagascar	2
6. Sweden	29	29. Australia	7	52. Peru	2
7. Japan	29	30. Kyrgyzstan	7	53. Portugal	2
8. Azerbaijan	28	31. Namibia	7	54. France	2
9. Tajikistan	28	32. Argentine	6	55. Algeria	1
10. Finland	26	33. Afganistan	6	56. Hugary	1
11. Macedonia	25	34. Bolivia	6	57. Dominican Rep.	1
12. Italy	24	35. Chile	6	58. Libya	1
13. Great Britain	23	36. Greece	5	59. Malawi	1
14. Rep. South Africa	23	37. Congo DR	5	60. Nepal	1
15. Bulgaria	20	38. Belgium	4	61. Nigeria	1
16. Mexico	20	39. Egypt	4	62. Poland	1
17. Vietnam	17	40. Spain	4	63. Romania	1
18. India	15	41. Mali	4	64. Turkmenistan	1
19. Canada	15	42. Myanmar	4	65. Switzerland	1
20. Ukraine	15	43. Armenia	3	66. Ethiopia	1
21. Norway	13	44. Belarus	3		
22. Czech Republic	13	45. Tanzania	3		
23. Pakistan	13	46. Gwinea	2		

Seven specimens came from the bottom of Atlantic, Pacific, Indian and Arctic oceans; two specimen from Space; seven – are synthetic materials and for three specimens locality unknown.

Unfortunately there were no data on locality of that piece.

New acquisitions classified by geography

Obtained mineral specimens originated from 66 countries of the world, ocean's bottom, space, human laboratories (Table. 2).

Russia

Kola Peninsula. As usual most of Russian recent acquisitions are from that area. This time 108 specimens (78 mineral species) added. By the main Kola Peninsula objects it's distributed this way: **Khibiny massif** – 48 (33), **Lovozero massif** – 27 (23), **Kovdor** – 12 (10), **Keyvy** – 12 (8).

The most scientifically valuable acquisitions from **Khibiny massif** are type specimens (or their parts) of ten discovered here new mineral species (middendorfite, fluorcalciobriholite, tsepinite-Na, labyrinthite, wilhelmramsayite, georgbarsanovite, nechelyustovite, andrianovite, armbrusterite, podlesnoite), and also other speci-

mens of newly discovered species – ivanyukite-Na and ivanyukite-K. Besides that the diversity of minerals from Khibiny amplified with lucasite-(Ce), orickite, chlorbartonite. We have to mention new finds of megacyclite and kostylevite (in crystals) much better by quality compare to ealier found stuff and also cuboctahedral crystal of villiaumite about 1 cm in size from Koashva mine. A few items curved out astrophyllite and again villiaumite were good enough to add it to gem collection. The most part of specimens from Khibiny donated by I.V. Pekov and A.P. Khomyakov.

Among type specimens – there are six recently discovered from **Lovozero massif** – chesnokovite, dualite, pautovite, gjerdingenite-Ca, caryochroite. Species diversity was supplemented with punkaruavite, adamsite-(Y), gobbinsite, bykovaite, eirikite. Specimens were donated by I.V. Pekov, A.P. Khomyakov, V.G. Grishin, P.M. Kartashov, V.V. Levitsky. Petko M. Petrov and Mikhail N. Maleev – colleagues from Bulgarian National Museum "Earth and Men" (Sofia) donated to the Museum manganbelyankinite that they found during

expedition to Kola Peninsula deposits in 2008. Surprisingly it turned out to be the new mineral species for the Museum. Also, number of specimens supplemented species diversity of Palitra pegmatite, Lovozero massif.

Three new mineral species from **Kovdor** were catalogued. These are: golyshkevite, mogovidite and phosphoinnelite. Karchevskiyite type specimen was received from the author, S.N. Britvin. The other grantors are I.V. Pekov and N.V. Chukanov.

Amongst the acquisitions from **Keyvy** it is worthwhile to mention spectacular intergrowth of three crystals of almandine; the biggest one of which is approximately 12 cm across (Makzabak). Another almandine crystals combination from Takhlintuiv Mt. was donated by B.B. Shkursky. The most interesting among the new found material are massive coarse-grained tveitite-(Y) and staurolite from new localities, mentioned above.

Karelia (14 specimens, 14 mineral species). Among them there is one type specimen – malyshevite from Srednyaya Padma deposit. The majority of other specimens represent mineral associations of Vuorijarvi massif.

From European part of Russia south of Karelia and west of Ural foothills also 14 specimens obtained. Those represented by 7 species among which three are newly described. Chukanovite and droninoite are terrestrial minerals but were formed by weathering of Dronino meteorite found in Kasimov region. Third one is lakargiite from Lakargi Mt., Kabardino-Balkaria, North Caucasus. The recently “rehabilitated” species calico-olivine also came from that locality. The grantors are: A.E. Zadov, E.V. Galuskin, I. Galuskina, V.Gazeev, N.N. Pertsev.

Ural: There are 50 specimens (40 species) are obtained from Ural Mts. The most attractive is probably the one with long subparallel golden millerite needles in calcite from Saranovskoe deposit. Very good (probably best of species) specimen of polyakovite-(Ce) from Ilmeny, South Ural donated by S.V. Kolisnichenko. Prismatic colorless euclase crystal about 3 cm in size was first from Emerald mines. Euclase was found at that location recently. Two type specimens were catalogued: fluorellestadite and potassic-ferri-magnesioidanagaite. A series of PGM rare minerals – rhodarsenide, palladodymite, polkanovite were donated by S.N. Britvin. Those are grains a several dozen of

micromerers in size in epoxy microprobe mounts. They came with an analytical data and images in backscattered electrons. Delafossite from Uchaly deposit (South Ural), vernadite and other manganese containing minerals were catalogued after processing and study of working materials collected by P.F. Andrushchenko and A.T. Suslov. It's worth to mention yellow platy stolzite crystal about 0.5 cm from Pelengichey 2 near Zhelannoe deposit (North Ural) granted by M.M. Moiseev and thortveitite inclusions in quartz from Astafievskoe deposit (South Ural).

The most interesting acquisitions from **Altay Mts.** (6) are outstanding dendritic aggregates of native copper crystals which individuals are up to 1.5 cm across. This is new material recently found at Rubtsovskoe deposit, near Rubtsovsk town (Photo 12).

Krasnoyarsky kray (11 specimens, 9 mineral species). One of the new mineral species is ferroskutterudite, found in Komsomolsky mine in Norilsk ore-field. Dendritic löllingite aggregates and okenite spherulites from the same locality

Photo 12. Copper. Dendrite. Size 7 cm. Rubtsovskoe deposit near Rubtsovsk, Altay Mts., Russia. Exchange. Cat. No 92732. Photo N.A. Pekova



were donated by E.M. Spiridonov. Rather good octahedral pyrochlore crystal 7 cm in size from Tatarka river, Eniseysky Ridge, was purchased in 2007 at the auction held in Colorado Mining School (Golden, Colorado, USA).

Baikal, Transbaikal regions and Irkutskaya oblast'. These regions supplied 107 specimens (35 mineral species) altogether. Catalogued type specimens are batisivite, dovyrenite and tounkite. Interesting material arrived from deposits near Zheleznogorsk town, Angaro-Ilimsky, Irkutskaya region. Besides above mentioned various clinochlore from Korshunovskoe deposit there are giant (up to 9 cm) splitted white hydrotalcite crystals from Rudnogorskoe deposit. Materials from Yoko-Dovyrensky massif donated by A.E. Zadov and N.N. Pertsev, were supplemented, apart of dovyrenite, with jennite, suolunite and plombierite. Specimens with manganbingtonite crystals from Krasnokamensk group of skarn deposits of Eastern Sayan Mts. were donated by R.A. Vinogradova. Good quality eudidymite and helvite specimens from Ermakovskoe deposit were donated by I.I. Kupriyanova and E.P. Shpanov. Significant number of specimens from lithium-mica collection studied, originate from Vishnyakovskoe and Alexandrovskoe deposits, between Tagul and Biryusa rivers, Eastern Sayan Mts. and from Orlovskoe deposit, Transbaikal. The zonal cross-sections of elbaite crystals from Malkhan and lazurite from Malobystrinskoe deposit were mentioned above.

Photo 13. Hedenbergite-wollastonite skarn. Borosilikatnoe deposit, Dalnegorsk, Primorsky Krai, Russia. Polished plate. Size 25 cm. Exchange. Cat. No PDK8081. Photo N.A. Pekova.



The greatest part of 11 arrived specimens from **Tuva** are represented by skutterudite, safflorite and nickeline from Khovu-Aksy deposit, donated by Raisa A. Vinogradova; also type specimens of karasugite were catalogued.

The largest part of acquisitions from **Yakutia** (55 specimens, 29 mineral species) is represented by kimberlite minerals. Apart of rock-forming and accessory minerals these are moissanite, rutile, djerfisherite, rasvumite, nyerereite, troilite, kyanite. Type specimens from Yakutia are the following: hydroxylborite, aqualite, mangazeite, rudenkoite. Another rare minerals such as pertsevite from Snezhnoe deposit, aluminomagnesiophulsite (Tas-Khayakhtakh Ridge, Verkhoynye), allabogdanite from Onello meteorite and miassite from Aldan river placers, also should be mentioned.

Khabarovsk Krai (9 specimens, 4 mineral species). Two isoferroplatinum cubic crystals from Konder massif were obtained. One of them, 0.5 cm across, is a fluorite type twin naturally decorated with gold. There was no such a material in the Museum before, although many foreign museums own it. A sceptre shape amethyst from Zimmermanovka was mentioned above.

The most part of 22 specimens (12 mineral species) from **Primorsky Krai** is from Dalnegorsk town area deposits. Besides amethyst druse, sphalerite and siderite aggregates discussed earlier, one of the noticeable specimens is native arsenic nodule fragment, up to 11 cm across from Borosilikatnoe deposit open pit, donated by Yuri Pustov. Polished "scenery" hedenbergite-wollastonite skarn plate was recorded to the collection of gems (photo 13). Bournonite crystal from 2nd Sovetsky mine was donated by V.N. Kalachev. Minerals from other areas within Primorsky Krai to be mentioned are: kimuraite-(Y), lantanite-(Nd) from Abramovskoe, donated by V.V. Seredin.

Chukotka (9 specimens, 4 mineral species). The most interesting new for the Museum mineral haxonite, detected in Egvekinot meteorite and donated by S.N. Britvin.

Kamchatka and Kuril Islands (23 specimens, 18 mineral species). Besides uncommonly terminated pyrite and molybdenite crystals from Lastochka deposit, the upper reaches of Ayanka river (donated by I.M. Mertsalov), all other specimens originate from Tolbachik, Mutnovsky (Kamchatka) and Kudryavy (Iturup Island) volcanic fumarolic sublimates.

Amongst them there are type specimen of abramovite and recently discovered tazieffite (named after well-known volcanologist) A series of rare minerals from Tolbachik volcano: urusovite, leningradite, atlasovite, georgbokiite etc. — were donated by well-known volcanist and mineralogist L.P. Vergasova. The new found of kudriavite from Mutnovsky volcano, donated by G.P. Ponomarev is more impressive and presentable than that from the type-locality at Kudryavy volcano.

It is significant to mention an individual remarkable donation made by O.I. Kotlyar. This is a large fragment of Seymchan meteorite cut from one side, over 400 kg and approximately 90 x 55 x 33 cm in size (photo. 14). The change from iron octahedrite to pallasite is clearly visible on the cut surface, as well as elongated schreibersite crystals. This meteorite fragment was found during recent expeditions near Seymchan, Magadan region and is extremely valuable donation to the Museum.

CIS (former USSR republics)

Kazakhstan (112). The overwhelming number of acquisitions from this country are previously mentioned minerals collected near Tauchik, Mangyshlak; and also landscape moss agates from Pstan. Amongst rare minerals there are chistyakovaite and uramarsite type specimen, and recently discovered new mineral phosphohedyphane, found in old specimens from Ken-Choku.

Azerbaijan (28). Almost all the acquisitions were received from collecting trip held in 2008 to Dashkesan iron-ore deposit (described earlier), except rare mineral species niningerite, rudashevskiiite and schoellhornite found in Indarkh meteorite fell near Shusha village in 1891 (S.N. Britvin donation).

Tajikistan (28). Amongst new 'arrivals' there are type specimens of new minerals from Darai-Pioz massif: zeravshanite, pekovite, senkevichite, sokolovaite, faizievite and nalivkinite discovered by Museum researchers L.A. Pautov, A.A. Agakhanov, V.Yu. Karpenko and also zirsilite-(Ce) and carbokentbrooksite donated by A.P. Khomyakov. Besides, the specimens earlier collected from Tro canyon, Zeravshan Range were catalogued.

Ukraine (15). The most interesting specimens with black tabular groutite crystals up to



Photo 14. Seymchan meteorite (fragment). Size 90 cm. Weight > 400kg. Donated by O.I. Kotlyar. Photo N.A. Pekova.

1 cm in size and also cubic magnetite crystals from Zavalyevsky graphite deposit, Kirovogradskaya oblast'. These were collected and donated by I.V. Pekov and V.V. Levitsky.

Kyrgyzstan (7). The new found of nevadaite from Hodzha Rushnoy mazar locality, Batkenskaya oblast', was determined and donated by V.Yu. Karpenko.

Armenia (3). The whole lot is landscape moss agates from Idjevan donated by A.N. Korobkov and mentioned above.

Belarus (3): chromite, merrillite and stanfieldite from Bragin meteorite donated by S.N. Britvin and M.M. Moiseev.

Both specimens from **Georgia** are represented with braunite together with other manganese oxides from Chiatura deposit. The only specimen from **Turkmenistan** is a sphere made of calcite onyx from one of Karlyuk caves and catalogued into gemstone collection.

Other countries

The **USA** ranks next to Russia in the total number of mineral specimen acquisitions (120 specimens, of which 87 are separate mineral species from 24 states); specimens are predominantly from New Jersey (21), California (17) and Arizona (14). Specimens of wulfenite, fluorite, sphalerite, staurolite and willemite from the USA were already mentioned before in this paper. The greater part of these acquisitions is represented by rare mineral species – mostly pegmatitic phosphates from different states. The most significant are type specimen of ferromerrillite from Los Angeles meteorite discovered by S.N. Britvin, and fragment of a type specimen of samarskite-(Yb) donated by M. Origlieri.

Morocco (58). All the acquisitions are from Bou-Azzer ore-mining region and belong to the above mentioned collection donated by R.A. Vinogradova.

The museum received 29 specimens from each **Germany, Sweden and Japan**. Mainly they are rare minerals many of which are new for the Museum. Among them there is britvinite type specimen, discovered by Russians from Longban deposit in Sweden.

The most interesting among the new acquisitions from **Finland** (26) are tochilinite and haapalaite crystals from Otamo mine, Siikainen, donated by P. Paananen, series of specimen from Vitaniemi ore-field (vayrynenite, lithiophilite, purpurite etc.) collected by M.S. Alferova. Specimens from Parainen (Pargas) deposit, donated by N.V. Chukanov, contain recently discovered fluorphlogopite and fluoro-edenite.

Specimens of realgar, gypsum and kyanite from **Macedonia** (25) were already mentioned in the mineral species section of this review. Half of **Italian** specimens (24) are represented by new for the Museum mineral species, including alloriite and biachellaite. A series of the high-quality specimens of zeolites, some of which are new for the Museum, from Isle of Sky and mullite from type-locality on Isle of Mull, both – Scotland, **UK** were collected and donated by M.S. Alferova. The majority of acquisitions from **Republic of South Africa** are gold-bearing conglomerates from West Driffontein Gold Mine, Witwatersrand, donated by M.I. Novgorodova. Amongst mineral specimens from **Bulgaria** (20) it is worth to mention new mineral species of manganilvaite (type specimen) donated by the

author – Iv. Bonev, neotocite and rhodochrosite from Obrochische region, and galena hopper crystal intergrowth from Krushev Dol, Madan, Rhodopes donated by National Museum “Earth and Men” in Sofia. Specimens from **Mexico** (20) besides the above mentioned moganite specimens are represented by pinkish danburite crystals and druse from Charcas mine, San Luis Potosi, big (11 cm across) rhombododecahedron of grossular from Sierra de Las Cruces. The most exciting acquisitions from **Vietnam** (17) – are elbaite, aquamarine, ‘gem-quality’ amazonite, spinel – all were described above.

Among specimens from **India** (15) there are several large spectacular pieces of apophyllite, stilbite and scolecite. **Canada** (15) is represented with specimens of meyonite from Greenville, Quebec, showing bright fluorescence and number of rare minerals including two type specimens of gjerdingenite-Na and niveolanite discovered by I.V. Pekov. **Norway** and **Czech Republic** supplied 13 specimens each. These are mostly new mineral species for the Museum. The finest acquisitions from **Pakistan** (11) include orange-brown translucent columnar bastnäsite-(Ce) crystal approximately 3.5 cm long from Warsak (Wanna); tabular brookite crystals from Kharan, Balochistan; forsterite crystal intergrowths from Suppat area, Manshera; group of transparent pale-brown topaz crystals on albite (clevelandite) from Shigar Valley (donated by A. Ivonin) and schörl crystals overgrown by clevelandite, from the same locality (donated by F. Wafi). The most interesting specimen from **China** (12) is high quality specimen of a recently discovered ottensite, Qinglong, Guizhou Province. Fluorite druses, amethyst geode and agate from Brazil (11) were mentioned above; also the following **Brazilian** specimens were donated or exchanged: uvite crystal on quartz from Brumado (A. Ivonin), massive coarse-grained rhodonite from Conselheiro Lafaiete, Minas Gerais (D.I. Belakovskiy) and recently discovered menezesite.

From other countries first of all should be mentioned tetragontrioctahedral spessartine crystals from Engusero Sambu mine close to Loliondo town, **Tanzania** (photo 15). One of the spessartine crystals was donated by L.V. Olysyh. This is new material start coming to the market in the late 2007. The opal pseudomorph after belemnite from Cober Pedy, **Australia**

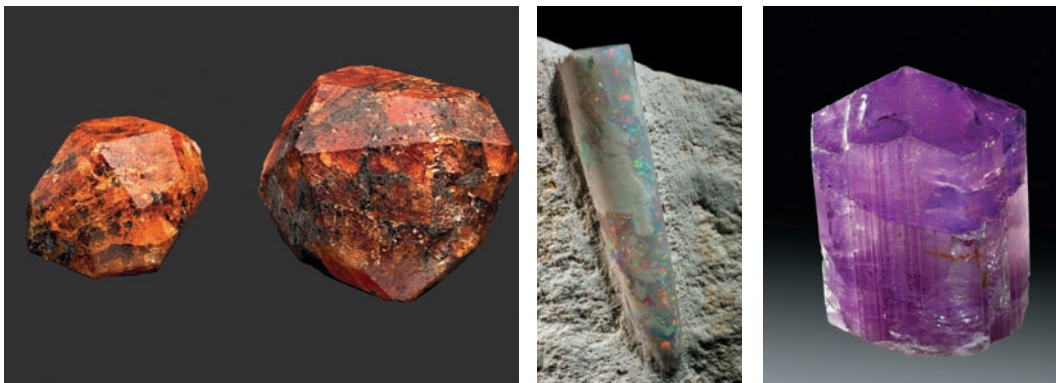


Photo 15. Spessartite. Tetragon-threeoctahedral crystals with black inclusions of manganese oxides and with mica inclusions. Engusero Sambu village, 35 km north-east of town Loliondo, Tanzania. On the left – size 4 cm. Cat. No 92529, Donated by L.V. Olysysh. On the right – size 6 cm. Cat. No 92573. Purchase.

Photo 16. Noble opal. Pseudomorph after belemnite. Size 4 cm, Cober Pedy, Australia. Cat. No OP 2451. Exchange.

Photo 17. Marialite. Prismatic crystal 3.5 cm in size. Badakhshan, Afganistan. Donated by D.I. Belakovskiy. Cat. No 92395.

Photo N.A. Pekova

Photo 18. Synthetic quartz. Broken natural quartz druze regenerated with synthetic quartz in an autoclave. Crystal termination colored blue by cobalt. Size 19 cm. Grown in Alexandrov city (VNIISIMS), Purchase. Cat. No K4973.



(photo 16) catalogued into pseudomorph collection. Relatively small but intensively coloured marialite crystal from **Afghanistan** (photo 17) is very similar to those from Kukurt river valley, Eastern Pamir, Tajikistan. Andradite crystals intergrowth, vesuvianite crystal along with the new specimens of prehnite and epidote have been arrived from Kayes region, Mali.

The most geographically exotic acquisition was donated by A.A. Laiba. It is seabed ground collected in Arctic Ocean, near the Northern Pole on the 1st of August 2007 by scientific expedition "Academician Fedorov" survey vessel. According to the X-ray data it consists of chlorite-quartz-mica aggregate.

Synthetic blue quartz druse coloured by cobalt compounds, from Alexandrov synthetic materials plant (VNIISIMS) is the most interesting among all the artificial materials obtained (photo 18).

New acquisitions by it's type and source

The bigger part of new acquisitions – 60 % donated to Museum by 150 persons and 6 organizations. Among contributors – 132 are Russian citizens and 18 are citizens of nine other countries. Fersman Mineralogical Museum RAS very grateful to all contributors.

The most active donator for indicated period was again I.V. Pekov who contributed 109 specimens mainly from Khibiny and Lovozero massifs, Kola, Russia and from some foreign deposits. Among donated items – 12 type specimens of new mineral species. A big collection (82 specimens), mostly from Bou Azzer, Morocco gifted by R.A. Vinogradova. D.I. Belakovskiy donated 62 specimens. 35 items contributed by T.N. Shuriga. Valuable specimens donated by N.V. Chukanov (24), S.N. Britvin (23), A.I. Ponomarenko (22), J.E. Patterson (22), V.V. Levitsky (20), M.I. Novgorodova (17), A.L. Kidwell (17), P.F. Andrushchenko (16), A.V. Kasatkin (16), A.O. Agafonov (15), E.M. Spiridonov (15), A.P. Khomyakov, N.P. Suslov (12), D.A. Romanov (11), I.V. Banhchikova (10), G.A. Pelymsky (10).

Five or more specimens donated by A.A. Agakhanov, M.S. Alferova, B.A. Bogatyrev, I.V. Chaplygin, K. Erler, V.G. Grishin, E.P. Gurov, V.Yu. Karpenko, M.M. Moiseev, L.A. Pautov, N.N. Pertsev, V.V. Ponomarenko, G.P. Ponomarev, L.S. Skobel, A.D. Slukin, L.P. Vergasova, E.M. Verichev, A.V. Voloshin, A.E. Zadov.

Up to 5 specimens donated by A.M. Abdrakhimov, D.V. Abramov, S.V. Afanasiev, G.V. Agapova, P.V. Bantsekov, V.L. Barsukov, N.B. Belenkov, V.E. Beltenev, S.I. Belykh, N. Bondarenko, Iv. Bonev, E.A. Borisova, L.V. Borisova, V. Brekler, V.G. Bubennikov, G.I. Bubennikova, F. Chalidze, A.A. Chernikov, B.V. Chesnokov, D.V. Davydov, W. De Lorrain, L.V. Dmitriev, Zh.V. Dombrovskaya, M.D. Dorfman, Yu.M. Dymkov, R.D. Dzhenchuraeva, A. Firer, G.N. Gamyani, V.M. Gazeev, A.A. Godovikov, E.V. Golubovskaya, S.S. Gorokhov, A.S. Gorshkov, N. Gospodinov, Yu.D. Gritsenko, S.V. Gritsuk, W. Heller, A. Ivanov, O.K. Ivanov, V.G. Ivanov, A. Ivonin, V.N. Kalachev, B.Z. Kantor, P.M. Kartashev, V.I. Kazansky, A. Klevtsov, K.K. Klopotov, A. Klyuchkin, Yu.S. Kobayashov, S.V. Kolisnichenko, A.E. Kolomentsev, A.A. Konev, V.G. Korinevsky, A.N. Korobkov, T. Korson, O.I. Kotlyar, Yu. Kovach, I. Kovalenko, I.I. Kupriyanova, A.A. Laiba, S.A. Lazurenkov, A. Levin, V.N. Levin, R. Liferovich, O.A. Lopatkin, A.O. Mazarovich, I.M. Mertsalov, K. Moisyuk, M. Monzer, N.N. Mozgova, A.B. Nikiforov, L.V. Olysyh, M. Origlieri, P. Paanen, W. Paar, W. Pinch, A.S. Podlesnyi,

Yu.K. Pustov, L.Z. Reznitsky, G.V. Rile, O.M. Rosen, V.V. Rudnev, D.A. Ryabukhin, T.V. Ryleeva, N. Saakyan, R. Saakyan, D.A. Sadilenko, A.N. Sapozhnikov, E.I. Semenov, V.V. Seredin, L.I. Shabynin, V.V. Sharygin, B.B. Shkursky, E.P. Shpanov, G.A. Sidorenko, S.F. Sobolev, E.L. Sokolova, A.V. Surkov, P.P. Tarasov, I.A. Tkachenko, V.V. Tkachenko, D.E. Tonkacheev, A.G. Turchkova, N.G. Udovkina, B.I. Vaintrub, S. Vasil'ev, B.M. Vladimirov, F. Wafi, T. Weidner, M.A. Yudovskaya and G.B. Zhilinsky.

Among organizations nine specimens were contributed by Museum "Earth and Men", Sofia, Bulgaria; Museum of Irkutsk Polytechnical institute, Russia; Museum of Moscow Oblast' pedagogical university, Russia; Academy of Sciences, Sofia, Bulgaria; Polar Urals geologyprospectical expeditions and group of companies "Stone Flower".

Of 157 specimens catalogued in 2006–2008 which were collected by Museum staff more than one half (93) were actually collected before indicated period. It mostly related to expeditions of the end of 1980-s or even earlier. They catalogued with a delay because it took a long time to process, to prepare, to make indentifications, labels etc. The rest (64) were collected recently mostly in collection tours which were not paid by Museum.

19 members of Museum's staff took part in collecting mineral specimens which were catalogued at indicated period. The most part collected with participation of D.V. Abramov (70), A.B. Nikiforov (69), D.A. Romanov (54), D.I. Belakovskiy (36), M.S. Alferova (27), T.M. Pavlova (15), B.B. Shkursky (14), S.N. Nenasheva (10), N.A. Mokhova (8), M.M. Moiseev (6), and also M.D. Dorfman, A.I. Ponomarenko, E.L. Sokolova, V.I. Stepanov, L.A. Pautov, A.A. Agakhanov, V.Yu. Karpenko, A.V. Kovalev, N.S. Nikulshin.

Finishing that review we want to thank again on behalf of Fersman Mineralogical Museum RAS all those who made their contributions of any kind for Museum and make possible that review to appear.

The authors also thank I.V. Pekov and A.B. Nikiforov for discussions, valueable notes and help in preparation of that review.

Appendix №1. List of mineral species new for Fersman Mineralogical Museum catalogued in 2006–2008

1. Abramovite *	52. Faizievite *	103. Lourenswalsite	154. Pokrovskite
2. Adamsite-(Y)	53. Falcondoite	104. Lucasite-(Ce)	155. Polkanovite
3. Allabogdanite	54. Felbertalite	105. Magneshoegbomite-6N6S	
4. Allochalcoselite	55. Ferrarisite	106. Majorite	156. Potassicferri- magnesosadanagaite
5. Alloriite	56. Ferroactinolite	107. Malyshevite *	157. Potosiite
6. Aluminocerite-(Ce)	57. Ferroaluminoceladonite	108. Manganbelyankinite	158. Pseudorutile
7. Aluminomagnesiohulsite	58. Ferrohornblende	109. Manganilvaite	159. Punkaruavite
8. Ammoniojarosite	59. Ferrokentbrooksit	110. Manganocummingtonite	160. Richelsdorfite
9. Andrianovite	60. Ferromerrillite	111. Manganogrunerite	161. Ringwoodite
10. Aqualite	61. Ferroskutterudite *	112. Mangazeite	162. Roedderite
11. Argentojarosite	62. Ferrostrunzite	113. Marinellite	163. Roesslerite
12. Armbrusterite	63. Fizilyite	114. Menezesite	164. Rouaite
13. Artroite	64. Fluorcalciobriitholite	115. Merrillite	165. Rudashevskite
14. Altikaite	65. Fluorophlogopite	116. Metavariscite	166. Sahamalite-(Ce)
15. Barahonaite-(Fe)	66. Footemineite	117. Metavauxite	167. Samarskite-(Yb)
16. Bararite	67. Francoisite-(Nd)	118. Miassite	168. Schafarzskite
17. Barringerite	68. Francoisite-(Ce)	119. Middendorfit	169. Scheuchzerite
18. Batisvite	69. Georgbarsanovite *	120. Morimotoite	170. Schoellhornite
19. Belendorfite	70. Georgbokiite	121. Mozartite	171. Schulenbergite
20. Bendadaite	71. Gillardite	122. Mrazekite	172. Seamanite
21. Biachellaite	72. Gjerdingene-Na	123. Nalivkinite *	173. Senkevichite *
22. Bobjonosite	73. Gjerdingene-Ca	124. Nanpingite	174. Sewardite
23. Bonaccordite	74. Glaucoicerinite	125. Nealite	175. Sidwillite
24. Brassite	75. Haapalaite	126. Nechelyustovite	176. Simonkolleite
25. Britvinite *	76. Hafnon	127. Nichromite	177. Skorpionite
26. Brownmillerite	77. Hagendorfit	128. Nickelphosphide	178. Slawsonite
27. Burkeite	78. Hallimondite	129. Niningerite	179. Sokolovaite *
28. Bykovaite	79. Haxonite	130. Niveolanite *	180. Stanfieldite
29. Cadmoindite	80. Heideite	131. Olmiite	181. Stishovite
30. Calcio-olivine	81. Heulandite-Ba	132. Orickite	182. Straczekite
31. Calderite	82. Hundholmenite-(Y)	133. Orthocrysotile	183. Stratlingite
32. Carbokentbrooksit	83. Hydroxylbastnaesite-(Ce)	134. Ottensite	184. Stronalsite
33. Carlosturanite	84. Hydroxylborite	135. Paarite	185. Suessite
34. Carlsbergite	85. Ivanyukite-K	136. Painite	186. Suolunite
35. Caryochroite	86. Ivanyukite-Na	137. Palladodymite	187. Takedaite
36. Caryopilite	87. Janhaugite	138. Paradamite	188. Tamaite
37. Cascandite	88. Jasmundite	139. Parafransoletite	189. Taseqite
38. Challacolloite	89. Johachidolite	140. Paramelaconite	190. Tazieffite
39. Chesnokovite	90. Kamarizaite *	141. Parasymplectite	191. Tounkite
40. Chistyakovaite	91. Karasugite	142. Paratooite-(La)	192. Tsepinite-Na
41. Chlorbartonite	92. Karchevskiyite	143. Pautovite *	193. Uramarsite
42. Chukanovite	93. Katoite	144. Pekovite *	194. Vikingite
43. Cochromite	94. Keilite	145. Pellouxite	195. Wilhelmramsayite
44. Coiraite	95. Kozoite-(La)	146. Perryite	196. Wittiter
45. Dovyrenite	96. Krieselite	147. Pertsevite	197. Xocolatlite
46. Droninoite	97. Labyrinthisite	148. Phosphohedyphane	198. Yvonite
47. Dualite	98. Lakargiite	149. Phosphoinnelite *	199. Zeravshanite *
48. Earshannonite	99. Lantanite-(Nd)	150. Piergorite-(Ce)	200. Zirsilite-(Ce)
49. Eirikite	100. Levyne-Ca	151. Pinchite	
50. Eskimoite	101. Liebenbergite	152. Platynite	
51. Esseneite	102. Lingunite	153. Podlesnoite	

Mineral species given in bold represented by type specimens or cotypes or their fragments.

* – mineral species discovered by Museum staff or in collaboration with Museum staff.



Personalities



ALEXANDER EVGEN'EVICH FERSMAN IN THE ILMENY MOUNTAINS

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A.E. Fersman was connected to the Ilmeny Mountains for 30 years. There were several fields and periods in his activities. The first field involved the study of mineralogy and geochemistry of the Ilmeny region. It was started in 1912 by the Radium Expedition of the Academy of Sciences and continued until the mid-1930's. The second field was organizational. It involved three periods: foundation of the Ilmeny Reserve (1918–1920); conversion of the Reserve into a scientific center (1934–1937); and organization of mineralogical exploration in the Reserve (1934–1942).

4 photos, 5 references.

Keywords: Academician A.E. Fersman; mineralogy of the Ilmeny Mountains; the Ilmeny State Reserve.

The purpose of this article is to introduce readers to the survey works and organizational activities of A.E. Fersman that connected him to the Ilmeny Mountains.

In 1911, V.I. Vernadsky obtained substantial support from the Academy of Sciences (where he transferred after leaving his position at the Moscow University in 1909) for systematic study of radioactive occurrences on the vast territory of our country. The Radium Expedition started its work at the Urals, and Vladimir Ivanovich (Vernadsky) invited Alexander Evgen'evich (Fersman) to participate.

However, A.E. Fersman was not able to visit Urals in 1911. In spring of 1912, April 16, Alexander Evgen'evich wrote to Vernadsky: "Dear Vladimir Ivanovich... Would it be possible to arrange some kind of business trip to Urals for me through the Academy of Sciences (without pay)? I just need an official paper to show them. Because there no financial support for this summer?..." (Fersman, 1965, p. 441). Alexander Evgen'evich's wish was fulfilled. During summer of 1912, he traveled through a number of plants and mines at the Urals, got familiar with the ores of Kyshtym, visited the Ilmeny Mountains, where he collected specimens with the Radium Expedition, worked in the Kochkar region at the famous Sanarka River, and visited Murzinka. For the first time, Fersman described in detail his visit to the Ilmeny Mountains in his book "Gems of Russia" in a chapter "Ilmeny Mountains". The book was published in Petrograd in 1920.

This trip played a critical role in the life of the young scientist, sealing his interest in pegmatites and gems. In the Ilmeny, Fersman first observed the regularities of quartz and feldspar intergrowth, based on which he later on formulated several scientific laws. The

Urals with its nature and mineral treasures absorbed Alexander Evgen'evich for a long time. On July 5, 1912, he wrote to Vernadsky: "Dear Vladimir Ivanovich. I left Miass yesterday after spending 6 hours in the Kusinskaya marble quarry. Almost no minerals, but I still asked Fedorovsky to collect specimens of whatever available. From outside view, this quarry is colossal and very interesting. Kryzhanovsky returned to Miass and now works with enthusiasm. Sample analyses of granite and aeschynite produced remarkable results, and revealed the genetic relationship of the aeschynite with absolutely unusual conditions of origin in all deposits ..." (Fersman, 1965, p. 441).

Since June 1913, Alexander Evgen'evich continued his work at the Northern, Middle, and Southern Urals. "Chelyabinsk, 7/17/1913. Dear Vladimir Ivanovich! Now we are heading back to Ekaterinburg from the Ilmeny Mountains... We rode all over the northern part of the Ilmeny Mountains, collected interesting black mineral near Selyankino and examined a few mines by Ishkul. Today we visited the Saveliev Log and are going to Ekaterinburg. We looked at the asbestos in the Miass valley..." (Fersman, 1965, p. 443).

In 1925, A.E. Fersman described some precious stone deposits in the second volume of his work "Precious Stones." The book provides a brief historical overview for the Ilmeny Mountains area starting from the Pallas time to the years of the Radium Expedition. Further given is a short geological description and then more detailed examination of the pegmatite veins.

In 1932, the second edition of the book "Pegmatites" by A.E. Fersman was published. This comprehensive study of the pegmatites covered different kinds of veins in the Ilmeny

Mountains (mostly those of granite type). Mineralization of the Blumovskaya Mine is studied in particular detail.

Alexander Evgen'evich also wrote about the pegmatites in the 5th issue of the Transactions of the Ilmeny Reserve in 1936. In 1922, he reported detailed data on zeolites of the Ilmeny Mountains in his work on Russian zeolites (result of his work in 1909 – 1916).

Alexander Evgen'evich combined his research work with his broad government and society service. In 1919, at the age of 36, A.E. Fersman was elected Academician. He was content with the attention of the Soviet Government to the development of science and natural protection. Later, he repeatedly mentioned in central press the foundation of the Ilmeny Reserve as a remarkable conservation measure. "I remember us – all members of the Radium Expedition – gathering at the school balcony near the Miass station and dreaming about the future. This was in the very beginning of the first imperialistic war, years of the dire tsar reaction and bureaucratic corruption. I remember saying to my comrades in radium: "I picture the future of the Ilmenys in a somewhat fantastic light. There is a resort in a magical pine forest on the top of the Ilmeny Mountain, far from the dust and troubles of the valley. There is a cable railroad from the station of the Siberian transit to the top of the mountain. Powerful mines of the pegmatite veins with pure feldspar and nepheline prepare material for the largest-scale ceramic industry in Miass and Cherbarkul. Down the mountain, on the lakeshore, in place of the old forest roadblock, there will be Natural and Historical Station, which will be a center for managing the mines of the Ilmeny Mountain and protection of its treasures, museum, library, laboratory... This is the vision of the faraway future. But we have to fight for it. It is needed for science, industrial prosperity, culture, and progress of the whole South Urals... One should not be afraid that the beauty of the Ilmeny Mountains will be lost along with their wilderness and hospitality. The beauty of the whole is not separable from those lost mines and piles, dreadful mountain roads, the wicker on the logs, and the plain beauty of the campfire with the pot on a piece of blue amazonite. The intricate combination of these small things creates the present. It bears not only poetry and virgin beauty, but also an incentive for work, creation, and revealing the mysteries of nature". I was saying that when the scientific studies were carried out under very hard conditions.

Our expedition made stops in abandoned Bashkirian villages.

... People remember the hard year of 1920. In those years of titanic struggle, Vladimir Il'ich (Lenin) finds time to listen and to discuss an absolutely untimely project, as it then seemed, presented to Sovnarkom by the Head of the Mining Division N.M. Fedorovsky – to create the first in the world reserve of mineral treasures in the South Urals, near the station of Miass. On May 14th, 1920, Lenin signed a remarkable document that in the epoch of a great fight for mineral resources, strengthened the idea of their protection and required wise and efficient utilization of the productive forces of the country.

This is how with the genius of Vladimir Il'ich, the world's first reserve of earth interior was founded in the Ilmeny (Fersman, 1935).

One of the tendencies of the academic science in the Soviet Union in the early 1930s was "technologization" and "de-centralization". The territorial network of the scientific institutes, in which the academic science was emphasized, started to develop.

The Committee for Bases of the Academy of Sciences, which was established in October 1931, led the organization of local stationary scientific cells. A.E. Fersman was part of this Committee. The Committee worked in close collaboration with local political and Soviet governing organs. The opening of the Ural Division of the Academy of Sciences was preceded by substantial preparatory work. Fersman played a special role in the creation of the Ural Division. On this issue, he consulted with Sergo Ordzhonikidze and Party and Soviet leaders at the Urals. A.E. Fersman was appointed the Head of the Ural Division of the Academy of Sciences.

Institutes and expeditions were organized; works of the Ural Division of the Academy of Sciences were published. At that time Fersman worked hard to build the material and scientific base of the Ilmeny State Reserve. In 1927, during his next visit to the South Urals, Academician Fersman noted the high intensity of the works that were carried out in the reserve. In that year, the newspapers "Proletarskaya Mysl" ("Working Class Thought") and "Uralsky Rabochy" ("Ural Worker") published reviews by A.E. Fersman, in which he noted the excellent progress in the area. In the guest register of the Ilmeny Reserve of 1929, there is a record by Alexander Evgen'evich saying that in the very start of the expedition for search of the radium ores, its members could not even dream of the

working conditions that present now at the Ilmeny mineral deposits following and changes over the last one and half decades. Now the Ilmeny Mountains became more accessible for mineralogical studies, and the Reserve appears as a cultural center. Old, collapsed mines were cleared and brought to "museum condition". Mysteries of the underground world, previously hidden, are now readily presented to an inquisitive eye of mineralogist, thanks to the efforts of the Reserve personnel. The Russian mineralogy can be proud of how the treasures of the Ilmeny Mountains are managed.

Alexander Evgen'evich dreamt of turning the Ilmeny Reserve into the leading research institution in the South Urals. He published a number of articles in newspapers, communicated to the government representatives of the Soviet organs both personally and in writing, spoke at various meetings, science conference, and regional Soviet Congress.

In summer of 1934, A.E. Fersman wrote to Koscheyev, the Director of the Ilmeny Reserve, about his disappointment with how difficult it was to promote a very clear and important idea of creation of a strong unified scientific center at the Urals. He proposed to make the Ilmeny a scientific interface connecting Chelyabinsk and Magnitogorsk with the all-round support of the Chelyabinsk Ispolkom (Executive Committee). "The Ilmeny idea is very serious, and it is now easier to get things going with organization of a scientific center of the South Urals, which will be the first research institution of the Chelyabinsk Ispolkom. I have no doubts, he will seize this idea, since Chelyabinsk now sits without scientific support. Who is there in the Ispolkom? Could you give me the first and last name of the Representative? I will write him about the role that well-established laboratories and the institute can play in the development of the whole South Urals. I am now more and more convinced that such connection of the institute to the industrial zone will be particularly important" (This and further presented quotes of A.E. Fersman were taken from Butorina, 1992).

In 1934–1935, A.E. Fersman worked very hard to solve this problem. Here is the list of some documents related to the issue: Resolution of the Soviet Organizing Committee of the Chelyabinsk District of April 11, 1934, № 330 "On the Organization of the Ilmeny Research Field Station"; Resolution of the Organizing Committee of

the Chelyabinsk District of August 15, 1934, № 1220 "On the Status of the Ilmeny Mineralogical Reserve"; letter from A.E. Fersman of September 5, 1934 to the Deputy Director of the Chelyabinsk District Planning Committee M.P. Korolkov; letter from A.E. Fersman of October 20, 1934, to the Committee on Reserves about appending the Argazin area to the Ilmeny Reserve; extract from the protocol of the meeting of the Council of the Academy of Sciences of the USSR of November 25, 1934, about A.E. Fersman's report on the Ural Division, which acknowledges the necessity of including the Ilmeny Reserve to the Academy of Sciences as a complex research institution in the South Urals, providing budget funds for construction in 1935–1937, and including it in the expedition plan SOPS for 1935; protocol of the meeting of the extended Council on Reserves of May 4, 1935, about the development and reconstruction of the Ilmeny Reserve into a complex institution (report by A.E. Fersman); letter from A.E. Fersman of December 22, 1935 to the Representative of the Chelyabinsk District Executive Committee M.A. Sovetnikov about providing funds in 1936 for the construction of a scientific station in the Ilmeny Mountains (Butorina, 1992, pp. 59–71).

In 1934, A.E. Fersman made the first steps towards the establishment of the Ilmeny



Fig. 1. At the conference in the Ilmeny Reserve. July 1934 (left to right): N.M. Fedorovsky, A.E. Fersman, E.M. Fersman, and V.I. Kryzhanovsky. Photo from the Ilmeny Reserve archive.

Reserve scientific center. From the July 28th to July 31st, 1934, the first scientific conference worked in the Ilmeny. It was related to the problems of geochemistry of basic magmas of the Urals and was based on the results of long-term scientific studies of the genesis of mineral deposits (Fig. 1).

After the conference, despite feeling sick, Fersman went to Chelyabinsk for participation in the meeting of the Council of the District Deputy Soviet Organizing Committee, where he made a presentation on the productive forces of the South Urals.

In the same year, on November 10th, a conference on coal chemistry of the Chelyabinsk basin was held at the Ilmeny Reserve. The conference gathered geologists, mining engineers, chemists, technologists and was chaired by A.E. Fersman. When opening the conference, Alexander Evgen'evich said that the future of the Urals will primarily depend on how we use the coal resources. In this respect, the Chelyabinsk area is the pride of the Urals. In 1935, A.E. Fersman was the editor of the special volume of scientific papers of the Ural Division of the Academy of Sciences of the USSR, Ilmeny Series "Chelyabinsk Coals", published by the decision of the Academy of Sciences of the USSR. Alexander Evgen'evich wrote the preface and conclusions to this edition.

At the 1st Soviet Congress of the Chelyabinsk District in January 1935, A.E. Fersman greeted the delegates and emphasized three main tasks: exposure of the natural resources, their proper utilization, and including science and technology into the base for the organization of the productive forces in the district. Special attention was paid to the need of establishment of a scientific center on the border between Europe and Asia. Alexander Evgen'evich wrote to M.A. Sovetnikov about the Ilmeny Reserve and its future prospects: "This is a natural science center that serves the whole South Urals with laboratorial and field studies, and we would like to turn it into a major research institute with permanent staff and permanently equipped laboratory, library, and museum. Even now (with its own facilities and equipment), it can help the development of the mining industry in the South Urals.

This spring, after finishing my medical treatment abroad, I plan spending some time in the Ilmeny Reserve and do several scientific studies there. With best regards – Academician A.E. Fersman. 26.03.34."

Alexander Evgen'evich made a significant contribution to the establishment of the material base of the Ilmeny Reserve. November 5, 1934, he wrote to V.I. Vernadsky from Miass: "Dear Vladimir Ivanovich! I am now in the Ilmeny, where big construction has started. It is not so cozy here now, but some contours of the big project can already be seen! In Sverdlovsk, finally, after 22 fruitless projects, they have come up with the 23rd, so we will demonstrate it in Moscow at the November session..."

Designing the buildings for the "mining station of Academy of Sciences" was carried out in Leningrad with Fersman's personal involvement in defining technical specifications and preparing the explanatory note. The main building was supposed to include museum and scientific library; the second construction object would include a scientist and international tourist hall. The buildings were planned for completion by 1937 – by the arrival of the delegates of the International Geological Congress.

The project involved the creation of a research station, a laboratory, a museum, and centers for scientific ideas, expedition ideas, field works, where one could receive a consultation, study mineral samples, and perform any other research. The same complex would include the central science club, conference hall, and scientist residence hall, where meetings for staff could be convened.

Work in the Urals in 1932–1934 convinced Fersman that a large complex expedition should be organized here by the Academy of Sciences of the USSR for solving two major tasks: study of the rock formations related to mineral deposits and complex agricultural assessment. The crews cruised over a large territory from Bashkiria and Chelyabinsk district in the north to the Orenburg district and Western Kazakhstan in the south (Fig. 2).

On February 4th, 1935, A.E. Fersman was a chairman of the meeting with the representatives of the Chelyabinsk district who were delegated to the 7th Soviet Congress and were in Moscow. The meeting was related to the works and studies at the South Urals and was held in the Lomonosov Institute of Academy of Sciences of the USSR in Moscow. The participants from the Academy of Sciences introduced the Chelyabinsk representatives to the research that was underway or planned at the South Urals and outlined the general picture of the future prospects (OGAChO, v. 10-a, p. 20). The Ilmeny Reserve was a separate topic. The project of the building complex of



Fig. 2. In the Ilmeny Reserve, 1935. The photo is a gift of Elsukov, the former student of the Sverdlovsk Mining Institute (previously unpublished).

the central base of the Reserve — research station, scientist hall, museum, tourist hall on the shore of the Ilmeny Lake was shown to the guests. A.E. Fersman announced that all should be prepared for the reception of the participants of the International Geological Congress in the fall of 1937.

In August of 1935, Alexander Evgen'evich offered to Professor V.I. Kryzhanovskiy, the director of the Ilmeny mineralogical crew of the complex expedition of the Academy of Sciences, to take part in the automobile race Ilmenys-Orsk. Fersman's substitute in the expedition, I.N. Shinkarev and E.M. Rozhanskaya also participated. The course went through the work places of seven crews of the South Ural Complex Expedition. They traveled in two vehicles: a car (Ford type) and a 1.5-ton truck. For 16 days, the participants covered 2374 km, visited 27 most important mineral deposits, collected about two tons of specimens for museums and scientific studies. While on the road, they organized several meetings with the expedition crews and local officials.

Obtained scientific materials were very significant. Some lost and forgotten deposits were searched and found. The mineralogical collections were later presented at a special exhibition in the Mineralogical Museum of the Academy of Sciences of the USSR in Moscow. The publishing house of the Academy of Sciences issued a separate book "Our Auto Race through the South Urals". (Fersman, Kryzhanovskiy, 1936).

In his organizational work, A.E. Fersman was supported by geoscientists and his collaborators from the Radium Expedition of the pre-Revolution Academy of Sciences. The Organizational Committee of the Chelyabinsk District passed the resolution for the establishment of the Ilmeny scientific station and by scientists' request applied to VTsIK USSR for changing the status of the Ilmeny Mineralogical Reserve to "complex". The Reserve received additional funds from the local budget.

A.E. Fersman's applications and the resolution of the Chelyabinsk District Executive Committee set the ground for the government document. The Resolution of VTsIK of the Russian Federation of December 1st, 1935, the Ilmeny Reserve was assigned the title "Complex", on which territory any industrial activity is prohibited. However, the Reserve was transferred to the authority of the Committee for Reserves, and became a scientific center only in 1970s.

Alexander Evgen'evich came to the Ilmeny Reserve once again in September of 1936 to prepare for the International Geological Congress. He chaired at the meeting of the Reserve personnel, listened to some presentations, provided some practical advice, and formulated the tasks for the future research and development in the Reserve. Unfortunately, because of illness, Alexander Evgen'evich could not participate in the work of the International Geological Congress in the Ilmenys in 1937.

The Second World War began. Having finished the evacuation of the Khibiny Division, Alexander Evgen'evich led four defense committees and organized three expeditions. Under his leadership, very diverse assignments were carried out in close contact with the military. But the main area developed by Fersman and his co-workers was the strategic natural resources. At the Urals, he verified the results of the previous years and obtained new data. "The war did not stop the exploration works. On the contrary, it enhanced them, made them more intense, " – Alexander Evgen'evich noted in his brochure "Urals – the Treasury of the Soviet Union", published by Profizdat in 1942. In parallel, he spoke in hospitals, universities, and factories. Only in 1942, Alexander Evgen'evich gave 21 lectures, in addition to his speeches in some parts of the Western front.

During those severe days, Alexander Evgen'evich did not forget the Ilmeny. The Institute of Geosciences, in which he was the Director, was evacuated to the Urals, partially to the Ilmeny Reserve. Fersman repeatedly came there during the hard war times (Fig. 3).

I found some records in the Reserve archives from the meeting of the Reserve personnel with Academician A.E. Fersman on July 27, 1942, on the "scientific areas of

research for the geologists of the Reserve." During his visit to Sverdlovsk to chair the meeting of Ural geologists, Fersman found time to stop by at Ilmeny and discuss the research topics developed by the geologists in the Reserve. At that meeting, among the attending personnel were the Director of the Ilmeny Reserve M.Ya. Barabashkin, Deputy Director for Science V. A. Vasnetsov, Manager of the Mine Station A.I. Simonov, geologists M.S. Afanasiev and L.N. Subbotina, and two scientists from the evacuated Institute of Geosciences of Academy of Sciences, Professor V.I. Kryzhanovskiy and Fersman's co-worker A.A. Saukov.

The first item on the agenda was "Inventory and Passportization of the mines". This work had been done in the Reserve for years, but had stopped because of the war. It was noted that "the Summary on the Reserve mines, which was convenient for daily use in research and organizational activities" was missing in the Reserve's 1942 Annual Report; only the obsolete and incomplete guide for 1935 was included. The need for passportization of mines was pointed out by Academician A.E. Fersman. His request to compile a summary on the mineralogical mines of the Reserve, based on the pre-war studies of B.A. Berezin, T.I. Ustinova, and A.N. Zavarits-

Fig. 3. A.E. Fersman with the staff of the Ilmeny Reserve, 1942. Photo from the archive of the Ural Division of the RAS.



ky, and concurrent updating the Reserve specimen collections, was fulfilled.

The next question on the agenda was about ore mineral studies. In the records, the first task is formulated as follows: "Watch for and collect materials on zircon and Mine 28. Delegate V.I. Kryzhanovsky to supervise this work and to report monthly on the results". "Zircon have been used as cutting stone, beautiful gem, sparkling with fire. Now it is needed for different areas of military industry, — A.E. Fersman wrote in his book "Urals — the Treasury of the Soviet Union".

The second task was related to the study of molybdenite from the Chernoe Lake region. In spring of 1942, the Sverdlovsk geological survey was permitted to develop molybdenum on the territory of the Reserve. A.E. Fersman recommended the Reserve personnel "to provide mineralogy and characterization of the ore body of the molybdenum deposit" near the Chernoe Lake and "raised a question about the completion of the survey of the deposit by the Sverdlovsk survey crew". This work was finished by the end of the year. Fersman noted that development of the deposit can be done only manually.

Development of the Selyankin niobium deposit was also discussed. In 1934, the Institute of Applied Mineralogy (Sverdlovsk Division) discovered a large niobium deposit in the Selyankin region (which then was out of the reserved territory). In 1942, A.E. Fersman wrote: "Now the South Urals produces the world's only niobium ore in the form of ilmenorutile. The name of the mineral connects it to the famous Ilmeny Mountains, which are true mineralogical paradise in the South Urals. This niobium ore is the future metal of steel airplanes" ("Urals — the Treasury of the Soviet Union").

The third series of questions was related to the non-ore resources — mica, ceramic materials, quartz sands. Certain people were assigned responsible for the "evaluation of the mica content of the pegmatite veins", utilization of the nepheline-feldspar rocks (consumers — Bishkil, abrasive plant, tank Kirov plant, Chelyabinsk etc.), work on "Quartz molding sands in Miass region". The sands were necessary for the automobile plant that was evacuated to Miass from Moscow.

Recommendations of the Alexander Evgen'evich Fersman given at his last meeting with the Ilmeny geologists on June 27, 1942, were fulfilled. His words from the book "Urals — the Treasury of the Soviet Union" were confirmed: "Scientists and researchers of the



Fig. 4. Memorial board on the Administration Building of the Ilmeny Reserve; established in 1986.

Urals were ranked high among the Ural fighters of the labor front".

One cannot talk about the Urals, its past, present, and future without remembering the true singer of its glory — Academician A.E. Fersman. The present-day Lenin Ilmeny State Reserve, Ural Division of Russian Academy of Sciences, which was founded by dedication of A.Fersman, preserves the memory of him. This involves not only the memorial board with the dates when the scientist worked in the Ilmeny Mountains (Fig. 4) and a special stand in the Reserve Museum, but also the white buildings of the laboratory and museum, which were constructed in the early 1980s at the central base of the Reserve, where Alexander Evgen'evich envisioned them.

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GEORGIY P. BARSANOV – THE DIRECTOR OF THE FERSMAN MINERALOGICAL MUSEUM (1956–1976)

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Georgiy Pavlovich Barsanov joined the museum staff as a junior scientist in 1931, graduated recently from the Leningrad State University. At that time the director of the museum was A.E. Fersman, who had gathered many talented young scientists to work with him. Those young people would go on to make lots of developments in the field of mineralogy. The museum was a part of LIGEM (Lomonosov Institute of geochemistry, mineralogy and crystallography) and along with museum curation duties they did intensive research.

The mineralogical collection, that accounted several tens of thousands of exhibits, was moved from Leningrad to Moscow in 1934. It was a gigantic task: wrapping and boxing, taking inventory, controlling the loading and unloading of the material, which occupied 45 railway carriages. The collection was placed in the riding hall of former count A.G. Orlov. Preparation of an exhibition to XVII session of the International Geological Congress of 1937 went on almost simultaneously with this. The exhibition was placed in the halls of the museum, halls of Moscow conservatory and outdoor in the park adjacent to the museum. Georgiy Pavlovich took a very active part in those and other later labour-consuming works, which demanded knowledge and skills in various fields. These exhibitions taught him the museum business in all its details.

Because the museum was a part of a research institute, its scientists carried out intensive research work. The activity of the museum was appreciated by the Academy of Science not on the basis of achievements in the museum business but mainly by the quality of the scientific research. It was like that in those times, as well as in later years. Written books, articles, the creation and defense of theses was considered more important than museum work.

This period was a time of rapid development in the Earth sciences and reclamation of the national natural resources. Georgiy Pavlovich participated in many science field

trips to the Caucasus, Middle Asia, Urals, Kola Peninsula, starting from in 1926, even before beginning to work at the museum. He donated more than 2100 specimens to the collections of the mineralogical museum in those and later years.

Georgiy Pavlovich Barsanov began to study the unique rare-metal mineralization of the Ilmen Mountains starting from the late 1930s. He made a significant contribution to the studies of the region by detailing the mineralogy of rare-metal deposits of South Urals, characterizing the chemical and physical features of metamict rare metal minerals, discovering and describing new mineral species.

Georgiy Pavlovich was mobilized in 1941. He was the head of the staff, and then a commander of a combat engineer battalion, during which time he was severely contused. He was evacuated to the Ilmen natural reserve in the Urals, where part of the museum collection and its staff were moved for the duration of the war. In spite of serious health issues, he continued to study the mineralogy of the Ilmen Mountains. Besides detailed studies of the material and summarizing all the obtained data, he worked out a theory of metamict decay and methods of investigating metamict minerals.

Georgiy P. Barsanov defended two theses: one for the Candidate Degree in geological and mineralogical sciences with the title "Mineralogy of Ilmen Mountains" in 1943, and the doctoral thesis "Methods of study and systematic of rare earth niobates and tantalites" in 1947. The doctoral thesis was awarded a prize from the Department of geological and geographical sciences of the Academy of Science of the USSR.

Georgiy Pavlovich executed work as the scientific secretary of the mineralogical museum starting from 1944. He held the position of senior scientist in the period from 1947 to 1952, leading the scientific and organizational work in the museum, supervising postgraduate students, and acting as the director of the museum on many occasions.

His teaching experience started at the Moscow Institute of Base Metals and Gold in 1937, far before the war, and continued till 1953 in the Moscow State University. G.P. Barsanov created his original course on genetic mineralogy to present the ideas of V.I. Vernadsky and A.E. Fersman in a modern way. He started to reconsider new data on the chemical composition and structure of minerals and later created a mineral classification system based on the contemporary structural-chemical basis in 1959.

It is clear that by 1950s G.P. Barsanov was already a mature mineralogy scientist and very professional in museum work. Therefore, it is natural that he was assigned as a director of the museum in 1952 when academician D.S. Belyankin left the position, after being the director since 1947. At almost the same time, in 1953 G.P. Barsanov became the chair of the mineralogical department at the geological faculty of Moscow State University. Later he would be the dean of this faculty from 1957 to 1961.

The assignment of Barsanov as an executive director coincided with repair and restoration works on the museum buildings. Thanks to his persistence the museum was funded to repair the roof damaged during the war, and restore the unique painted ceiling that had been severely harmed due to the leaking roof.

Excellent knowledge of the details of museum business allowed Georgiy Pavlovich to make some novel changes when reopening the museum after renovation that simplified the work in the museum. He made big changes to the scientific essence of the exhibits, allocation of funds, and inventory and recordkeeping, which were made in a short period of time thanks to well organized work. All the staff members of the museum took part in that gigantic work.

The museum had a huge amount of material in a vast repository, which had been ordered according to Dana's classification system. It was not easy to locate material, therefore to make it easier an alphabetical index was created for the first time under the supervision of G.P. Barsanov. Mineral names in the index were ordered by N.A. Kruglova, followed by the numbers of the storage shelves, drawers and showcases where they were placed. Such an index had only existed before for collections from mineral deposits. S.V. Vlasova ordered material of the systematic collection within every mineral name by mineral deposits and every drawer had the same

ordering principle. Every drawer was supplied with inventory descriptions. These changes simplified the use of funds and allocating existing and newly obtained samples.

The collection of lapidary and precious stones was catalogued in the Book of Movements made by M.B. Chistyakova, where all moves of the specimens were described.

Because museum material was used as etalons in comparative studies by many institutions, new card indexes were created by M.A. Smirnova to show a) minerals given for investigation; b) results of analyses of the museum material.

Rapid development of mineralogy in 1960–1970s and the discovery of many new minerals triggered the appearance of new indexes of minerals discovered in USSR, written by G.A. Annenkova, later M.D. Dorfman and S.V. Vlasova.

Replenishing of the museum's collections originated from different sources. Many exhibits came from the expeditions of museum staff, with other interesting material coming from other academic and non-academic organizations. New minerals found in the USSR were officially registered only after their etalon specimens were delivered to the main geological museums of the USSR. Sometimes unique samples came to the museum with its own specific scientific research. It was this way when U.L. Orlov, the museum's scientist, worked on the morphology of diamonds. He also studied collections of the Gokhran of the USSR, besides the museum's own collection. After the study the unique material was completed it was passed on to the museum repository.

A big role in drawing new funds in, was through the commercial department of the museum named the Mineral Bureau. It was established in the times of A.E. Fersman and worked on forming mineral collections for high schools and higher educational institutes. Minerals were collected from many regions of the country, with the best samples placed in the museum collection and lesser quality samples being sold by the Mineral Bureau. The museum used the funds raised by this work to purchase further specimens.

The size of the collection, the significant number of new accessions, the presence of precious stones and metals required special handling and storing, which increased the necessity for additional staff. At the recommendation of the commission of the Gokhran

of the USSR, Georgiy Pavlovich insisted on funding two staff positions of senior custodians for the main repository and temporary repository. There were no such positions in the museum system of the Academy of Science before.

Georgiy Pavlovich Barsanov had wide scientific interests. He studied theoretical and applied mineralogy. He developed his own mineral classification based on new scientific achievements, studied the mineral composition of deposits in the South Osetia and Ilmen Mountains, the process of metamict decay, luminescence properties of minerals and the origin of their coloration. Additionally he was interested in composition and genetic peculiarities of jaspers and cryptocrystalline silica, typomorphic properties of tourmaline. Georgiy Pavlovich paid a lot of attention to the history of Russian mineralogy. His vast circle of interests is shown in the number of published papers (more than 150 titles). Many of his interests were realized in the museum's exhibitions, prepared by the museum's staff under his supervision.

The museum's staff, under the lead of Georgiy Pavlovich, performed a colossal work on restoration and renewal of the exhibition for the reopening of the museum after its restoration in 1953 and a few years after that.

The previous exposition "Systematic of mineral species" was made according to Dana's system and was restored in the first place. The composition of minerals was not given in oxide form but in the new contemporary structural formula. The system of mineral classification based on structural-chemical properties was published in 1959. M.A. Smirnova. The museum's staff, remodeled the exposition to fit the new Barsanov's system in the following few years. Every mineral species was presented with its each variety ordered according to the temperatures of their genesis in different mineral assemblages.

The exhibition "Geochemistry of elements in mineral forming processes" created in time of A.E. Fersman and V.I. Krizhanovsky was totally renewed and remodeled. It showed minerals containing an element that were formed at different stages and conditions of the mineral-forming processes, in various compositions and genesis. The exposition was also furnished with plenty of illustrations. The exhibition was very detailed and informative, but was reduced later because of lack of the space for it and it has not been updated or sup-

plemented with new material except for some sections.

A completely new exhibition "**Mineral forming processes**" was created in the same years under the lead of G.P. Barsanov. It is currently named "Types of mineral associations in the Earth's crust". It replaced a small exposition, some sections of which represented mineral assemblages of certain deposits or regions, which was formed to the International Geological Congress in 1937. The new exhibition contained sections with generalized material characterizing different deposits of certain types from magmatic to supergene. Almost all the museum's staff participated in creating this large exhibition. Some sections represented research of the museum's staff, for example, pegmatite types by A.I. Ginsburg. The exhibition reflected the state-of-the-art in the science and had approval from the national and international science community. It dated with time and is constantly being upgraded.

An exhibition entitled "**Mineral crystals**" by A.N. Labuntsov and V.A. Sheveleva, showed all crystals ordered according to their symmetry by various systems, with indexes of faces marked, and was supplied with large text and graphic material.

Ontogeny, a separate branch of mineralogy started to develop during the 1950–1960s. N.I. Ginsburg created a show on this division in 1950s. It was dedicated to the substitution of one mineral with another and was called "Pseudomorphs". An exhibition "Forms of mineral occurrence" was created by V.V. Yakybova to continue the topic later in 1966 for the 250th anniversary of the museum. Now all three exhibitions ("Crystals", "Pseudomorphs" and "Forms...") are combined into one display, showing all types of occurrence of minerals in nature. There is no such exposition in other museums and the idea of it was formulated in the time of G.P. Barsanov.

The exhibition "**Colors of minerals**" was reorganized in the time of Georgiy Pavlovich. Causes of mineral coloration started to be investigated in 1950s, and there were some light absorption spectra presented for several minerals originating from the first works on the topic by the Institute of Crystallography of Academy of Science. That first exhibition was created by M.S. Amirzyants, later – Barsanova. It was significantly remodeled by M.E. Yakovleva and furnished with graphic material on the

base of newly obtained data in 1968. This exhibition "Causes of coloration in minerals" created in the time of Georgiy Pavlovich exists still and has not dated.

Rapid development of experimental mineralogy started in those years. There were many synthetic minerals grown and this part of mineralogy was shown in the collections and expositions of the museum. The exhibition "Synthetic analogues of natural minerals" was combined by G.A. Annenkova and M.A. Smirnova. It was transformed into an exposition with synthetic and natural stones and imitations used in jewellery.

Georgiy Pavlovich was interested in the history of mineralogy and this interest was reflected in the exposition "The history of mineralogy and Mineralogical Museum in Russia and USSR" starting from Peter's the Great Berg-college and Cunstcamera to the present day. He started organizing the exhibition in the early 1950s. Specimens of minerals discovered in Russia and minerals named after Russian scientists are part of the show that was made by V.A. Sheveleva.

Mineralogy, as other geosciences, was booming in 1950 — 1960. A large number of scientific expeditions and laboratory investigations of minerals led to discoveries of new mineral species. To reflect those achievements the exhibition "Minerals discovered in Russia and USSR" was formed by G.A. Annenkova and M.D. Dorfman. There has been so much material to show in the recent years along with the lack of show space that only minerals discovered in Russia in the last 10 years are shown in it.

The exhibition "Minerals of Moscow region" showed past interest in regional mineralogy. It was first created in the time of Georgiy Pavlovich by A.N. Labuntsov and V.A. Sheveleva.

The exposition "New acquisitions" came to existence in the time of Georgiy Pavlovich. It was created by G.A. Annenkova in 1966 for the 250th anniversary of the museum and became permanent and is regularly renewed since then.

The collection of lapidary and precious stones had been in the museum since 1920s and Georgiy Pavlovich paid a great attention to it. Artist V.I. Levanidov was hired to modernize its look for the first time in the museum's history. He created showcases, in which samples were not considered as a set of particular specimens but looked like a unique piece of art. M.A. Smirnova played a big role in

forming this big exposition by revising and selecting show specimens.

Besides permanent exhibitions there were many temporary shows dedicated to some events and memorable dates. Some of them became permanent like the afore-mentioned "New acquisitions" created for the 250th anniversary of the museum.

Renewal of the big geological map was done for the same event. White spots represented areas which had previously not been geologically mapped in the territory of the Soviet Union. So the white spots on the map had to be eliminated. The new map was projected onto the blank areas whilst an artist standing on a ladder painted the lacking parts. The work was done under the supervision of V.A. Kornetova.

The bronze memorable medal was cast for the 250th anniversary of the museum.

A temporary exhibition was made to the Centennial anniversary of V.I. Lenin. The topic was hard to choose. Lenin's decree for creating the Ilmen natural reserve was chosen to make the subject of the exposition "Ilmen Mountains — the first mineralogical reserve in the world". It showed specimens from Ilmen mountains with texts and pictures. An exhibition was also made for the 90th anniversary of A.E. Fersman.

The museum exposition was located in the former riding hall, which was about 900 square meters in size (about 9000 square feet) with a high ceiling, was light with several old chandeliers dating to the 1930s. In the twilight and even in cloudy dusky days it was almost impossible to see what was shown in the showcases. Attempts to change the lighting in the museum were taken only in time of Georgiy Pavlovich and were undertaken by A.V. Ionov. Electricity was conducted to the vertical showcases standing along the walls and light incandescent bulbs appeared on the inner sides of the showcase walls. From the contemporary point of view it was something terrible: the light was directed to the viewer, samples on the sides made long shadows and the center of the exposition did not have enough light. Nevertheless, the staff were very excited about the lighting — it was far from perfect, but one could see what was in the showcases. Luminescent light bulbs became available and they started studying how to improve their spectrum to make it closer to natural day light to have specimens look natural. However, the change of the old incandescent lights to the modern ones happened only after Georgiy

Pavlovich left the museum, during a long period of renovation.

It's necessary to stress that the modern scientific essence of the museum's expositions was formed in the time of Georgiy Pavlovich. They were reduced, widened or modernized but the general direction has not changed till now.

Georgiy Pavlovich was appointed as a director in 1948, when the museum was a separate scientific organization with its own research program, which was carried out with participation of majority of its staff members.

Pegmatites were one of the main research subjects in 1950 – 1970. The works were carried out by A.I. Ginsburg, V.A. Kornetova, M.E. Yakovleva, M.B. Chistyakova, post-graduate students T.I. Timchenko, G.N. Taranovsky, L.N. Rossovsky and others in different regions: in the Urals, Middle Asia, in Transbaikalia, in Tuva and Kazakhstan. A.N. Labuntsov and later M.D. Dorfman and G.A. Annenkova studied alkaline pegmatites on the Kola Peninsular. Studies of minerals of rare metals and rare earth elements were a part of the pegmatite research.

Many articles and monographs were published, doctoral and candidate theses defended on the results of the investigations. Studies of A.I. Ginsburg had particular value in those works. He discovered a pollucite deposit on Kalbinsky range in Eastern Kazakhstan and was awarded a Stalin prize for it.

Although the pegmatite topic was the main research of the museum, there were other topics. N.G. Sumin studied iron skarn deposits, Yu.L. Orlov did a research on morphology of diamond crystals, O.L. Sve-shnikova studied mineralogy of silver and silver-base metal deposits. The results of the works were published in articles and monographs.

Part of the studies was carried out on the museum's collection material. Sometimes it was used just as a comparative material for the studies mentioned above. Some works were focused particularly on the museum's samples. For example, G.P. Barsanov and M.E. Yakovleva made a work on chalcodites, jasper, tourmalines, obsidian, V.V. Yakubova worked on inclusions in quartz, Yu.L. Orlov studied diamonds.

In this manner, the small staff successfully carried out research on different problems of mineralogy.

Laboratory facilities were needed for the research made in the museum. An X-ray laboratory, spectral emission laboratory and polishing shop were found in the time of Georgiy Pavlovich, as well as an existing small chemical laboratory. Having those facilities made the research independent from IGEM laboratory, which was loaded with work on their own projects. The IGEM (The institute of geology of ore deposits, petrography, mineralogy and geochemistry of the Academy of Science) shared the communist party unit, trade-union management and the same scientific council with the mineralogical museum.

Results of research were published in the museum's journal called "New data on minerals from USSR". Later it was renamed into "New data on minerals" because in the time of Georgiy Pavlovich the geography of the studied projects widened. Georgiy Pavlovich was the editor of the journal from 1949, sharing this work with academician D.S. Belyankin until 1953.

It needs to be mentioned, that Georgiy Pavlovich paid a significant attention to the scientific interests of his staff. In times of strictly planned economy it was hard to change research direction or deviate to a foreign topic once it was planned and approved. People who came to work in the museum had their own established scientific interests that sometimes did not match the direction of the museum research. Georgiy Pavlovich did not contradict them if they could give him a good reason to justify their denial to work in the common direction. Such people continued their studies like Yu.L. Orlov, who got interested in diamond studies before starting work in the museum. Attempts to make him do research on pegmatites did not inspire him but only depressed him. So, Georgiy Pavlovich gave him blessing to work on his favorite diamonds. As a result a solid monograph was written on diamond morphology and a doctoral thesis was defended a few years later.

Georgiy Pavlovich was not inclined to manage the people or the group of researchers as a guide or a nanny. He knew perfectly the business abilities and personal qualities of the people he managed and allowed them to apply their initiatives and skillfully used their help.

Georgiy Pavlovich paid a lot of attention to the museum activity in popularizing science. Besides regular excursions for the

school pupils, students and other visitors there was a mineralogical interest club for high school pupils. It was organized in time when B.I. Krizhanovsky was the head of the museum from 1932 to 1947. He played a big role in the museum development and replenishing of its collections. Future museum staff and some famous scientists attended the club in their school years: V.A. Kornetova, A.I. Ginsburg, A.A. Beus and others. Georgiy Pavlovich tried to attract to the club teaching not only the museum's staff but also enthusiastic people from the outside. E.Ya. Gurieva, the future postgraduate student of G.P. Barsanov, was such an enthusiastic person, who gained a taste for teaching early in her student years. Later being a senior lecturer at Moscow institute of fine chemical technology she brought her students to the museum on the regular basis to improve their knowledge in mineralogy.

The scientific mineralogical club was organized for specialists in the time of V.I. Vernadsky and A.E. Fersman. Its meetings were regularly held when Georgiy Pavlovich was the head of the museum. It was easy to find a lecturer for the meetings because there were so many research reports and theses that needed to be discussed with colleagues. Reports were made by the young as well as by the very experienced scientists like academician N.V. Belov. Georgiy Pavlovich always attended the meetings, took an active part in the discussion and made conclusions to it. Sometimes a lecturer would be unclear and the subject would only become understandable after Georgiy Pavlovich made his summary. The club was lead by A.I. Ginsburg before 1957 and later by M.D. Dorfman.

Simultaneously with scientific and pedagogical activity Georgiy Pavlovich did research managing and public work. He was an editor of various periodical titles, collected books and reference books, a main scientific editor-consultant of the second and the third edition of Big Soviet Encyclopedia, a member of editorial board of scientific journals. G.P. Barsanov entered a commission on natural reserves in 1954 and participated in developing a project of the Commission on nature protection. Georgiy Pavlovich was a vice-president of International Mineralogical Association between 1960 and 1964 and a member of a range of commissions of the organization. He was a member of the

All-Union Mineralogical Society and was many times among the council of the society. He also was an emeritus member of the Bulgarian Geological Society. He was granted a title of the honored Worker of Science of the RSFSR. His merits were honored by the order of the Red Banner of Labor, by three orders of the Badge of Honor and several medals of the USSR: The medal for the Conspicuous Gallantry is among them.

We need to stress the fact that G.P. Barsanov was a dean of the geological faculty of Moscow State University and worked as a head of the museum voluntarily from 1957 because he was not allowed to hold two executive positions at once.

A new mineral barsanovite, found by the museum's staff member M.D. Dorfman, was named after G.P. Barsanov.

The authority of Georgiy Pavlovich was beyond exception. Nevertheless, he never lowered the staff member's dignity, did not demonstrate their shortcomings. On the contrary he always found good people's qualities, which could merit the business. When his eyebrow rose on his usually calm face it meant that the person he was talking to went too far and it was time for him to reconsider his position. He successfully pacified quarrels that were so common in a mainly female work collective. And it seemed that everything went smoothly, without any worries and faults. Now the time when Georgiy Pavlovich Barsanov was the director is memorable as a calm period without commotion, what actually was not exactly true. His visible calmness was a result of his gigantic moderation and intelligence but not a peace and clear skies.

Georgiy Pavlovich had various interests and hobbies, which were connected not only with the science. He loved music, photography, he hunted for mushrooms, grew indoor flowers and went ice-fishing. Georgiy Pavlovich was a cheerful person with good sense of humor. He gladly spoke to the staff members, made jokes with them when walking along the museum's hall where all the museum's staff had their work desks. It made all his colleagues feel comfortable and secure. People who worked with Georgiy Pavlovich remember him with love and gratefulness.

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GEORGIY PAVLOVICH BARSANOV AS I REMEMBER HIM

Erika Ya. Gur'eva

I am most likely one of few people who has known Georgiy Pavlovich Barsanov for more than 60 years. Once when I was doing my post-graduate studies under his supervision he asked me "Erika, when did we meet? You always have been floating before my eyes".

I cannot say for sure the time when I started "to float before his eyes" but I remember perfectly how I first saw him. It was soon after the war. I was looking at minerals in showcases in the museum and Georgiy Pavlovich was descending the stairs to the museums hall. He was walking with crutches after recovering from a severe battle injury. It took him a lot of effort and his face was drawn. For some reason I have hidden behind the showcase because I did not want him to see me.

In 1947, as a first year student of the Moscow State University I headed a school hobby group. In the beginning it was held at Sverdlovsky district Schoolchildren's Palace. Later I got tired of coming there with all rock samples and slides and I transferred the group to the department. Sometimes I took them to the museum.

As far as I remember, meetings of the All-Union Mineralogical Society often took place in the museum, as well as the museum mineralogical seminar that still continues to function there. I participated in their meetings with pleasure.

One year later, I found a love that has lasted my whole life! My beloved is quartz. I was amazed by everything in the mineral: the simplicity of the composition and complexity of the structure (oxide by chemistry and silicate by structure), the enormous industrial value and the beauty of its crystals, the omnipresence and rarity of industrial quality samples. Everything was striking! I read about it and looked at it, looked and read. There was only one place to look at my subject – Fersman Mineralogical Museum.

I read articles on quartz by G.G. Lemmlein published in the *Doklady Akademii Nauk SSSR* (Reports of Earth Sciences). The articles were written in telegraphese and I was totally confused. Nikolay Alexeevich Smolyaninov, the chair of mineralogical department, advised me to ask Georgiy Glebovich Lemmlein personally and wrote him a note.

G.G. Lemmlein worked in the Institute of Crystallography of the Academy of Science and I imagined him as a grey-haired old man with large beard. I came to the Institute of Crystallography, found the office, knocked at the door and came in. I was struck by the sight of a big room, the floor covered with a carpet of several layers of printed articles. A fairly young brown haired man with a modern hairstyle was crawling on the floor trying to put in order the prints. I paused not knowing what to do because there was no space to step. "Are you looking for me? Come on in and sit down", Georgiy Glebovich invited me. I watched my steps. Walking along the wall to a table, I tried not to step on "the science". Georgiy Glebovich read the note, talked with me, and offered me an opportunity to work on the problem of quartz coloration in his laboratory. I immediately agreed. You bet! I could not even dream of such good fortune!

After graduating from Lomonosov Moscow University in 1951, I was appointed to work in the IGEM (the Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry of the Academy of Science) at the department of non-metallic minerals, lead by Valeriy Petrovich Petrov. Georgiy Pavlovich knew V.P. Petrov from studying with him in Tbilisi. I headed a school hobby group in the museum from the very beginning of the work in the IGEM with the blessing of Georgiy Pavlovich. I remember well some colleagues who worked in the museum in 1950s. The first one was Malva Alexandrovna Smirnova. I met her long before she came to the museum because we started studying together in the same department at the university. I also frequently encountered Natan Il'ich Ginsburg, Valentina Vasilyevna Yakubova, Maria Efremovna Yakovleva, Valeriya Alexandrovna Kometova...

I remember Alexander Nikolaevich Labuntsov. One instance is etched in my memory: a certain young man came to consult with him. Alexander Nikolaevich referred the man to Ekaterina Evtikhievna Kostyleva because she had better knowledge of the subject. "What do you know? She is such a horrid woman!" – said the guest out loud. "Do you think so?" –

humbly replied Alexander Nikolaevich, — "You know, I have not found that despite living with her for many years".

I remember Moisey Davidovich Dorfman, the permanent scientific secretary of the mineralogical seminar. He used to invite me to the meetings until recently. It is very unfortunate that I have not been able to attend the meetings in recent years.

V.P. Petrov changed the theme of my investigation three times in IGEM. Besides that I had to perform tasks for the SOPS (Council for studying industrial forces of the country). I had to do research on refractories, white clays and so on. Besides my main studies I had a deviation to the side interest — quartz. It was my "forbidden" love! I studied it little by little, wrote small articles on inclusions in quartz, its associations and regularities of intergrowth with other minerals. As a rule those papers were published in the Proceedings of the Mineralogical Museum. V.P. Petrov called them my "scientific waste".

I worked in the department of non-metallic ores of the IGEM for 9 years. I finished writing a thesis on defects in muscovite crystals. I passed the qualifying examinations for the Candidate Degree, had papers published, and the thesis was case bound. I handed the thesis to V.P. Petrov, the head of the department. He put the work in his drawer and locked it there for two years. Regarding questions about the fate of my thesis, he replied that he had handed it to a prominent specialist on muscovite, for reference. I waited.

Once I visited Volodya Fin'ko, a colleague of the department. He graduated from the MSU a year after me. I noticed the familiar spine of my thesis on his bookshelf and asked him how he happened to have it. He said, "the boss gave me a work that was completely out of my field." Volodya had not even read the author's name because it was "out of subject" for him. I had to go to V.P. Petrov and ask him what happened. He replied: "the thesis was not good enough for defense. It was obsolete!" I noticed that it was his fault it became obsolete. "Why did you use dated material? Write for a daily newspaper," he said.

I was bitterly hurt. The resentment became even stronger with the fact that V.P. Petrov switched the topic of my study from muscovite to clay half a year before this happened. According to the vivid expression of V. Fin'ko, clay "was completely out of my field".

I went to Georgiy Pavlovich. Who else could console my resentment and bitterness? Georgiy Pavlovich suggested I enter the postgraduate



Fig 1. G.P. Barsanov in his room at the Lomonosov Moscow State University. 1970s.

program under his supervision. I considered coming to the MSU with my muscovite studies and agreed right away. I had plenty of time and thought I would revise the thesis and add new material... However Georgiy Pavlovich tapped on my "scientific waste" sitting on a desk and said: "Erika, we will do a study on quartz." I was very happy that at last my "forbidden" love had become "legal"!

Georgiy Pavlovich was interested in whether the low temperature α -quartz or high temperature β -quartz originally occurred in pegmatites in general and particularly in graphic intergrowths. Transition of β -quartz into α -quartz occurs at 573°C. It means that all quartz on the earth's surface represents its α -variety. Georgiy Pavlovich thought that quartz in pegmatites was originally the high temperature variety. This idea needed to be proved.

Georgiy Pavlovich from the first days of my postgraduate studies acquainted me with teaching. My first class consisted of soil science students. Their course started with crystallography. I was shocked because I found that I had forgotten everything! Georgiy Pavlovich told me: "Erika, you cannot forget it. Take a book, browse through it, take crystal models, look at them thoroughly, turn them around, and go." What else could I do? I browsed, looked and went. Then it started: 8 hours of preparation followed



Fig. 2.
E.Ya. Gur'eva, post-graduate student of G.P. Barsanov

by 2 hours of lesson! There was no single sample or crystal students saw that would miss my thorough observation from every side. I was lucky that soil science students had a brief course.

I was dreaming to pass through examinations as quickly as possible and proceed with quartz studies, which I realized would be a big technical problem. I had to pass exams on special subjects such as general mineralogy and mineralogy of quartz. I assumed the exam would be administrated in the traditional way. Georgiy Pavlovich anticipated my assumption, "What exam on general mineralogy are you talking about? Your students examine you every week on this subject!" It was the truth! My next group consisted of geology students: 16 boys and one girl. When I have entered the auditorium for the first time, no one stood up to greet me. Three boys at the last row of desks were smoking, sitting with their feet on the desks and blowing rings of smoke to the ceiling. "Be so kind as to stand up," I said, "and you by the wall stop smoking!" My words yielded no response. "Well, lets waste time now so you will not have time closer to exams," – I said and took care of my own business. In a little while later, the female student said: "All right guys, that's enough of playing the fool". All stood up and the lesson went on. Those students exasperated me bringing samples for mineral identification to every lesson. I was afraid of coming to the class. Once the students stuffed a crack in granite with a soft piece of bread colored with blue watercolor and asked what mineral it was.

I remember one student brought a sample which I did not recognize from first glance. "Where is it from?" I asked. "From the Carpathians," he answered. I came to the window and looked attentively at the small green

segregations. Aegerine! From the Kola Peninsula! They were not a classical crystals associated with bright eudialyte, but very plain grayish-green and eroded. I turned back to the students. The owner of the sample walked away. I explained to the rest of the students about the sample and added "this is not from Carpathians but from the Kola Peninsula. Carpathian samples I will show him on the examination!" After that instance the students did not dare to examine me.

Once I could not come to the class because of an examination for the Candidate Degree. But I did not have the actual examination again. Georgiy Pavlovich objected: "Do you want an exam with examination paper and three questions? No! You will make a report on the chair meeting describing quartz in general and specifically, your work questions." My report lasted for 30 – 40 minutes and was followed with answering questions and then examination protocol was finished. This decision was very wise. First, this way was much more serious than plain "examination paper and 3 questions". Secondly, it was a rehearsal of the thesis defense.

I looked through the collections of the Mineralogical Museum and ones at the chair before resuming work with quartz in pegmatites. Crystals of β -quartz were well formed hexagonal bipyramids of grey color. I was surprised by the fact that the commonly used symmetry formula for them was L_66L_2 (P6₄22). The low temperature quartz crystal formula: L_33L_2 is understandable; the crystal has trapezoidal faces. This faces are absent in high, or β -quartz. I looked through the bibliography in Russian and English. There were no any references of trapezoidal faces in β -quartz. I went to ask Georgiy Pavlovich. He took an interest in it and checked the bibliography in French and, I think, in Spanish. The result was the same.

Georgiy Pavlovich advised me to contact N.V. Belov on this question. I came to his office and asked why L_66L_2 was the symmetry formula for β -quartz. "What do you expect?" asked Nikolay Vasilyevich. "I expected 7 more mirror planes of symmetry and a center of symmetry," I replied. Nikolay Vasilyevich put his hands on his hips: "What makes you so clever?" "I'm from the Chair of Mineralogy", I replied, "a postgraduate student of Georgiy Pavlovich". "So, if you are a postgraduate student and more over one of Georgiy Pavlovich, you should know that if there is a trapezoidal face present, there can be neither planes nor center of symmetry!" – he exclaimed. "I know, but there

is no trapezoidal face," I defended myself.

N.V. Belov had a thought and said: "Write to Shubnikov." I wrote. In return, Alexey Vasilyevich (Shubnikov) sent me a sketch of β -quartz structure that he calculated. According to the structure its formula was $L_6\delta L_2$. This drawing by Shubnikov I included in my thesis.

I started studying quartz twin crystals. Works by E.V. Tsinzerling from the Crystallography Institute helped me a lot with understanding this subject. α - and β -quartz have different twinning but it does not change during polymorph transition. It was easy to observe on macro crystals. Thin sections were a different matter. I had to etch quartz grains with fluoric acid after having covered adjacent feldspar with paraffine in advance. It was very easy to destroy thin sections. It took a lot of thin sections and polished sections which I prepared all by myself. I am grateful to N.A. Smolyaninov who forced us, fifth-year students, despite of our strong resistance, to learn how to make thin sections. He told us: "I understand that you may not have the need to make them, but you need to know how to judge the quality of the work."

There is a volume change of the quartz when α - β -transition happens. Formation of cellular texture occurs in quartz as a consequence. I had to make a number of micro photographs to prove it because the difference between twin patterns and peculiarities of cellular structure is hard to explain in words. I also had to do a lot of optical microscopy.

Georgiy Pavlovich allowed me to use A.E. Fersman's collection on pegmatites from the museum when I started the work. "You would not make such a collection until the end of your days," said Georgiy Pavlovich with irony, "I suggest Alexander Eugen'evich would agree with your participation in this work." As a supervisor, Georgiy Pavlovich was an easy person to talk with and very attentive. He was not a person who would push. He never said "Do this, do that...". Sometimes he just said: "Why would you not try this?" He had a light hand giving advice and I thought that it was me who hit upon the idea! Only later did I realize that it had been a prompt from Georgiy Pavlovich. I had studied pegmatites from various deposits and obtained the result: quartz in graphic textured pegmatites was initially a high temperature β -polymorph. The supposition of Georgiy Pavlovich was proved to be true!

Georgiy Pavlovich in my memory was a very intellectual person. When I used to enter his office, or more correctly, flew into it; I immediately sat down to prevent Georgiy Pavlovich

from standing up. He was very witty. Once, a final-year student came to his study. He was boastful and swanky and said "I have bought myself a motorcycle". "What for?" asked Georgiy Pavlovich. The student replied "I want to travel the world". "This one, or the other?" Georgiy Pavlovich asked.

While preparing for the defense of my thesis, I went on teaching students. Georgiy Pavlovich was a dean of the Geological faculty in that time, and every thing concerning students was keenly interesting for him. I briefly told him about our classes, said: "Everything is good, as usual, I obscure students brains..." Once Georgiy Pavlovich said to me: "Erika, if you obscure the brains even for a couple of students — it will be a good deal!"

Naturally, I could not finish the dissertation in three years. Georgiy Pavlovich proposed me to the department committee that I continued working in the department and they accepted. Some people did not believe that I would succeed when I had started work on the thesis. Even G.G. Lemmlein questioned whether it was a topic for the post graduate thesis during one of our meetings. Only Georgiy Pavlovich believed in my success and backed me up in everything. When it was close to the defense I told him about it. Georgiy Pavlovich laughed and said: "God knew who he had given the understanding to!" By the way, the polished and etched samples of quartz were stored for a long time in Georgiy Pavlovich's office on the lower shelf of the bookcase.

The defense was successful. Three colleagues from the department of non-metallic ores of the IGEM listened to my defense. They shared how V.P. Petrov received the synopsis of my thesis and showed it to everyone at the institute saying: "What an excellent job my pupils do!" Georgiy Pavlovich didn't pay attention to this event, he even took the anecdote with a good sense of humor.

I have fond memories of New Year's celebrations for the children at the University. I brought my son Sergey in the morning, and left him on the 27th floor in the museum. Then we had lunch together in the professors dining hall. Georgiy Pavlovich came with his daughter Tanya and we went down to the party. Georgiy Pavlovich took the children by the hands and they entered the circle dance... I watched them and was so happy. It was very nice, so cheerful and touching!

In my memory Georgiy Pavlovich stands out as a wise, very kind, intelligent and excellent man with a good sense of humor.

Mineralogical Notes



Fe-DOMINATED BOGDANOVITE, $\text{Au}_5\text{CuFe}_2(\text{Te,Pb})_2$, FROM CEMENTATION ZONE OF THE AGINSKY GOLD-TELLURIDE DEPOSIT, KAMCHATKA PENINSULA, RUSSIA

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Fe-dominated bogdanovite, $\text{Au}_5\text{CuFe}_2(\text{Te,Pb})_2$, a specific supergene mineral, occurs in the weathering profile (in cementation zone) of the Aginsky gold-telluride deposit, Kamchatka Peninsula, Russia. Bogdanovite has been formed as a result of replacement of hypogene kostovite, krennerite, sylvanite, altaite, nagyagite, bornite, and chalcocopyrite. The mineral is associated with Fe-Pb and Fe-Cu-Pb tellurites. In the oxidized zone, bogdanovite is replaced by fine-grained segregations of gold, balyakinite, and plumbotellurite. The composition of Fe-dominated bogdanovite (average of four point analyses) is as follows, wt %: 60.35 Au, 2.19 Ag, 4.63 Cu, 9.33 Fe, 9.99 Te, 12.83 Pb, 0.07 Se; total is 99.39. Formula is as follows: $\text{Au}_{4.33}\text{Ag}_{0.29}\text{Cu}_{1.03}\text{Fe}_{2.36}\text{Te}_{1.11}\text{Pb}_{0.87}\text{Se}_{0.01}$. Bogdanovite has a metallic type of conductivity and relatively high microhardness $\text{VHN}_{20} = 290 - 354 \text{ kg/mm}^2$, average 321 kg/mm^2 ($n = 14$). The mineral is anisotropic, biaxial. It is extremely specific in reflected light. Color bireflectance varying from grey and light violet to bright golden and red, and strong color anisotropy are characteristic features. Reflectance ranges from 2 to 43% in visible light. Change of reflectance sign at 670 nm is typical. According to optical parameters, the symmetry of bogdanovite is not higher than orthorhombic. According to X-ray diffraction data, bogdanovite is interstitial superstructure of the Me_4X type derived from face-centered lattice of gold. Parameter of the primitive pseudocubic subcell is 4.087 Å. Color images of Fe-dominated bogdanovite are first shown that will assist for corrected application of term bogdanovite.

2 figures, 13 references.

Keywords: bogdanovite, gold-telluride deposit, Kamchatka.

Currently, 41 mineral species of gold are known; seventeen of them were identified in weathering profile. The newly formed gold minerals are: gold of high fineness; Cu-bearing gold group minerals; sooty tellurides; gold tellurides, selenides, and sulfides including petzite, AuAg_3Te_2 , sylvanite, AuAgTe_4 , mutmannite, AuAgTe_2 , petrovskaite $\text{AuAg}(\text{S,Se})$; and plumbotellurites, stibioplumbotellurites, bilibinskite, $\text{Au}_5\text{Cu}_3(\text{Te,Pb})_5$, Sb-rich bilibinskite, $\text{Au}_6\text{Cu}_2(\text{Te,Pb,Sb,Bi})_5$, Cu-rich bogdanovite $\text{Au}_5\text{Cu}_3(\text{Te,Pb})_2$, Fe-rich bogdanovite $\text{Au}_5\text{CuFe}_2(\text{Te,Pb})_2$, bezsmertnovite $\text{Au}_4\text{Cu}(\text{Te,Pb})$; and oxides AuSbO_3 and AuTeO_3 (Sindeeva, 1959; Petrovskaya, 1973; Nesterenko *et al.*, 1984; Spiridonov and Chvileva, 1979, 1982, 1985; Chvileva *et al.*, 1988; Nekrasov, 1991).

(altaite, tellurobismuthite, rucklidgeite, sylvanite, krennerite, kostovite, petzite, hessite, and nagyagite), and native gold are ore minerals. Their fine segregations are irregular distributed in chalcedony-like quartz forming gold-rich clusters up to a few decimeters across (Sakharova *et al.*, 1984).

Outcropped ore is significantly oxidized and leached. Vein quartz contains clusters of limomite and malachite, tellurite, plumbotellurite, mackayite, balyakinite (Spiridonov, 1980), other supergene tellurites, fine-scalloped supergene gold, and chlorargyrite. Between primary ore and oxidized zone, there is cementation zone, where most hypogene tellurides, bornite and part of chalcocopyrite are replaced by aggregates of Fe-Pb and Fe-Cu-Pb tellurites and various gold plumbotellurites.

Aginsky deposit

The Aginsky epithermal volcanic-related vein type low-sulfidation gold-telluride deposit (Shchepot'ev *et al.*, 1989; Naumova, 1996) located in the Central-Kamchatka structure is controlled by the Tertiary arc volcanic rocks. By geomorphology, the deposit is a sufficiently high mountain. Ore veins are composed of multiple crustified crusts of chalcedony-like quartz, which cement fragments of altered volcanic and terrigenous rocks. Altered wall-rocks are hydromica and dickite argillic and silicified rocks (Naumova, 1996). Sulfides (pyrite, chalcocopyrite, bornite-chalcocopyrite intergrowths, and fahlores including goldfieldite), tellurides

Fe-dominated bogdanovite from the Aginsky deposit

Bogdanovite occurs along cleavage of krennerite and sylvanite, relicts of which were observed in its segregations. Relicts of kostovite, altaite, and nagyagite in bogdanovite are extremely rare. These poor stable minerals are completely replaced. Bogdanovite partially replaced hypogene bornite and chalcocopyrite. Cu-dominated bogdanovite is associated with bilibinskite and Fe-Cu-Pb tellurites, bezsmertnovite, and Cu-bearing gold. Fe-dominated bogdanovite is associated with Fe-Pb tellurides (Fig. 1); between these minerals there are compromise growth surfaces.

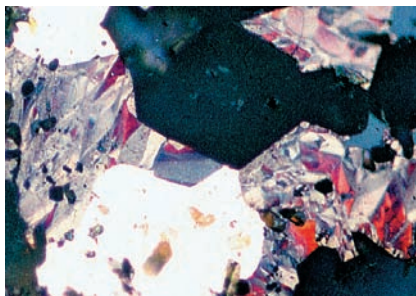
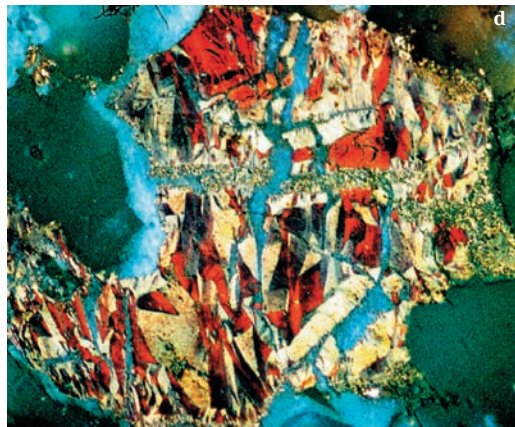
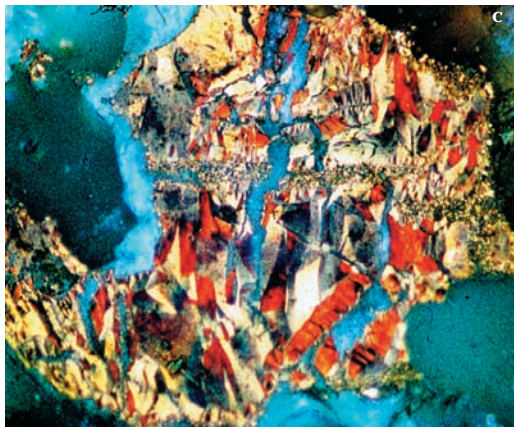
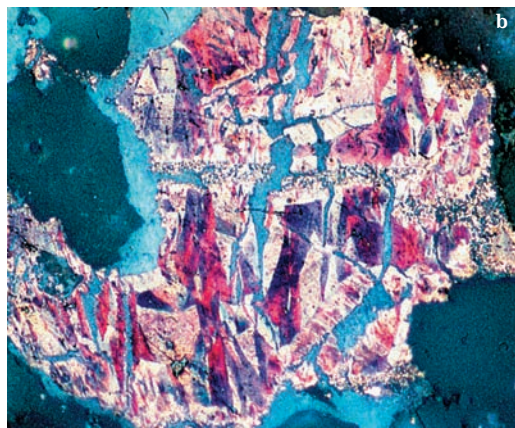
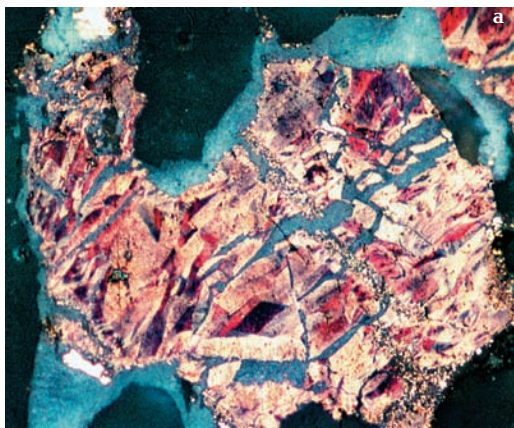


Fig. 1. Photomicrograph of Fe-dominated bogdanovite with bright color bireflectance, a pseudomorph after hypogene kostovite, krennerite, and altaite, filling interstices between crystals of quartz and hypogene gold (white-yellow) and intergrown with Fe-Pb tellurite (bluish gray). Reflected light, parallel polaroids. Image width 0.25 mm.

Fig. 2. Photomicrograph of segregations of Fe-dominated bogdanovite. a, b – bright color bireflectance, parallel polaroids; c, d – very strong color effects of anisotropy, crossed polaroids. Bogdanovite partially replaced balyakinite (sky blue) and tiny grains of gold of high fineness. Image width 0.35 mm.



Fe-dominated bogdanovite occurs as intergrowths of randomly oriented crystals, which are frequently split (Figs. 1, 2). Segregations are up to 1 mm in size; monoblocks are not more than 20 μm in size. Megascopally, it looks like bornite. It is well polished. Bogdanovite has a metallic type of conductivity and relatively high microhardness $\text{VHN}_{20} = 290 - 354 \text{ kg/mm}^2$; mean value is 321 kg/mm^2 ($n = 14$); it is harder than gold.

In reflected light in light position, it is like bornite. In dark position, the mineral is uncommonly distinctive; the strong and contrast color

effects of bireflectance and anisotropy are characteristic (Figs. 1, 2). The reflectance ranges from weak (2%) to medium (43%). In variable cross-sections, the mineral color ranges from grayish violet and magenta crimson to bright golden yellow and red. The measured values of reflectance in air are as follows, $R_g, R_p, R_m, \%$: 15.6, 11.5, 13.9 (400 nm), 14.8, 9.5, 13.0 (420 nm), 14.2, 8.0, 12.8 (440 nm), 13.8, 6.7, 12.1 (460 nm), 13.8, 5.4, 11.6 (480 nm), – 15.6, 4.4, 11.7 (500 nm), 21.5, 3.4, 13.5 (520 nm), 28.3, 2.5, 16.3 (540 nm), 33.5, 2.2, 19.1 (560 nm), 36.4, 3.0, 21.0 (580 nm), 37.9, 5.9, 22.2 (600 nm), 38.3, 11.9, 22.6 (620 nm), 37.4, 21.0, 22.6

(640 nm), 35.8, 29.9, 22.5 (660 nm), 33.9, 36.9, 22.3 (680 nm), 31.7, 42.8, 22.0 (700 nm); analyst T.N. Chvileva, Institute of Mineralogy, Geochemistry, and Crystal Chemistry of Rere Elements, Moscow, Russia. The reflectances of Fe-dominated and Cu-dominated bogdanovite are similar. The section of curve R_g is similar to R section of gold. The mineral is biaxial. The reflectance sign changes at 670 nm. According to the most important color parameters, purity (color saturation, p) and hue (λ), bogdanovite ($p = 52\%$, $\lambda = 582$ nm) is close to native gold ($p = 48\%$, $\lambda = 577$ nm). The color saturation of gold was suggested to be the highest of all known ore minerals (Nekrasov, 1991). According to optical parameters, the symmetry of bogdanovite is not higher than orthorhombic.

The composition of Fe-dominated bogdanovite (average of four point analyses) is as follows, wt. %: 60.35 Au, 2.19 Ag, 4.63 Cu, 9.33 Fe, 9.99 Te, 12.83 Pb, 0.07 Se; total is 99.39. Formula is as follows: $(\text{Au}_{4.33}\text{Ag}_{0.29}\text{Cu}_{0.38})_5(\text{Cu}_{0.65}\text{Fe}_{0.35})\text{Fe}_{2.01}(\text{Te}_{1.11}\text{Pb}_{0.87}\text{Se}_{0.01})_{1.99}$ that is close to $\text{Au}_5\text{CuFe}_2(\text{Te,Pb})_2$.

X-ray powder diffraction pattern (Debye powder pattern) was recorded for the sample which had been chemically analyzed. X-ray powder diffraction pattern of bogdanovite was corrected using special picture with NaCl ($\lambda\text{FeK}\alpha$): 4.06 Å (0.5), 2.90 (0.5), 2.36 (10), 2.15 (1), 2.045 (6), 1.446 (6), 1.293 (0.5–1), 1.230 (8), 1.180 (3), 1.092 (2–3), 0.992 (2–3); analyst T.L. Evstigneeva, Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Moscow, Russia. According to d -spacing and relation of intensities, X-ray diffraction pattern of bogdanovite is close to that of gold reported by Berry and Thompson (1962). It allows suggestion that the structure of bogdanovite is close face-centered cubic lattice of gold. In comparison with gold, X-ray diffraction pattern of bogdanovite contains additional reflections, which like the strongest reflections are indexed on the basis of primitive pseudocubic cell with $a_0 = 4.087$ Å. Only weak reflection 2.15 Å (1) is not indexed in this subcell. According to X-ray diffraction data, bogdanovite is interstitial superstructure of the Me_4X type derived from face-centered lattice of gold (Spiridonov, Chvileva, 1979).

Replacement products of bogdanovite from the Aginsky deposit

Like other bilibinskite group minerals, Fe-dominated bogdanovite is ephemeral. In oxidized zone, they are extremely unstable and easily replaced by fine-grained aggre-

gates of gold of high fineness, tellurite, balyakinite, radjite, chololite, teynite, graemite, plumbotellurite, mackayite, and other tellurites, oxytellurites, and tellurates. Partially such replacement exhibits in the upper cementation zone (see Fig. 2).

Acknowledgments

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ABOUT MACKINAWITE INCLUSIONS IN GROSSULAR CRYSTALS AT THE TALNAKH (MT. OTDEL'NAYA) ACHTARANDITE LOCALITY

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The discovery of mackinawite in paragenesis with magnesio-chromite within inclusions in grossular garnet at the Otdel'naya mountain locality of achtarandite in the Talnakh region is described. An occurrence of the mackinawite is an evidence of the low-temperature conditions of the achtarandite mineral association formation.

1 figure, 3 references.

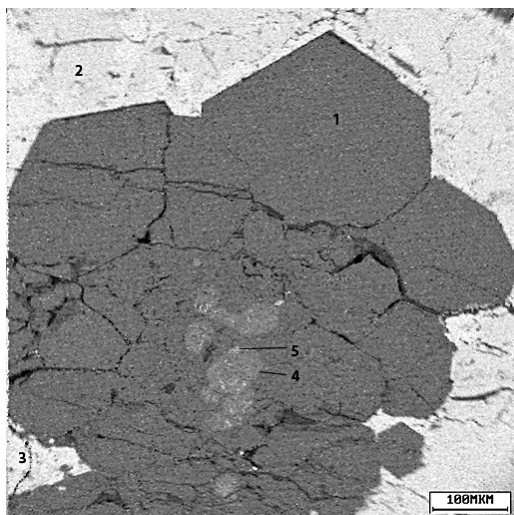
Keywords: mackinawite, grossular, prehnite-pumpellyite facies, low-grade metamorphism, Otdel'naya mountain.

Otdel'naya mountain locality of achtarandite in the Talnakh region is analogous to the world-known Wiluy river one in Yakutia by its mineral composition. The main ore-forming minerals at both localities are grossular, vesuvianite and achtarandite formed as phenocrysts in the strongly altered rocks. The most widely spread garnet at the Mt. Otdel'naya locality is Cr-Ti-containing grossular and grossular which constitute central and edge parts of a crystal respectively (Alferova, 2007). The garnet contains multiple mineral and fluid inclusions, and therefore looks semi-translucent. Mineral inclusions are represented with relatively high-temperature magnesio-chromite, Al-containing magnesio-chromite,

vesuvianite, amesite, stilbite, chalcopyrite and mackinawite — the most low-temperature of all above-listed.

The mackinawite occurs as a xenomorphic ingrowth up to 10 μ in the central, dark-green part of a garnet in contact with magnesio-chromite and within its crystals (Fig. 1). Chemical composition of the mackinawite corresponds to the formula $\text{Fe}_{0.64}\text{Ni}_{0.36}\text{Co}_{0.01}\text{S}_{0.99}$. Both the mackinawite presence and its ingrowths position in the phase contact zone testify to the low-grade forming conditions responding to the prehnite-pumpellyite facia of a low-grade metamorphism (Spiridonov *et al.*, 2000). Experimental study showed that the mackinawite stability field temperature limits are 50°C to 130–240°C (Takeno *et al.*, 1970). Thus, the mineral paragenesis with mackinawite once again reveals the low-temperature and multi-stage conditions of its formation at Mt. Otdel'naya achtarandite locality.

Figure 1. Cr-Ti-containing grossular aggregate (1) within pyrrhotite-pentlandite matrix (2) having chalcopyrite segregations (3), with alumo-magnesio-chromite inclusions (4) with mackinawite ingrowth (5). Mt. Otdel'naya, Talnakh.



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Discussions



THE ESSAYS ON FUNDAMENTAL AND GENETIC MINERALOGY: 3. MINERALS OF VARIABLE COMPOSITION WITH VARIABLE STRUCTURE AND PROBLEMS OF SPECIES FORMATION IN MINERALOGY. EUDIALYTE–EUCOLITES

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This paper is one of a series on genetic and fundamental mineralogy (Borutzky, 2005; 2006) where the problem of mineral species definition are discussed. In particular, the correlation of such fundamental terms in mineralogy as *mineral* – *mineral species* – *mineral variety* are considered, and compared to analogous nomenclature units in biology – another natural science. Also, the necessity for a genetic basis in mineral species definition is shown and the natural genetic taxonomy elaborated and applied to the feldspar group is demonstrated; this approach was used for the corresponding part in “Minerals” reference book (2003). The author insists that formalised structural and chemical criteria for mineral species recommended by the International Mineralogical Association (IMA) Commission on New Minerals, Nomenclature and Classification (CNMNC) without consideration of genesis discredits mineralogical science, because the result in unwarranted “reproduction” of abstract species which do not correspond to real discrete mineral entities widespread in certain geological environments. The paper is devoted to the detailed consideration of so-called *minerals of variable composition and variable structure* defined by the author (Borutzky, 1997; 1999) using the example of eudialyte-eucolites, and also the scientific and opportunistic problems accompanying the study of these chemically and structurally unique minerals. 6 figures, 111 references.

Keywords: minerals of variable composition and variable structure, eudialytes-eucolites, new mineral species, the new mineral species criteria.

If mineralogy is to be considered as a geological science¹, i.e. – a natural historical science, then the minerals (the main form of inorganic matter existence in nature) should be studied in accordance with their development history: as they were formed during geological processes and their continued existence until their destruction or replacement by other minerals. This study considers the complexity of chemical composition, real variations and crystal structure modifications which change during crystallization and post-crystallization transformations according to the physicochemical parameters of the mineral-forming and mineral-retentive environment.

The main criterion for *mineral species* differentiation is the existence of *independent stability fields* for the individual minerals in their totality with no drastic phase transitions boundaries, dissolution fields and with their *chemical and structural individuality* preserved. The *most significant* evidence of these are: crystal structure *type* and the preservation of the main chemical components ratio. This does not exclude *gradual* variations of chemical composition within the stability field which could be accompanied by some structural effects caused by adjustment to these changes; however these are to be considered as less significant, which, if they do not exceed the limits of a mineral species, be described as mineral varieties. The most and least significant evidence correlation is overviewed earlier (Borutzky, Urusov, 2008).

Thus a *genetic* approach to the problem of mineral species definition differs fundamentally from the commonly accepted formal criteria, which are recommended and used in the practice of new species approval by the IMA CNMNC. This approach is based on objective evidence of independent mineral phase formation during geological-geochemical processes; on the analysis of stability fields, real boundary changes during changing physical-chemical mineral-forming conditions, analysis of specific geological environments and their affect on modification of chemical composition and mineral structure.

These principles are appropriately the most applicable for the thoroughly studied, both structurally and physical-chemically, rock-forming minerals, for example alkaline feldspars (Borutzky, 2006). It is easy to show that real triclinic albite and microcline co-existing at low temperatures, contain not more than 5 and 10% of K- and Na-component respectively (which fundamentally differs from the CNMNC IMA “50% rule”), as they are divided by the solvus field. Chemical compositions of the high-temperature analbite (anorthoclase) and sanidine respectively vary from Ab₁₀₀ at 980°C to Ab₈₀Or₂₀ at 650°C, and from Or_{0–100} at 980° to Or_{90–100} at 500°C, divided into two stability fields – triclinic Na- and monoclinic K-feldspar, high-temperature solvus field and sloping straight line of non-quenching inversion

¹ – Not all the scientists accept this: some chemists consider mineralogy as a part of chemistry, and physicists – as a part of physics. Others believe that there is no such science and the only task for mineralogists is minerals detecting. Geochemistry, petrology and lithology determine their formation conditions, patterns/rules of mineral and their associations and distribution within geological formations. However it is well known from experience that it is difficult to do without a fundamental knowledge of mineral matter. Evidently this is the reason why the above mentioned scientists rarely use mineralogical indicators during analysis of rock-forming conditions at the certain geological regions.

$C2/m \rightarrow C\bar{1}$ (which also differs from the "50% rule"). Above 980° all the compounds from Ab_{100} to Or_{100} form *continuous isomorphous series* of monoclinic alkaline feldspars (the single stability field) that according to Lazarenko's (1963) concept allows consideration as a single mineral species (we shall name it K_2Na -sanidine, as it is not to be divided into two *species* due to its continuity). It is essential that these seven determined mineral species are not invented but are being formed in real geological conditions. At present not a single researcher familiar with modern achievements in the feldspar matter studies will conform to the rules of the CNMNC, as this would be equivalent to Stone Age concepts.

The situation is more complex with rare and as usual poorly understood minerals. Genetic criteria in this case are hidden in structural interrelations between the supposed mineral species. As mineral species are discrete mineral entities with equal features, then single whole individual (grain, crystal) cannot contain several mineral species. From our point of view, attribution of different crystal zones or sectors to different mineral species according to the formally applied *dominance rule* i.e. "50% rule" (which is used at crystallochemically unequal position in structure percentage) is nonsense. The wide spread application of this rule without genesis consideration clear the boundless opportunities for unwarranted "reproduction" of mineral species at the expense of former chemical and structural varieties of well-known minerals.

Intrastructural component substitutions (ion exchange) observed in mineral individuals, typical for zeolite-like structures, can cause certain difficulties. There are no phase boundaries within the grain, however component contents tend to change slightly from periphery towards the centre and along cracks. *Minerals with variable chemical composition and variable crystal structure* (conditionally named *MVCVS*) have a special place among the above mentioned minerals (Borutzky, 1997; 1999). The mineral-forming process of such a formations is a specific natural phenomenon, caused by their crystal structures' ability to involve large quantity of different chemical microelements from a mineral-forming medium, and to distribute them into suitable structural positions with their partial reorganization which does not modify the main structural motive of a mineral. Despite being of unusual complexity and straining of their structures, *MVCVS* appear to be stable and energy-wise in a relatively low-temperature probably non-equilibrium geochemical processes, which sensitively react to local changes of the solutions chemical composition and components interaction in the mineral-forming (mineral-preserving) environment. One of the typical *MVCVS* examples are eudialyte-eucolites described below.

Address to the opponents

«*Science is to be divided into natural (the humanities), unnatural (perverted) and perverted*».

Leo Landau

Traditional understanding of mineralogy was inculcated upon the author by his teachers — *mineralogists-geologists*. Opponents (Rastsvetaeva, 2006; Rastsvetaeva, Chukanov, 2006), inspired by fantastic progress in structural analysis methods during recent years, attempt (and not unsuccessfully) to impose purely crystallochemical understanding of mineralogy including speciation problems. It is most unlikely they would change their minds — this is "disease" of our time; moreover they are guided by officially accepted CNMNC recommendations. However there is no way of keeping silent regarding some of their remarks — it appears that they are either ignorant about the fundamental distinctions of the genetic approach and the essence of criticism of already known mineral species formal reproduction ("cloning"), or deliberately mislead readers arrogating to us arguments that were never expressed.

Thus, Ramiza K. Rastsvetaeva (2006) in the foreword of another "mineralogical tale", reprinted from "Nature" magazine, assumes that the main "(author's) argument against mineral species "clonong" ... is an anxiety that their number will overly increase". This "forgery" leads away from the main point. The problem is not in *quantity* but in *quality* of mineral species. Amongst living organisms there are millions of biological species, but they are all genetically well founded on observations in nature. On the basis of secondary, minor features without being genetic ones, one can be faced by incidents as happened with the butterfly *Ornithoptera paradisea* (fig. 1). Similar dimorphism in biology is widely spread. Of course no one will attribute cock or peacock to one species and hen and peahen to the other, even though they differ externally. It is quite another matter with insects, there are more than a million species, and it is not difficult to get confused and assume desirable from actual. The coloration of insects may vary from region to region, especially on isolated islands. Appearance of insects changes roughly depending on their age and stage of their development, for example butterflies: ovum — caterpillar — chrysalis — imago. What in common have bent worm and winged "fairy"? Nevertheless they both belong to one species.

Also, in mineralogy it is unlikely that somebody will discover new minerals within the feldspar group — it is well-studied. The other matter eudialytes — plenty of space to obscure the issue. Eudialyte is a rare mineral. The crux of the problem is understood only by several dozens of people, but they tend to find out about the new "discovery" only after the mineral was approved by the CNMNC — the "new" minerals are approved in secret by interested scientists who could



Fig. 1. These formally resemble butterflies were attributed to different biological species until it was discovered that the upper one is shining male of *Ornithoptera paradisea*, and the lower is his modest female partner in *paranja*. If genetic aspect of a speciation is not taken into account one could make even more mistakes in mineralogy as well.

raise an objection against it essentially. And what is ... "the pen is mightier than the sword" especially if the mineral has been named after distinguished scientist. And making a protest against new mineral species you correspondingly defame the scientist who you respect and who's name you would not like to pull about in any cause.

Opponents who object to comparison between mineralogy and biology, once again miss the point. We would not like to comment criticism (Rastsvetayeva, Chukanov, 2006) about incompetence of such a comparison: "minerals do not reproduce themselves and do not inherit chromosome from their parents". However the suggestion that the mineralogical "genetic code" could be found in the crystal unit cell, should be commented upon. The fundamental crystallography concept that the unit cell repeats without change within the crystal volume becomes a thing of the past. The *real* structure of a crystal radically differs from the idealized, averaged one due to it is imperfect, fragmentary, blocked, or local symmetry disturbance and atomic ordering, etc. within the crystal lattice volume which exceed one unit cell. These very structural features are to be studied nowadays during new structural varieties or new species definition. Random unit cell can not provide this information, moreover one can choose the unit cell according to the problem posed. For example, for better descriptions of feldspars specialists use the monoclinic cell with $C2/m$ symmetry instead of the formal $P2_1/m$, and triclinic $C1$ – instead of $P1$. "Genetic code" could be rather *crystal structure type*, which put limitations on the presence of either one compound or another. However in mineralogy as well as in biology there are mechanisms similar to mutation which help change structure according to the mineral-forming conditions.

In the chapter "principles of mineral species determination" of the above mentioned paper, Ramiza K.

Rastsvetayeva and Nikita V. Chukanov prove the advantage of *crystallochemical systematization* only because it was approved by the IMA. Yes, unfortunately it was approved, although as far back as 1926 and 1938 A.K. Boldyrev and A.E. Fersman warned against *formalized* division of isomorphous series into two species corresponding to its end-members on the dominance principle. They insisted upon their well-founded differentiation, and E.K. Lazarenko (1963) considered the division of *continuous* isomorphous series because it is *continuous* unnatural, and *conditionally* defined its end-members as mineral varieties. The author is in accord with the arguments of the above mentioned scientists (Borutzky, 2005; 2006). The argument that the similar taxonomy principle "is applied in strictly rational Genevan nomenclature of millions of organic compounds" is unfounded as mineralogy is not chemistry (which was pointed out by A.E. Fersman) but different, *geological, natural* science. Unlike organic chemistry, its objects are being formed, regardless of whether we want it or not, and "live" in geological time changing according to mineral-forming conditions.

And finally, our opponents give pair of minerals, gold and silver, as a "killing" example of an illustration of criticism of *continuous* isomorphous series attribution to a single mineral species. According to their opinion "following this rule formally we have to consider gold and silver as one mineral species. However how should we name it and respective deposits?" Why mislead the readers again? Opponents can not be unaware of the fact there is no *continuous* isomorphous series between gold and silver in nature, unless they both have the same structure and crystallise in $Fm3m$ symmetry. And division of an *imaginary* series would be profanation: silver normally contains up to 2–4% Au having maximum in *küstelite* (10% Au), and silver admixture in gold usually does not exceed 10–15%, maximum 30–45% in *electrum*; therefore stability fields of gold and silver in nature are not superposed. The conclusion about unlimited solubility between Au and Ag obviously originates from chemistry and engineering and unjustifiably transferred to nature. If these *natural* Au,Ag-alloys should be found they surely should be distinguished as individual mineral species and deserving either new name or expanding of already existing *electrum* term. Regarding *gold-silver* deposits there is no need to rename them because deposits are named after metals extracted and not after minerals, among which there are many Au- and Ag-minerals besides native gold and silver.

At the end just in case we will need to explain to possible future opponents the meaning of epigraph to this chapter. We would not like the progress within crystallochemistry or other fields transform mineralogy from natural science into a perverted one.

What is mineral with variable chemical composition and variable crystal structure – (MVCVS)

«The whole number of natural materials does not confine to formulae with prime and multiple ratio but is represented by intermediate members originated from complex chemical process...»

Alexander E. Fersman

Fairly speaking the limits of MVCVS term are uncertain. Any mineral even of a constant chemical composition can be "structurally-variable", and even its space group can vary (which is a speciation criteria, according to the CNMNC recommendations). For example, quartz SiO_2 can be *left* (sp.gr. $P3_121$) and right ($P3_221$), low-temperature α -quartz ($P3_121$; $P3_221$) or high-temperature β -quartz ($P6_222$; $P6_122$). The reason of changes in a space group in this case is minor differences of atoms in a lattice due to growth character or temperature decrease. Reasonably, no individual mineral species are distinguished among them. During cooling, anorthite $\text{CaAl}_2\text{Si}_2\text{O}_8$ transforms from *I-anorthite* (I 1) to primitive *P-anorthite* (P 1) also due to a slight displacement of Ca atoms within an invariable framework where Si and Al are strictly ordered because of compulsory 2:2 stoichiometry (by virtue of Lowenstein principle firmness). And again, these anorthites are considered as structural varieties and not as different mineral species.

Structural variations are quite common for any minerals of variable composition. Even isovalent isomorphous substitutions of ions of different size will cause expansion or contraction of co-ordination polyhedra and respectively distortion of angles between O–Si–O bonds in silicates. This is accompanied by linear and angle parameters of a unit cell as happens with alkaline feldspars. The more noticeable structure "distortions" are caused by heterovalent isomorphous substitutions, by "block" isomorphism etc. Illustration for the latter are plagioclases with blocked constitution where albite coexists with anorthite. It should be mentioned that all these variations occur within a single stability field of a mineral; but although they formally meet the CNMNC recommendations, the Commission does not make haste to proclaim these varieties as individual species. However, some "enthusiasts" launched intensive rethinking of mineralogical data for some mineral groups with variable composition, and it is essential to stop unwarranted "reproduction" of formal mineral species.

In the MVCVS structural variations related along with chemical composition ones are hypertrophied so much that these specific minerals can be attributed to a special group. Even Alexander E. Fersman (1914) drew attention to these objects, he named these "mutable" in other words able to vary "within species" or, biologically speaking – to *mutate*. What are their peculiarities?

Firstly, these are *minerals of complex composition and multi-component structure* which permits the presence of considerably different ion (cation and anion) sizes, electrostatic charges and acid-basic properties that is accompanied with non-destructive crystal lattice local reconstruction of some areas within the crystal structure. Quite often there are several *heterogeneous* radicals in such structures which is, according to Dmitry Yu. Pushcharovsky (Crystallochemical systematization..., 1985), not energetically advantageous from the position of equilibrium energy because it does not meet "economy principle" by L. Pauling, but at the same time obviously has priority in front of a mineral aggregate with the same components, at least, in some specific mineral-forming processes. Dmitry Yu. Pushcharovsky assumes that such structures can be formed by means of competitive influence of several physical-chemical factors, during *postmagmatic* processes at relatively low temperatures and pressures and mineral-forming environment enriched in volatile fluids. Thus, for example eudialyte concurrently includes 3-members $[\text{Si}_3\text{O}_9]$ and 9-members $[\text{Si}_9\text{O}_{27}]$ rings moreover the latter could transform into crimped discs $[\text{SiSi}_9\text{O}_{27}(\text{OH})]$ or $[\text{MSi}_9\text{O}_{27}(\text{OH})_3]$ due to additional Si- tetrahedra or (Nb,Zr,Ti,W...) -octahedra occupying the ring's centres.

Secondly, in such structures one can distinguish a more or less *permanent framework*, consisting not only of Si,Al-tetrahedra, but of constantly present groups bonding them together, and also *additional cations, anions or their clusters*, that might fill spacious cavities and canals in the structure. The composition of these additional compounds can vary widely due to ion-exchange reactions between MVCVS and the environment. In other words, they are *zeolite-like* but with the greater number of interchangeable components which enables them "to adapt themselves" to the environmental changing conditions. Variations in chemical compositions of solutions, component activities ratio and their acid-basic interaction in the first place affect the extra-framework additional components composition. The more essential changes in mineral-forming environment chemistry may cause changes in the *framework* itself.

Thirdly, due to displacement of substituted atoms coordinates during local reconstruction, within the structure additional or "split" positions are formed. They are so close to each other that they cannot be occupied simultaneously and hence are occupied partially; the separate but formally equal structural positions and even micro-areas ("modules") with different composition and construction, related by symmetry appear in the structure. As a consequence of it either the *local change of structure* or identity periods disturbances occur, which in general result in space group or unit cell parameters (its reduplication for example) change. There are situations when "more rigid" atoms are distributed according to the more symmetrical law,

and "more loose" — according to the less symmetrical one, and therefore are to be described with different space groups within a single structure.

Fourthly, the same structural position might be occupied by different chemical elements (with, of course, coordinate displacement and coordinate polyhedra type change), and conversely — the same element might get "spread" over different positions. It can cause insurmountable difficulties both during structural analysis and mineral species and varieties determination. Because on one hand it is impossible to evaluate strictly position occupancy by several elements at once, and on the other hand — one should refine the structure of every micro-volumes of a specimen studied to obtain an objective view on the elemental distribution along positions. As a result, a type specimen might presumably differ from an unstudied specimen, of the same mineral species.

Fifthly, additional components, as usual, are *minor impurities* in *MVCVS*, in quantities up to 5–10 wt.% and therefore do not change the chemical individuality of the phase during the geochemical process and cannot fragment its stability field (at least if there is no data published). On the other hand, *MVCVS* contain the whole number of additional components at once, and therefore it is obviously incorrect to reduce the multi-component formation to binary isomorphous series (or several binary series).

Specific peculiarities of *MVCVS*, in our opinion, enable one to consider them as continuous complex multi-component isomorphous series, i.e. as indivisible mineral series with the whole family of chemical, structural and structural-chemical varieties, at least until convincing data on their stability fields existence in geological environment becomes available. It is important to understand that the CNMNC recommendations on chemical and structural criteria should be applied with care because the objects are not genuine polymorphs but minor displacements of atoms positions and order-disorder effect within the lattice that results in symmetry lowering. Further to realise that there is no sense of micro-impurity position dominance fixation because it does not affect the host-mineral chemical identity. Meanwhile (back to geology) *MVCVS* forming processes deserves careful analysis as they are formed by means of ion-exchanging reactions during metasomatic rocks alteration or later re-crystallisation of metasomatic rocks. The change in chemical composition normally does not affect phase boundary origin as a sign of individual stability fields. Most likely these interrelations show at incomplete processes, equilibrium absence and, finally, metastability of the mineral formations. Figuratively speaking we take the natural process by surprise during its progress, and can analyse its stages and trend owing to these minerals — sensitive mineral indicators.

Historical "oblivion"

«We were interested in drops of saami blood disseminated in tundra, this remarkable stone from Khibiny and Lovozero tundras, which name is eudialyte and which has no equal in the whole world...»

Alexander E. Fersman «Recollections of stone»

The study of eudialytes-eucolites has a long history persistently covered up by modern researchers. Eudialyte was discovered in 1801 by Trommsdorff who unexpectedly detected zirconium in a red "lamellar" garnet with distinct cleavage from Greenland. The first "complete" chemical analysis was performed by Friedrich Stromeyer in 1818; if the determination of five components (Na_2O , CaO , FeO , SiO_2 and ZrO_2) can be named "complete" correctly — at present more than 20 chemical elements detected in eudialyte. However those five are still the principal, mineral-forming elements and constitute 85–90% of its composition. In 1844 at Langesundfjorden (Norway) an unusual "brown wöhlerite" was found and also described as "hyacinth"; later it was considered as an individual mineral *eucolite*. In 1857 N. Møller and A. Damour proved that this is a variety of eudialyte enriched in heavy elements, and A. Des Cloizeaux determined that it differed from eudialyte by its optically negative sign. The full description was presented by V.S. Brögger (Brögger, 1890); in that eucolite P.T. Cleve determined twelve components Na_2O , K_2O , CaO , FeO , MnO , Ce_2O_3 , Y_2O_3 , SiO_2 , ZrO_2 , Nb_2O_5 , Cl and H_2O . Almost 100 years later eudialytes-eucolites from Langesundfjorden were chemically re-studied by H.J. Bollingberg (Bollingberg *et al.*, 1983) who confirmed that Norwegian eucolites are distinctly enriched in niobium and cerium. It should be mentioned that the differences in optical sign was to cause difficulties for eucolite "biography" in the future.

Once again we stress that *eucolite* is not an individual mineral but a *eudialyte* variety, enriched in heavy elements and formed in slightly different geological environment. Mineralogists never tried to close this term down "dramatically" (according to R.K. Rastvetayeva (2007), moreover they tried to define this term concretely and understand what geological-geochemical environments it was formed in. Later investigations revealed that in alkaline complexes where eudialyte-eucolites are most abundant, one can use a term *eucolitization* of eudialyte — geochemically significant natural process superposed on the latest stages of a mineral formation due to change of mineral-forming chemistry.

Many scientists C.-F. Rammelsberg, P. Groat, V.S. Brögger, C. Hintze, J. Dana, F. Zambonini, B. Gossner, F. Mussgnug, W.H. Zachariassen, F. Machatschek, W. Kunitz attempted to understand the contradictory data on chemical composition, optical features and specific gravity of eudialyte-eucolites, which were obtained by the beginning of the last century because this rare mineral was found only in a few regions in the world.

The data on the chemical composition and features of eudialyte-euclolites were considerably widened as a result of Alexander E. Fersman's expeditions to Khibiny and Lovozero massifs in the Kola peninsula (Minerals..., 1937); for the first time they were related to the geological environment of mineral occurrence, and hence it is hard to overestimate the national researchers contribution in eudialyte investigation. Earlier Wilhelm Ramsay (Ramsay, 1983) described zonal grains of eudialyte from Kola, that revealed different optical sign and specific gravity and surmised an isomorphous series between eudialyte and euclolite as that would have explained the relationship between mineral features and its chemical composition. Nowadays when researchers are equipped with microprobe this sort of analysis seem to be primitive, but back in the crystalloptical pre-structural epoch of mineralogical-petrological investigations, these results were considerable and revealed the mineral matter change within separate individuals of eudialyte. The first fundamental data on eudialytes-euclolites belong to Ekaterina E. Kostyleva-Labuntsova (Kostyleva, 1929; 1936). Systematic investigation of eudialyte-euclolites from the Kola peninsula, eudialyte from Kangerdluarssuq and Narsarsuk (Greenland) and euclolite from Langesundfjorden and Arøya (Norway) and Arkansas (USA) enabled her to conclude that there is an isomorphous series between eudialyte enriched in Na, K, H and euclolite enriched in Ca, Mn, Fe, Mg. Specific gravity and refractive indices increase from eudialyte to euclolite, optical sign changes from (" + ") positive to (" - ") negative and the typical raspberry-red colour change to yellow and reddish-brown. She also performed crystallographic investigations and paragenetic associations analysis. Kostyleva concluded that the chemical composition of the mineral is related to composition of the host rocks, in particular, in the Khibiny massif euclolite and accessory calcium minerals prevail, and in Lovozero — so do eudialyte and sodium minerals. Also she concluded that there is no relation between crystal habit, c/a ratio and the position in the isomorphous series, i.e. "structure" depends only upon growth conditions and does not depend on chemical composition.

Unfortunately, Kostyleva fundamental study was not accepted in full. Vladimir G. Feklichev (Feklichev, 1963; 1965; 1973; 1979; Feklichev *et al.*, 1965) who contributed a lot in further Kola eudialyte studies, tried to re-interpret Kostyleva conclusions on the basis of his newly obtained data. He (Feklichev, 1963) simplified Kostyleva's concept and arrogated to her primitive division of an isomorphous series to sodium eudialytes (" + ") and calcium euclolites (" - "). He forgot about other components and their relationship with specific gravity, refraction of light, colour and geological position, and suggested the consideration of the terms eudialyte, mesolite and euclolite only as *optical varieties of eudialyte* with no immediate relationship of

optical sign and chemical composition. On the basis of 15 samples of eudialyte studied he defined three types of eudialyte from Khibiny: 1) large group of *ferriferous series* eudialyte where $Fe > Mn$ (optically " + ", " - " and " ± "), 2) *manganous series* eudialyte with $Mn > Fe$ (in general, " ") and 3) *hydrous and hydrous-potassic series* eudialyte which contain considerable amount of water and decreased amount of alkali and are sodium deficient. It was found that the first group is typical for khibinites, ijolite-urtites and lyavchorrites (however is abundant in another complexes), the second group — for foyaites and ristschorrites of "Yukspor type", the third group — for ristschorrites of "Poachvumchorr type". Feklichev compiled a diagram " n_e / n_o " with fields for " + " and " - " varieties, and therefore assumed that optical sign does not depend directly on refraction of light; nevertheless the most abundant ferriferous eudialytes (both " + " and " - ") occupy the central part of a diagram, and *hydrous-potassic* (" + ") and all *manganous* (" - ") eudialytes — occupy the extreme left and right parts of a diagram respectively. Thus, claiming his own conclusions differ from Kostyleva's he nevertheless verified them because increasing Fe total (especially Fe^{2+}), Mn and less REE — increases light refraction, and increasing of water content — decreases.

Later, Vladimir G. Feklichev (1979) worked in detail on 13 new analyses of eudialyte from Khibiny and showed that the unit cell volume varies from 1743 to 1794 Å³ and the largest belonging to eudialyte enriched in K and H_2O^+ , substituted Na; its volume decreases as Na is substituted by Mn, Ca, REE and Fe^{2+} — and by Fe^{3+} , Nb, Ta, Ti or Zr. The same trend exists for specific gravity — from 2.74 to 3.03 and correlates with increasing optically negative varieties. According to his optical spectrometric study at wavelength of 400–700 nm, the typical raspberry-red colour of eudialyte is due to Mn^{3+} (absorption maximum 520 nm); Fe^{2+} , Fe^{3+} and Ti does not affect the colour, but brown and yellow varieties are likely to be coloured by Fe^{3+} . We will mention in advance that this conclusion proved not to be true and typical raspberry-red eudialyte colour, like gillespite, is due to Fe^{2+} in an uncommon "square" coordination (Pol'shin *et al.*, 1991).

Thus Vladimir G. Feklichev did not understand the general point of Ekaterina E. Kostyleva-Labuntsova's work who revealed that *euclolite* does not mean only negative optical sign but, in the first place, means heavy high-charged atoms occupying positions in eudialyte; and investigations confirmed that this process is accompanied by decreasing unit cell size, increasing specific gravity, refractive indices and also conversion of optical indicatrix orientation.

The chemical composition of eudialyte was studied in detail by Irina D. Borneman-Starynkevich (1945; 1975). She worked on 23 full eudialyte analyses in her doctor's thesis (1945) and on 88 in her last paper (1975).

Component content variations in eudialyte according to her data (in %): SiO₂ 43.4–52.5, ZrO₂ 9.1–16.4, TiO₂ 0–4.0, (Nb,Ta)₂O₅ 0–3.7, Al₂O₃ 0–2.9, Fe₂O₃ 0–6.7, FeO 0–7.3, MgO 0–1.8, MnO 0.2–11.1, (Ca,Sr)O 3.5–15.9, REE₂O₃ 0–8.2, Na₂O 7.5–15.9, K₂O 0–3.8, Cl 0–2.4, H₂O 0–3.1². Irina D. Borneman-Starynkevich approached the investigations as a chemist and her main objective was chemical formula derivation, but she also was involved in the eudialyte-eucolite problem analysis. She divided eudialyte and eucolite according to the mineral optical sign, however it reflects only the $n_o : n_e$ ratio; the absolute value of refraction of light and specific gravity might be more informative. Originally (Borneman-Starynkevich, 1945) she came to the conclusion that change of optical sign from "+" to "-" and specific gravity increasing (from 2.94 to 3.03) within the eudialyte-eucolite series do correlate with partial substitution of (Na₂ZrSi₃O₉ + Na₃Si₃O₆(OH)₃) for (NaCaFeSi₃O₉ + Ca₂FeSi₃O₉). However, the excess of Na was detected and the role of Nb and Ti – uncertain. As a stalwart of Vladimir I. Vernadsky, Irina D. assumed that excessive sodium has "side bond" (Vladimir I. Vernadsky term) with chlorine, and Nb and Ti content in eudialyte is due to micro-admixtures of loparite. Consulting with the patriarchy of soviet crystallography, academician Nikolay V. Belov, she found that the unit cell parameter variations are insignificant, there was a basement for normalization of all the analyses (including non x-rayed ones) using rhombohedral cell volume (1760 Å³ – Golyshev *et al.*, 1971 or 1793 Å³ – Gossner, Mussgnug, 1930) and specific gravity measurements. The results obtained caused bewilderment as in 34 of the 60 most trustworthy analyses the Si coefficient was close to 25, in 18 – close to 26 and in the other 8 – close to 24, which was impossible for silicates and alumosilicates – minerals with a permanent Si,Al-radical. Coefficients at A group (Na, K, Ca, Sr, REE, Mn) and B group (Zr, Fe³⁺, Fe²⁺, Mg, Mn, Ti, Al, Nb, Ta) were not constant and the complex formula could not be "simplified" by means of "number of formula unit" cancellation. Decoding the eudialyte structure (Giuseppetti *et al.*, 1970; 1971; Golyshev *et al.*, 1971; 1972) explained this fact from the structural point of view. Moreover the mineral appeared to be a zeolite-like ion-exchanger which corresponded to assumption about "side groups" in eudialyte, however the composition arrived at was (Na,K,Ca,Sr,Ba,REE, Mn)₅(O,OH,Cl)₁₀ (Borneman-Starynkevich, 1975).

Data on typomorphism of eudialyte-eucolite from different complexes of the Khibiny massif were systematised in the book "Mineralogy of Khibiny massif" (1978) where new chemical analyses of samples used in later crystal structure refinement are presented. Facing

the history of eudialyte study enables us to make some important conclusions.

Firstly, eudialyte is a mineral of complex variable composition, regularly changing depending on mineral-forming environmental chemistry. This allows use of its typomorphic features as a mineral indicator of geological-geochemical conditions of rocks, pegmatites and some ore-body genesis and evolution.

Secondly, eudialyte varieties can be described within the natural eudialyte-eucolite isomorphous series where chemical composition correlates with the unit cell volume, specific gravity, refractive indices, optical sign, colour and other features. However this series cannot be described as a simple binary one or divided into several isomorphous series due to combined structure occupation of conjugate components which elementary composition limits by environment chemistry and crystal structure capacity.

Thirdly, "eucolitization" of eudialyte is a geochemically significant process as apparent by 1) its enrichment in heavy multi-valent chemical elements within less alkaline-basic rocks or 2) decreasing alkalinity-basicity during late evolution of alkaline complexes.

Fourthly, details and mechanisms of that replacement could not be understood without crystal structure refinement of eudialyte and its varieties, eucolite of different composition in particular.

Eudialyte as a mineral of variable composition and variable structure

There are excellent published overviews on the crystallochemistry of *eudialyte* (Rastsvetaeva, Borutzky, 1988; Rastsvetaeva, 1992; Johnsen, Grice, 1999; Rastsvetaeva, Khomyakov, 2001; Rastsvetaeva, Chukanov, 2006; Rastsvetaeva, 2007), and there is no need to retell them. Progress in crystallochemistry is obvious, but because of that, the eudialyte problem broke away from geology; moving from the mineralogical-geochemical area to a structural-chemical one. Although the author is not a structural analysis specialist, nevertheless would like to comment on both genetic and structural aspects of the problem.

The structural-chemical stage of eudialyte investigations began in 1971–1972 when its principal crystal structure was determined using the photomethod by Giuseppetti *et al.* (Giuseppetti *et al.*, 1970; 1971) on material from Greenland and independently by Golyshev *et al.*, (Golyshev *et al.*, 1971; 1972) on pegmatitic material from urtites from the Yukspor mountain in Khibiny (Dorfman, 1962). Some of eudialyte enigmas were cleared up (in particular the rea-

² – At present this list can be refined and supplemented: TiO₂ – up to 6.0 and Nb₂O₅ – up to 3.9, HfO₂ – up to 0.75, Ta₂O₅ – up to 6.3, WO₃ – up to 1.3, SrO – up to 8.9, La₂O₃ – up to 2.5, Ce₂O₃ – up to 3.9, Nd₂O₃ – up to 0.8, Pr₂O₃ – up to 0.3, Y₂O₃ – up to 1.6, F – up to 1.2, CO₂ – up to 0.8, SO₃ – up to 1.65.

son of variable Si content)³, but new mysteries appeared – crystallographers disagreed about the symmetry of the structure and site occupancy type. Giuseppetti *et al.* verified its typical centre-symmetrical space group as $R3m$, but Golyshev *et al.* decreased this symmetry to the acentric group $R3m$. It was discovered that eudialyte can occur in three space groups $R3m$, $R3m$ and $R32$ and $R3$ sub-group, as it was determined that the position of some atoms (Na and Fe in particular) reveals a loss of the centre of symmetry, rotation axes 2 and planes of symmetry. According to Giuseppetti, these components have enlarged and asymmetric ellipsoids of thermal oscillation. Golyshev pointed out that Na cations statistically “wander” over empty cells in zeolite-like eudialyte.

Thus it was shown right away that symmetry variations are due to the slight distortion of the structure, with the displacement of poorly-fixed atoms. But unfortunately at present they highlight the differences in symmetry; this is used for classification of the minerals of eudialyte “group” (Khomyakov, 2004; Khomyakov *et al.*, 2006) and for multiplication (“reproduction”) of mineral species which becomes possible due to increase of non-equivalent structural positions, thus the “dominance rule” is applicable. Eudialyte structure refinement resulted in the general conclusion: the mineral is a zirconium-bearing analogue of a zeolite with more or less constant framework complicated by the additional Si (or Zr) atoms and “extra-framework” cations and anions occupying chambers in the framework which position cannot be estimated by means of the photo-method. Besides the structural aspects of euclite remained unclear.

Structural-chemical study of eudialyte-euclites was continued in the late 80s – early 90s by Ramiza K. Rastsvetaeva on specimens from our collection using Enraf-Nonius diffractometer and AREN programs. At present nobody refers to those works. Why? Of course there were disadvantages to those “pioneer” studies but on their basis the *principal* conclusions were obtained and those very structural works were the *fundamental basis* for determination (Borutzky, 1997; 1999) of *minerals of variable composition and variable structure (MVCVS)* and the structural explanation of the competence of the *eudialyte-euclite series* determination with a concrete definition of isomorphous replacements taking place during *euclitization* of eudialyte. Apparently, for today’s “selectionists” of eudialyte mineral species who baselessly expand the so-called eudialyte group and develop its nomenclature (Johnsen, Grice, 1999; Johnsen *et al.*, 2003;

Khomyakov, 2004; Khomyakov *et al.*, 2006,) it is disadvantageously to remember those studies.

The crystal structure of proper eudialyte was refined on the material from ijolite-urtites from Khibiny (M.N. Sokolova specimen No 817/M, Rasvumchorr mountain, table 1, No 3), chemically close to eudialyte from Yukspor mountain (M.D. Dorfman specimen, table 1, No 2) (Rastsvetaeva, Andrianov, 1987; Rastsvetaeva, Borutzky, 1988). Applying the modernized method for the eudialyte crystal structure enabled refinement of the coordinates of all the extralattice framework atoms, determination of their new positions and also revealed some “split” and “close” positions that could be statistically occupied by atoms of variable composition, valency and size.

It was shown that 9-members rings [Si₉O₂₇] are to be centered simultaneously both with “additional” Si-tetrahedra and “additional” octahedral, with different orientation. “Additional” silicon was “spread” over Si₇ and new Si₉ positions (with occupancy coefficient *o.c.* 0.53 and 0.37) in the upper ring and also Si₉ with *o.c.* 0.43 in the lower one. The “additional” octahedron with *o.c.* 0.30 in the lower ring was apparently occupied with aluminium or zirconium excess (Giuseppetti *et al.*, 1971) or other multi-valent cations (Nb, Ti), with or instead of Al. It was discovered that the square “iron” position could be occupied with another elements by displacement of coordinates and transforming of “square” into other coordination polyhedra: 5-apex pyramid (in case of Fe³⁺ or Mn²⁺) and octahedron (in case of Ti⁴⁺ or its statistical substitution by Na₇ and Na₁₅ octahedra away from the ⁴⁴Fe centre for 2.0 and 1.05 Å. Instead of the four Na positions revealed by the photomethod, 15 Na and one K one were discovered. Three of them are located in the central chamber (2.5 x 6.5 Å) in between the 9-member rings connected with the pseudocentre of symmetry: Na₄ on the plane of symmetry (7-apex polyhedra) and Na₁₂ and Na₆ positions (the latter decreases local symmetry to $R3$) distant from the first one for 0.52 Å and 1.54 Å respectively. Two Na- and one K-positions are located in the upper chamber: Na₂ (9-apex polyhedron), Na₅ distant from it for 0.93 Å, and K (10-apex polyhedron); two positions Na₉ and Na₁₀ distant from the K one for 0.50 and 0.40 Å; and also Na₁₄ position distant from Na₇ along the *c*₃ axis for 0.51 Å. Found in the lower chamber were: Na₁ (10-apex polyhedron), with split from it (0.51 Å) Na₁₁ position (might be occupied with Sr) and Na₃ (7-apex polyhedron), related with Cl₁ atom and with split from it (0.70 Å) Na₆ position; and Na₁₃ position on the *c*₃ axis close to Na₁₅. All the eudialyte varieties could be described on the basis of this structure.

³ – In Italian version the content of the cell Na₁₂Ca₆Fe₃Zr_{3.36}Si₂₄O₇₂Cl_{0.68} (Z = 3) was calculated for 24 atoms of Si distributed by three tetrahedral positions: Si₁ in 3-member rings [Si₃O₉], Si₂ and Si₃ in 9-member rings [Si₉O₂₇], the excess of zirconium is placed by authors to the centre of 9-member ring. In Russian version of structure, the cell content Na₁₄Ca₆Zr₃Si₂₅O₈₀Cl_{1.6} (Z = 3) is calculated for 25 atoms of Si and distributed among positions split according to acentric group $R3m$. Eight positions of Si were determined: Si₁ and Si₂ in 3-member rings [Si₃O₉], Si₃, Si₄, Si₅ and Si₆ in 9-member rings [Si₉O₂₇] and two “additional” atoms Si₇ and Si₈ with *o.c.* (occupancy coefficient) = 0.5 each, occupying centres of 9-member rings as radicals [Si₁₀O₂₄(OH)₃].

Later the structure of five *eucolites* were defined: from an aegirine-salite-orthoclase pegmatite in khibinites from Chasnochorr, Khibiny (No 638, table 1, No 4) (Rastsvetaeva *et al.*, 1988), two *eucolites* of contrasting composition (Rastsvetaeva, Borutzky, 1990) – a rare-earth-ferriferous one (REE_2O_3 4.13, FeO 5.11, Fe_2O_3 0.97, MnO 2.29 wt.%) from an albitized arfvedsonite-microcline pegmatite in khibinites from Petrelius mountain, Khibiny (No 325, table 1, No 5) (Mineralogy of Khibiny massif, 1978) and a rare-earth-manganous eucolite (REE_2O_3 5.36, FeO 2.53, Fe_2O_3 1.56, MnO 5.92 wt.%) from a pegmatite in nephelite syenites from the Yenisei range (No 1008-6, table 1, No 6) (Sveshnikova, Burova, 1965) (their physical and spectroscopic properties were studied earlier (Borutzky *et al.*, 1968) and also two specimens known in the literature as “reddish-brown” and “yellowish-green” *barsanovites* (Dorfman *et al.*, 1963; 1965) from natural dumps in the river Petrelius valley which, by chemical composition, are typical eucolites (table 1, No 7–8) (Rastsvetaeva *et al.*, 1987; 1990).

Detailed structural analysis of eucolites of different chemical compositions (Rastsvetaeva *et al.*, 1987; 1988; 1990; Rastsvetaeva, Borutzky, 1990; Rastsvetaeva, 1992) revealed that low multi-valent elements occupation result in asymmetrization of the crystal structure, first of all in the centre of symmetry loss. “Additional” Si atoms “spread” over the centres of 9-member rings tend to stand apart in the upper ring and “additional” octahedral Zr, Ti, Nb, Al atoms – in the lower ring. There are five statistically possible variants for the occupation of 9-rings centres with “additional” cations as tetrahedral and octahedral with different orientation which results in Na occupancy in the central chamber (fig. 2). In eucolite No 638 mixed occupation takes place: “additional” Si atoms are “spread” over Si_7 (o.c. 0.60), Si_9 (o.c. 0.21) positions in the upper ring and Si_8 (o.c. 0.28) position in the lower ring; titanium (o.c. 0.16) is localized in the upper ring, niobium and aluminium

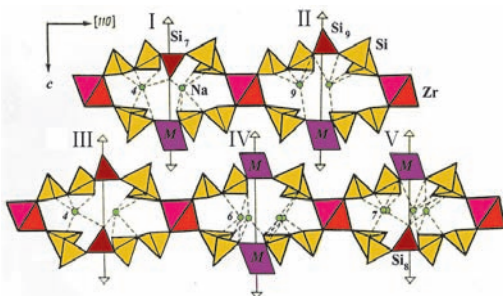
(o.c. 0.71) – in the M_1 position of the lower ring. Sodium is distributed over four positions: Na_4 (7-apex polyhedron, o.c. 0.13), Na_9 (o.c. 0.19), Na_6 (5-apex polyhedron, o.c. 0.23) and Na_7 (o.c. 0.09). Similar distribution of “additional” cations was determined in other eucolites (table 1, No 5–7), in “yellowish-green barsanovite” (table 1, No 8) silicon is ordered in the upper ring (Si_7 , o.c. 0.95), niobium and zirconium (M_1 , o.c. 1.00) – in the lower ring. The “iron” position in eucolites is normally split to “square” $^{14}Fe^{2+}$ and “half-octahedron” M_2 occupied by Fe^{3+} and Mn besides Fe^{2+} ; however in some cases for example in TR, Fe-eucolite No 325 it is occupied with zirconium ($Fe^{2+}_{1.29}Fe^{3+}_{1.28}Zr_{0.28}$) $_{\Sigma=2.85}$, and Mn together with REE were found in the “sodium” M_3 -polyhedron of the lower zeolite chamber – ($Mn_{1.45}REE_{1.07}Na_{0.42}$) $_{\Sigma=2.94}$. In TR, Mn-eucolite No 1008-6 Mn occupies three positions: “iron” one ($Fe^{2+}_{0.96}Fe^{3+}_{0.79}Mn^{2+}_{0.86}Al^{3+}_{0.23}Ti^{4+}_{0.10}$) $_{\Sigma=2.94}$, M_3 -polyhedron of the lower zeolite chamber ($Mn_{0.37}REE_{1.01}Na_{1.59}$) $_{\Sigma=2.97}$ and Ca-octahedra of 6-member rings ($Ca_{4.6}Mn_{1.4}$) $_6$. Maximum distorted structure by example of “yellowish-green barsanovite” is shown on figure 3. In the lower chamber the rigid [$M_1M_2M_3$] clusters of $Zr^{15}Fe^{2+}Mn$ or $Nb^{14}Fe^{2+}REE$ atoms are formed, and in the upper one – structurally identical groups $Cl^{15}Fe^{3+}Na$ or $(OH)^{14}Fe^{2+}Mn$.

A number of refinements performed by Ramiza K. Rastsvetaeva using our material demonstrated structural changes occurring during eucolitization of eudialyte and proved it to be a valid MVCVS. Investigations showed that even structure framework might undergo partial alterations, for instance Ca-octahedra might be substituted with Mn, and excess of Ti and Zr might occupy atypical positions for example the “iron” one.

Nearly ten years later structural studies of eudialyte-eucolites were repeated abroad by foreign researchers (Johnsen, Gault, 1997; Johnsen, Grice, 1999)⁴. They fulfilled “unification” of structural positions and analysis of their number changes due to symmetry difference (fig. 4a,b).

On the basis of 17 eudialyte structural examinations (table 1, No 11–27) Ole Johnsen and Joel Grice (Johnsen, Grice, 1999) considered their three structural modifications ($R\ 3m$, $R3m$ и $R3$) and detected part of the framework positions: {Si(1), Si(3), Si(3s), Si(5)} – {Si(1–6)} and {Si(1), Si(2), Si(3), Si(4), Si(5a), Si(5b), Si(6a) and Si(6b)}⁵; Zr and {O(1–3, 7–9, 13–15, 19–20)} – {O(1–18)} and {O(1–6, 7a, 7b, 8–9, 10a, 10b, 11–12, 13a, 13b, 14a, 14b, 15,

Fig. 2. Five statistically possible occupancy choices of central positions within translation-identical 9-member Si-O rings [Si_9O_{27}] by “additional” Si-tetrahedra and M-octahedra in eudialyte-eucolites, and corresponding distribution of sodium atoms in the “central” chamber. After R.K. Rastsvetaeva *et al.* (1988). In the real structures we observe statistical occupancy among different position combinations.



⁴ – 60 specimens were studied using EMPA, 17 of them deserved structure refinement.

⁵ – In the acentric structure [$Si(1)_3O_9$] and [$Si(3)_3Si(5)_6O_{27}$] rings split into [$Si(1)_3O_9$] and [$Si(2)_3O_9$], and [$Si(3)_3Si(5)_6O_{27}$] and [$Si(4)_3Si(6)_6O_{27}$] and form layers containing either even or odd silicon positions. Displacement and rotation of tetrahedra enable the centre of 9-member ring to be occupied either with Si tetrahedron or with Nb-sized octahedron. Displaced Si(3s) position in case of $R3m$ reveals central symmetry deviation which however does not reach Si(3) and Si(4) atomic positions in $R3m$. Positions Si(5) and Si(6) are getting split in case of $R3$.

Table 1. Comparison of structural and chemical data of Eudialyte-Eucolites

Mineral	Chemical and structural information*	References
1 Eudialyte-R $\bar{3}m$ Naujakasik Greenland	$Na_{12}yK_0.3Ca_{5.8}REE_{0.2}Fe^{2+}_{2.6}Fe^{3+}_{0.2}Mn_{0.2}Zr_{1.3}Nb_{0.2}Si_{24}O_{72}Cl_{1.0}H_{3.6}$ [Si = 24] $Na_{12}[Ca, REE]_6(Fe^{2+}, Fe^{3+}, Mn, Mg)_3[Zr]_3(Zr, Nb)_3[Si_3O_9]_2[Si_9O_{27-y}(OH)_y]_2Cl_2$ (x = 0.1-0.9; y = 1-3; z = 0.7-1.4) $Na_{12}[Ca]_6Fe_3[Zr]_3Zr_{0.36}Si_3O_{92}[Si_9O_{27}]_2(Cl)_0.63$ $Na_{15}Ca_6Fe_3Zr_3Si(Si_{25}O_{73})(O, OH, H_2O)_3(Cl, OH)_2$	Giuseppi <i>et al.</i> , 1970; 1971
2 Eudialyte-R $\bar{3}m$ Yukspor Khibiny	$Na_{13.9}K_{0.5}Ca_{6.2}Sr_{7.0}REE_{0.1}Fe^{2+}_{2.5}Fe^{3+}_{0.2}Mn_{0.3}Mg_{0.2}Zr_{2.9}Ti_{10.2}Si_{25.2}O_{73.1}Cl_{1.6}4.1H_2O$ [V 1760 Å ³ ; d 2.87] $Na_{12}[Ca]_6Fe_3[Zr]_3Si[Si_3O_9]_2[Si_9O_{27}][Si_9O_{27}(OH)] + (Na, K, Cl, O, OH)$ $Na_{15}Ca_6Fe_3Zr_3Si(Si_{25}O_{73})(O, OH, H_2O)_3(Cl, OH)_2$	Dorfman, 1962; Golyshev <i>et al.</i> , 1971; 1972;
3 Eudialyte-R $\bar{3}m$ No 817/M Rasumchorr Khibiny	$Na_{14.1}K_{1.3}Ca_{5.7}Sr_{0.3}REE_{0.1}Fe^{2+}_{1.8}Fe^{3+}_{0.2}Mn_{0.2}Al_{0.1}Zr_{2.9}Ti_{10.3}Nb_{0.0}Si_{24.1}O_{73}Cl_{1.7}1.7H_2O$ [V 1758 Å ³ ; d 2.74] $Na_{14.8}K_{1.4}Ca_{6.0}Sr_{0.3}RE_{0.1}Fe^{2+}_{1.8}Fe^{3+}_{0.3}Mn_{0.2}Al_{0.1}Zr_{3.0}Ti_{10.3}Nb_{0.6}Si_{25.3}O_{73}Cl_{1.8}1.8H_2O$ [Si = 25.3] {Na(2) ₂ , Na(5) _{0.84} }Zr _{2.97} {Na(9) _{1.26} Na(10) _{0.57} K _{1.20} }Zr _{3.03} {Na(4) _{1.50} Na(6) _{1.26} Na(12) _{0.24} }Zr _{3.00} × × {Na(1) ₂ , Na(11) _{0.72} }Zr _{3.00} {Na(3) ₂ , Na(8) _{0.87} }Zr _{2.97} {Ca ₆ {Fe ²⁺ _{1.92} M ²⁺ =(Fe ²⁺ _{0.24} Ti _{0.31} Si _{0.57} }Zr _{2.49} × × {Na(7) _{0.21} Na(13) _{0.23} Na(14) _{0.33} Na(15) _{0.18} }Zr _{3.00} {Zr ₃ {Si(9) _{0.37} Si(7) _{0.53} }Zr _{3.00} {Si(8) _{0.43} Al _{0.30} }Zr _{3.00} × × {Si(2) _{0.9} }Zr _{3.00} {Si(5) ₃ }Zr _{3.00} {Si(1) ₆ Si(4) ₂ }Zr _{3.00} {Si(3) ₆ Si(6) _{0.83} Si(10) _{0.16} }Zr _{3.00} × × {OH(1) _{0.53} OH(2) _{0.37} OH(3) _{0.81} OH(4) _{0.43} OH(5) _{0.30} }Zr _{3.00} {Cl(1) _{1.72} } {Na _{14.7} K _{1.2} }Ca ₆ {Fe _{1.9} (Fe, Mn, Ti) _{0.5} }Zr ₃ {Si _{10.4} Al _{0.3} }Si ₂₅ O ₇₃ Cl _{1.7} 2.4H ₂ O $Na_{15}Ca_6Fe_3Zr_3Si(Si_{25}O_{73})(O, OH, H_2O)_3(Cl, OH)_2$	Rastsvetaeva, Andrianov, 1987; Rastsvetaeva, Borutzky, 1988
4 Eucolite - R $\bar{3}m$ No 638 Chasnochorr Khibiny	$Na_{12}7K_0.4Ca_6.1Sr_{0.4}REE_{0.9}Fe^{2+}_{2.5}Fe^{3+}_{0.3}Mn_{0.6}Mg_{0.5}Al_{0.5}Zr_{3.1}Ti_{10.3}Nb_{0.4}Si_{24.1}O_{73}Cl_{1.2}3.0H_2O$ [V 1755 Å ³ ; d 3.00] {Na(2) ₁ , Na(5) _{1.08} }Zr _{2.94} {Na(1) _{1.74} M(4)=(Na, Sr, Mg) _{1.08} }Zr _{2.82} {Na(4) _{0.39} Na(6) _{1.33} Na(7) _{0.54} Na(9) _{0.57} }Zr _{2.88} × × {M(3)=(Na, REE) ₃ }Zr _{3.00} {Na(3) ₁ , Na(8) _{0.81} Na(10) _{0.33} }Zr _{2.94} {Ca ₆ {Fe ²⁺ _{1.32} M(2)=(Fe ²⁺ _{0.60} Mn _{0.76}) _{1.63} }Zr _{2.95} × × [Zr ₃ {Si(9) _{0.21} Ti _{0.16} Si(7) _{0.60} }Zr _{3.00} {Si(8) _{0.28} M(1)=(Nb _{0.41} Al _{0.30}) _{0.71} }Zr _{3.00} × × [Si ₂₄ O ₇₂]{OH(1) _{0.66} OH(2) _{0.32} OH(3) _{0.71} OH(4) _{0.27} OH(5) _{0.12} }Zr _{3.00} {Cl(1) _{0.73} Cl(2) _{0.64} }Zr _{3.00} × {Na ₉ {Na, K, Sr, REE, Mg} ₆ }Ca ₆ {Fe ²⁺ _{1.2} Fe ³⁺ _{0.27} Mn _{1.1} }Zr ₃ {Si ₁₀ }Nb _{0.4} Ti _{10.3} Si ₂₅ O ₇₃ Cl _{1.8} 1.8H ₂ O [Si = 25.3] $Na_{12.4}K_{0.4}Ca_{5.5}Sr_{0.2}REE_{0.8}Mg_{0.5}Fe^{2+}_{2.3}Fe^{3+}_{0.2}Mn_{0.6}Zr_{3.5}Ti_{10.1}Nb_{0.6}Al_{0.2}Si_{24.6}O_{73}Cl_{0.9}0.5H_2O$ [V 1765 Å ³ ; d = 3.04] {Na(9)=(Na _{1.36} K _{0.34}) ₂ , Na(10) _{1.05} }Zr _{2.75} {M(4)=(Na _{1.04} Sr _{0.19}) ₂ , Na(3) _{1.65} }Zr _{2.88} {Na(4) _{0.54} Na(5) _{0.21} }Zr _{2.85} × × {M(3)=(REE _{1.07} Mn _{1.45}) ₂ , Na(1) _{0.24} Na(2) _{0.18} }Zr _{2.94} {Na(7) _{0.51} Na(8) _{0.23} }Zr _{2.82} {Ca ₆ × × {Fe ²⁺ _{1.29} M(2)=Fe ³⁺ _{1.28} Zr _{0.28} }Zr _{3.00} {Si(7) _{0.73} Si(8) _{0.19} }Zr _{3.00} {Al _{0.14} M(1)=(Zr _{0.27} Nb _{0.60}) ₂ }Zr _{3.00} × × [Si ₂₄ O ₇₂]{OH(1) _{0.75} OH(2) _{0.29} }Zr _{3.00} {OH(3) ₂ , Si(4) _{0.22} OH(5) _{0.17} OH(7) _{0.66} Cl(1) _{0.60} }Zr _{3.00} {OH(1) _{0.70} × × {Na _{12.3} K _{0.4} Sr _{0.2} REE _{0.8} Mg _{0.5} }Ca ₅ {Fe ²⁺ _{2.3} Fe ³⁺ _{0.6} Mn _{1.0} }Zr ₃ {Zr _{0.6} Ti _{10.1} Nb _{0.6} Al _{0.1} }Si _{24.8} O ₇₂ Cl _{0.9} 2.5H ₂ O	Mineralogy of Khibiny massif, 1978; Rastsvetaeva <i>et al.</i> , 1988
5 REE, Fe- Eucolite R $\bar{3}m$ No 325 Petreluis Mt. Khibiny	$Na_{12}0K_0.3Ca_6.1Sr_{0.2}REE_{1.0}Fe^{2+}_{1.1}Fe^{3+}_{0.6}Mn_{2.7}Zr_{3.3}Ti_{10.1}Nb_{0.6}Al_{0.3}Si_{25.0}O_{73}Cl_{0.0}3.90H_2O$ [V 1767 Å ³ ; d 3.03] {Na(9)=(Na _{0.99} K _{0.33} (H ₂ O) _{0.66}) ₂ , Na(10) _{0.87} }Zr _{2.85} M(4)=(Na _{1.56}) ₃ Cl ₃ }Zr _{3.00} × × {Na(4) _{0.33} Na(5) _{0.77} Na(6) _{0.36} (H ₂ O) _{0.27} }Zr _{2.73} {M(3)=(REE _{1.01} Na _{1.1} Mn _{0.37}) ₂ , Na(1) _{0.33} Na(2) _{0.15} }Zr _{2.97} × × {Na(7) _{0.66} Na(8) _{0.28} }Zr _{2.94} {Ca ₆ {Fe ²⁺ _{0.96} M(2)=(Mn _{0.82} Fe ²⁺ _{0.76} Al _{0.22} Ti _{0.09}) ₂ }Zr _{2.94} }Zr _{3.00} × × {Si(7) _{0.55} Si(8) _{0.10} Si(9) _{0.27} }Zr _{3.00} {Al _{0.30} M(1)=(Zr _{0.13} Nb _{0.56}) ₂ }Zr _{3.00} }Zr _{3.00} × × {OH(1) _{0.56} OH(2) _{0.45} }Zr _{3.00} {OH(3) ₂ , Ti(4) _{0.30} OH(5) _{0.12} OH(6) _{0.60} OH(8) _{0.34} }Zr _{3.00} × {Ca ₂ , Na ₈ , Sr ₇ , Ti ₃ , K _{0.3} , REE _{0.2} }Zr _{3.00} {Fe ²⁺ _{0.7} Fe ³⁺ _{0.3} Mn _{0.4} Al _{0.1} }Zr _{3.00} {Zr _{1.8} Nb _{0.2} }Zr _{3.00} {Si ₂₂ (O, Cl, OH) ₃₇ [Si = 12] ** Na _{13.0} K _{0.4} Ca _{6.0} Sr _{0.6} REE _{0.4} Fe ²⁺ _{1.8} Fe ³⁺ _{0.6} Mn _{0.6} Al _{0.2} Zr _{3.2} Ti _{10.1} Nb _{0.4} Ta _{0.5} Si _{25.1} O ₇₃ Cl _{1.3} 2.08H ₂ O {Na(2) ₁ , Na(5) _{1.11} }Zr _{3.00} {Na(1) _{1.17} +K _{0.40} }Zr _{3.00} {Na(12) _{1.43} }Zr _{3.00} {Na(4) _{0.49} Na(6) _{1.56} Na(7) _{0.90} }Zr _{2.94} × × {M(3)=(Na _{0.70} REE _{0.37} Sr _{0.56} Mn _{0.57}) ₂ , Na(9) _{0.57} Na(1) _{0.21} }Zr _{2.97} {Na(3) _{1.65} Na(8) _{0.96} Na(10) _{0.33} }Zr _{2.94} {Ca ₆ × × {Fe ²⁺ _{1.17} M(2)=Fe ²⁺ _{0.66} Fe ³⁺ _{0.57} Mn _{0.60} }Zr _{3.00} {Zr ₃ {Si(9) _{0.21} Al _{0.05} Si(7) _{0.69} }Zr _{3.00} × × {Si(8) _{0.17} Ti _{0.07} M(1)=(Zr _{0.24} Nb _{0.36} Al _{0.13}) ₂ }Zr _{3.00} }Zr _{3.00} }Zr _{3.00} × × {OH(1) _{0.82} OH(2) _{0.22} OH(3) _{1.89} OH(4) _{0.27} OH(5) _{0.15} OH(6) _{0.21} OH(7) _{0.17} OH(8) _{0.60} }Zr _{3.00} {Cl(1) _{0.67} Cl(2) _{0.61} }Zr _{3.00} × (Na, Ca) ₉ (Mn, Fe) ₂ (Zr, Nb) ₂ Si ₁₂ (O, Cl, OH) ₃₇ **	Mineralogy of Khibiny massif, 1978; Rastsvetaeva, Borutzky, 1990
6 REE, Mn- Eucolite No 1008-6 R $\bar{3}m$ Srednie-Tatarsky massif Yenisei range	$Na_{12}0K_0.3Ca_6.1Sr_{0.2}REE_{1.0}Fe^{2+}_{1.1}Fe^{3+}_{0.6}Mn_{2.7}Zr_{3.3}Ti_{10.1}Nb_{0.6}Al_{0.3}Si_{25.0}O_{73}Cl_{0.0}3.90H_2O$ [V 1767 Å ³ ; d 3.03] {Na(9)=(Na _{0.99} K _{0.33} (H ₂ O) _{0.66}) ₂ , Na(10) _{0.87} }Zr _{2.85} M(4)=(Na _{1.56}) ₃ Cl ₃ }Zr _{3.00} × × {Na(4) _{0.33} Na(5) _{0.77} Na(6) _{0.36} (H ₂ O) _{0.27} }Zr _{2.73} {M(3)=(REE _{1.01} Na _{1.1} Mn _{0.37}) ₂ , Na(1) _{0.33} Na(2) _{0.15} }Zr _{2.97} × × {Na(7) _{0.66} Na(8) _{0.28} }Zr _{2.94} {Ca ₆ {Fe ²⁺ _{0.96} M(2)=(Mn _{0.82} Fe ²⁺ _{0.76} Al _{0.22} Ti _{0.09}) ₂ }Zr _{2.94} }Zr _{3.00} × × {Si(7) _{0.55} Si(8) _{0.10} Si(9) _{0.27} }Zr _{3.00} {Al _{0.30} M(1)=(Zr _{0.13} Nb _{0.56}) ₂ }Zr _{3.00} }Zr _{3.00} × × {OH(1) _{0.56} OH(2) _{0.45} }Zr _{3.00} {OH(3) ₂ , Ti(4) _{0.30} OH(5) _{0.12} OH(6) _{0.60} OH(8) _{0.34} }Zr _{3.00} × {Ca ₂ , Na ₈ , Sr ₇ , Ti ₃ , K _{0.3} , REE _{0.2} }Zr _{3.00} {Fe ²⁺ _{0.7} Fe ³⁺ _{0.3} Mn _{0.4} Al _{0.1} }Zr _{3.00} {Zr _{1.8} Nb _{0.2} }Zr _{3.00} {Si ₂₂ (O, Cl, OH) ₃₇ [Si = 12] ** Na _{13.0} K _{0.4} Ca _{6.0} Sr _{0.6} REE _{0.4} Fe ²⁺ _{1.8} Fe ³⁺ _{0.6} Mn _{0.6} Al _{0.2} Zr _{3.2} Ti _{10.1} Nb _{0.4} Ta _{0.5} Si _{25.1} O ₇₃ Cl _{1.3} 2.08H ₂ O {Na(2) ₁ , Na(5) _{1.11} }Zr _{3.00} {Na(1) _{1.17} +K _{0.40} }Zr _{3.00} {Na(12) _{1.43} }Zr _{3.00} {Na(4) _{0.49} Na(6) _{1.56} Na(7) _{0.90} }Zr _{2.94} × × {M(3)=(Na _{0.70} REE _{0.37} Sr _{0.56} Mn _{0.57}) ₂ , Na(9) _{0.57} Na(1) _{0.21} }Zr _{2.97} {Na(3) _{1.65} Na(8) _{0.96} Na(10) _{0.33} }Zr _{2.94} {Ca ₆ × × {Fe ²⁺ _{1.17} M(2)=Fe ²⁺ _{0.66} Fe ³⁺ _{0.57} Mn _{0.60} }Zr _{3.00} {Zr ₃ {Si(9) _{0.21} Al _{0.05} Si(7) _{0.69} }Zr _{3.00} × × {Si(8) _{0.17} Ti _{0.07} M(1)=(Zr _{0.24} Nb _{0.36} Al _{0.13}) ₂ }Zr _{3.00} }Zr _{3.00} }Zr _{3.00} × × {OH(1) _{0.82} OH(2) _{0.22} OH(3) _{1.89} OH(4) _{0.27} OH(5) _{0.15} OH(6) _{0.21} OH(7) _{0.17} OH(8) _{0.60} }Zr _{3.00} {Cl(1) _{0.67} Cl(2) _{0.61} }Zr _{3.00} × (Na, Ca) ₉ (Mn, Fe) ₂ (Zr, Nb) ₂ Si ₁₂ (O, Cl, OH) ₃₇ **	Sveshnikova, Burova, 1965; Rastsvetaeva, Borutzky, 1990
7 Barsanovite «reddish-brown» R $\bar{3}m$ river Petreluis valley Khibiny	$(Ca_3)_6(Na_5)_4S_4Sr_0.38REE_0.28Y_0.1Fe_2Mn_1.2Zr_3.2Hf_0.9Ti_0.1Nb_0.9Ta_0.0Si_25.3Cl_0.67$ [Si = 12] ** $Na_{11.2}K_0.4Ca_6.3Sr_0.8REE_0.6Fe^{2+}_{2.4}Fe^{3+}_{0.3}Mn_{1.7}Al_0.1Zr_3.3Ti_{10.1}Nb_{0.7}Si_{24.7}O_{73}Cl_{0.9}1.73H_2O$ [V 1756 Å ³ ; d 3.07] {Na(2) ₁ , Na(5) _{1.11} }Zr _{3.00} {Na(1) _{1.17} +K _{0.40} }Zr _{3.00} {Na(12) _{1.43} }Zr _{3.00} {Na(4) _{0.49} Na(6) _{1.56} Na(7) _{0.90} }Zr _{2.94} × × {M(3)=(Na _{0.70} REE _{0.37} Sr _{0.56} Mn _{0.57}) ₂ , Na(9) _{0.57} Na(1) _{0.21} }Zr _{2.97} {Na(3) _{1.65} Na(8) _{0.96} Na(10) _{0.33} }Zr _{2.94} {Ca ₆ × × {Fe ²⁺ _{1.17} M(2)=Fe ²⁺ _{0.66} Fe ³⁺ _{0.57} Mn _{0.60} }Zr _{3.00} {Zr ₃ {Si(9) _{0.21} Al _{0.05} Si(7) _{0.69} }Zr _{3.00} × × {Si(8) _{0.17} Ti _{0.07} M(1)=(Zr _{0.24} Nb _{0.36} Al _{0.13}) ₂ }Zr _{3.00} }Zr _{3.00} }Zr _{3.00} × × {OH(1) _{0.82} OH(2) _{0.22} OH(3) _{1.89} OH(4) _{0.27} OH(5) _{0.15} OH(6) _{0.21} OH(7) _{0.17} OH(8) _{0.60} }Zr _{3.00} {Cl(1) _{0.67} Cl(2) _{0.61} }Zr _{3.00} × (Na, Ca) ₉ (Mn, Fe) ₂ (Zr, Nb) ₂ Si ₁₂ (O, Cl, OH) ₃₇ **	Dorfman <i>et al.</i> , 1963; 1965; Rastsvetaeva <i>et al.</i> , 1987
8 Barsanovite «yellowish-green» river Petreluis valley Khibiny	$(Ca_3)_6(Na_5)_4S_4Sr_0.38REE_0.28Y_0.1Fe_2Mn_1.2Zr_3.2Hf_0.9Ti_0.1Nb_0.9Ta_0.0Si_25.3Cl_0.67$ [Si = 12] ** $Na_{11.2}K_0.4Ca_6.3Sr_0.8REE_0.6Fe^{2+}_{2.4}Fe^{3+}_{0.3}Mn_{1.7}Al_0.1Zr_3.3Ti_{10.1}Nb_{0.7}Si_{24.7}O_{73}Cl_{0.9}1.73H_2O$ [V 1756 Å ³ ; d 3.07] {Na(2) ₁ , Na(5) _{1.11} }Zr _{3.00} {Na(1) _{1.17} +K _{0.40} }Zr _{3.00} {Na(12) _{1.43} }Zr _{3.00} {Na(4) _{0.49} Na(6) _{1.56} Na(7) _{0.90} }Zr _{2.94} × × {M(3)=(Na _{0.70} REE _{0.37} Sr _{0.56} Mn _{0.57}) ₂ , Na(9) _{0.57} Na(1) _{0.21} }Zr _{2.97} {Na(3) _{1.65} Na(8) _{0.96} Na(10) _{0.33} }Zr _{2.94} {Ca ₆ × × {Fe ²⁺ _{1.17} M(2)=Fe ²⁺ _{0.66} Fe ³⁺ _{0.57} Mn _{0.60} }Zr _{3.00} {Zr ₃ {Si(9) _{0.21} Al _{0.05} Si(7) _{0.69} }Zr _{3.00} × × {Si(8) _{0.17} Ti _{0.07} M(1)=(Zr _{0.24} Nb _{0.36} Al _{0.13}) ₂ }Zr _{3.00} }Zr _{3.00} }Zr _{3.00} × × {OH(1) _{0.82} OH(2) _{0.22} OH(3) _{1.89} OH(4) _{0.27} OH(5) _{0.15} OH(6) _{0.21} OH(7) _{0.17} OH(8) _{0.60} }Zr _{3.00} {Cl(1) _{0.67} Cl(2) _{0.61} }Zr _{3.00} × (Na, Ca) ₉ (Mn, Fe) ₂ (Zr, Nb) ₂ Si ₁₂ (O, Cl, OH) ₃₇ **	Dorfman <i>et al.</i> , 1963; 1965; Rastsvetaeva <i>et al.</i> , 1990
9 Fe, Cl-analogue of kentbrooksit R $\bar{3}m$ New investigation of «yellowish-green barsanovite»	$Na_{11.7}K_0.2Ca_6.3Sr_0.7Ba_{0.0}RE_{0.6}Y_{0.1}Fe_2Mn_{1.2}Zr_3.2Hf_0.9Ti_{0.1}Nb_{0.9}Ta_{0.0}Si_{25.3}O_{76.5}Cl_{1.1}F_{0.6}1.4H_2O$ $Na(1)_3\{Na(2a)_1, Na(2b)_0, Na(2c)_1\}_3\{Na(3a)_1, Na(3b)_1, Na(3c)_1\}_3\{M_5=Mn_{1.0}Sr_{0.72}Ca_{0.33}Ce_{0.47}Y_{0.13}K_{0.25}\}_3\{Na(4a)_0, Na(4b)_2, Na(4c)_2\}_3\{Ca_6\{Fe^{2+}_{0.69}M_2=(Fe^{2+}_{1.86}Mn_{0.13}Zr_{0.27}Ti_{0.05}Si_{2.31}Zr_3\{Si(7)\}_3\{M_1=Nb_{0.8}Si_{0.2}\}_3 \times$ $\times [Si_3O_9]_2[Si_9O_{27}]_2\{O, OH, F\}Cl_2H_2O$ $Na_{12}(Mn, Sr, REE)_3Ca_6Fe^{2+}_{1.8}Zr_3[Si_3O_9]_2[Si_{10}O_{27}(OH)]_2[Si_9NbO_{27}(O, OH)_3](O, OH, F)Cl_2H_2O$	Ekimenkova <i>et al.</i> , 2000 ₂
10 Georgbarsanovite - new name of barsanovite It was approved by the CNMNC as new mineral	$Na_{11.7}K_0.2Ca_6.3Sr_0.7Ba_{0.0}L_{0.2}Ce_{0.3}Nd_{0.1}Y_{0.1}Fe^{2+}_{2.6}Mn_{1.2}Zr_3.2Hf_0.9Ti_{0.1}Nb_{0.9}Si_{25.3}O_{73}Cl_{1.1}F_{0.6}0.88H_2O$ [Σ cat. = 53] {N(1)=Na ₃ }N(2)=Na ₃ {N(3)=Na ₃ }N(4)=Mn _{1.0} Sr _{0.72} Ce _{0.47} Ca _{0.33} K _{0.25} Y _{0.13} Ba _{0.03} {Zr ₃ {Si(7) ₃ }Zr _{3.00} }Zr _{3.00} × × {M(1)=Ca ₆ }M(2)=Fe ²⁺ _{2.55} Zr _{0.27} Mn _{0.13} Ti _{0.05} }Zr _{3.00} {Zr ₃ {M(3)=Nb _{0.8} Si _{0.2} }Zr _{3.00} }Zr _{3.00} × × [Si ₂₄ O ₇₂]{O, OH, H ₂ O} ₃ {Cl, F} ₂ $Na_{12}(Mn, Sr, REE)_3Ca_6Fe^{2+}_{1.8}Zr_3Nb(Si_{25}O_{76})Cl_2(H_2O)$	Khomyakov <i>et a</i> 2005
11 Eudialyte-R $\bar{3}m$ No 9 Saint-Amable sill Quebec, Canada	$Na_{15.2}K_0.3Ca_3.7Sr_0.1REE_{0.3}Y_{0.2}Fe_{1.5}Mn_{2.2}Zr_{7.2}Ti_{10.8}Nb_{0.1}Al_{0.1}Si_{25.8}Cl_{0.4}H_{0.3...}$ [Σ anions = 75.39] $Na(1)_5, Na(4)_5, Na(6)_3, Sr_{10}$ {Zr _{26.00} Na(5) ₂ } {Ca ₃ , 79, Mn _{1.49} , REE _{0.38} Y _{0.17} Zr _{0.18} }Zr _{26.00} {Fe _{0.92} F _{0.57} Mn _{0.79} Ti _{0.25} }Zr _{21.61} × × [Zr ₅₀ Ti ₅₀]Zr _{30.00} {Si ₁ , 89, Nb ₁₁ }Zr _{22.00} ...	Johnsen, Grice, 1999
12 Eudialyte-R $\bar{3}m$ No 14 Narsarsuk S. Greenland	$Na_{15.4}K_0.3Ca_3.2Sr_{0.1}REE_{0.3}Y_{0.2}Fe_{1.5}Mn_{2.2}Zr_{7.2}Ti_{10.8}Nb_{0.1}Al_{0.1}Si_{25.8}Cl_{0.4}H_{0.3...}$ [Σ anions = 76.40] $Na(1)_5, Na(4)_5, Na(6)_3, Sr_{10}$ {Zr _{26.00} Na(5) ₂ } {Ca ₃ , 79, Mn _{1.49} , REE _{0.26} Y _{0.23} }Zr _{26.00} {Fe _{0.21} Mn _{0.29} }Zr _{20.50} × × [Zr ₈₆ Ti ₈₆	

13	Eudialyte-R $\bar{3}m$ No 15 Ilmussaag S. Greenland	$Na_{15.0}K_{0.3}Ca_{5.5}Sr_{0.0}REE_{0.4}Y_{0.1}Fe_{3.2}Mn_{0.2}Zr_{2.9}Hf_{0.0}Nb_{0.5}Ta_{0.0}Al_{0.2}Si_{25.7}Cl_{1.2}H_{2.0}O_9$ [Σ anions = 76.75] Na(1) _{5.92} {Na(4) _{4.92} K _{0.31} Ce _{0.27} Ca _{0.44} Sr _{0.06} } _{26.00} Na(5) _{2.20} {Ca _{5.15} Fe _{0.23} Mn _{0.24} REE _{0.22} Y _{0.14} } _{26.00} Fe _{0.52} F _{0.46} × × {Zr _{2.93} Nb _{0.05} Hf _{0.03} } _{23.00} {Si _{1.85} Nb _{0.15} } _{22.00} ...	Johnsen, Grice, 1999
14	Eudialyte-R $\bar{3}m$ No 10 Gardar complex E. Greenland	$Na_{15.7}K_{0.4}Ca_{6.6}Sr_{0.7}REE_{0.0}Y_{0.1}Fe_{1.8}Mn_{0.4}Zr_{2.8}Hf_{0.0}Ti_{0.2}Nb_{0.1}Al_{0.1}Si_{25.8}Cl_{1.0}H_{1.4}$ [Σ anions = 76.91] Na(1) _{5.77} {Na(4) _{4.29} K _{0.35} Ca _{0.71} Sr _{0.65} } _{26.00} Na(5) _{2.71} {Ca _{5.89} REE _{0.03} Y _{0.08} } _{26.00} {Fe _{1.90} Mn _{0.20} } _{22.10} Mn _{0.47} × × {Zr _{2.78} Ti _{0.22} } _{23.00} {Si _{1.84} Nb _{0.16} } _{22.00} ...	Johnsen, Grice, 1999
15	Eudialyte-R $\bar{3}m$ No 12 Gardar complex E. Greenland	$Na_{15.7}K_{0.3}Ca_{6.7}Sr_{0.8}REE_{0.0}Y_{0.0}Fe_{1.6}Mn_{0.7}Zr_{2.8}Hf_{0.0}Ti_{0.2}Nb_{0.3}Al_{0.1}Si_{25.8}Cl_{1.0}H_{2.4}$... [Σ anions = 77.96] Na(1) _{5.57} {Na(4) _{4.26} K _{0.26} Ca _{0.72} Sr _{0.76} } _{26.00} Na(5) _{2.97} {Ca _{5.91} REE _{0.03} Y _{0.06} } _{26.00} {Fe _{1.77} Mn _{0.35} } _{22.12} Mn _{0.39} × × {Zr _{2.80} Ti _{0.20} } _{23.00} {Si _{1.79} Nb _{0.21} } _{22.00} ...	Johnsen, Grice, 1999
16	Eudialyte-R $\bar{3}m$ No 7 Kipawa Quebec, Canada	$Na_{13.5}K_{0.7}Ca_{7.7}REE_{0.2}Y_{0.0}Fe_{0.7}Mn_{0.7}Zr_{2.9}Hf_{0.1}Ti_{0.0}Nb_{0.1}Al_{0.1}Si_{26.1}Cl_{1.0}H_{2.4}$... [Σ anions = 77.49] Na(1) _{5.89} {Na(4) _{2.87} K _{0.21} Ca _{0.22} } _{26.00} Na(5) _{3.04} {Ca _{5.08} REE _{0.23} Y _{0.69} } _{26.00} {Fe _{1.52} Mn _{0.30} } _{21.82} Mn _{0.40} × × {Zr _{2.90} Ti _{0.05} Hf _{0.04} } _{23.00} {Si _{1.71} Nb _{0.29} } _{22.00} ...	Johnsen, Grice, 1999
17	Eudialyte-R $\bar{3}m$ No 1 Mont Saint-Hilaire Quebec, Canada	$Na_{15.3}K_{0.3}Ca_{5.6}Sr_{0.1}REE_{0.3}Y_{0.1}Fe_{1.8}Mn_{1.4}Mg_{0.0}Zr_{3.0}Hf_{0.0}Ti_{0.1}Nb_{0.4}Ta_{0.0}Al_{0.1}Si_{25.8}Cl_{0.7}H_{2.5}$... [Σ anions = 77.48] Na(1) _{5.92} {Na(4) _{5.26} K _{0.29} Ca _{0.24} Sr _{0.12} REE _{0.09} } _{26.00} Na(5) _{2.98} {Ca _{5.32} Mn _{0.40} REE _{0.23} Y _{0.05} } _{26.00} {Fe _{1.77} Mn _{0.13} } _{22.00} Mn _{0.82} × × {Zr _{2.97} Ti _{0.03} } _{23.00} {Si _{1.69} Nb _{0.31} } _{22.00} ...	Johnsen, Grice, 1999
18	Eudialyte-R $\bar{3}m$ No 8 Kipawa Quebec, Canada	$Na_{14.8}K_{0.4}Ca_{6.5}Sr_{0.1}REE_{0.6}Y_{0.5}Fe_{0.5}Mn_{0.5}Mg_{0.1}Zr_{3.0}Hf_{0.0}Ti_{0.2}Nb_{0.1}Al_{0.1}Si_{25.6}Cl_{1.0}Fe_{0.9}H_{2.0}$... [Σ anions = 77.35] Na(1) _{8.84} {Na(4) _{7.77} K _{0.59} Ca _{1.70} Sr _{0.06} REE _{0.07} } _{26.00} Na(5) _{2.71} {Ca _{4.74} REE _{0.47} Y _{0.79} } _{26.00} {Fe _{1.32} Mn _{0.55} } _{21.87} × × {Fe _{0.25} Mg _{0.09} } _{20.34} {Zr ₃ } _{23.00} {Si _{1.63} Ti _{0.21} Nb _{0.16} } _{22.00} ...	Johnsen, Grice, 1999
19	Eudialyte-R $\bar{3}m$ No 11 Gardar complex E. Greenland	$Na_{14.6}K_{0.3}Ca_{6.8}Sr_{1.3}Ba_{0.1}REE_{0.1}Y_{0.1}Fe_{1.0}Mn_{1.4}Zr_{2.6}Ti_{0.3}Nb_{0.6}Si_{25.1}Cl_{0.9}H_{1.4}$... [Σ anions = 77.00] {Na(1) _{2.17} Ca _{0.81} } _{23.00} {Na(2) _{2.27} {Na(3) _{1.85} REE _{0.13} K _{0.30} Sr _{0.06} Ba _{0.07} } _{23.01} {Na(4) _{2.36} Sr _{0.62} } _{23.00} Na(5) _{3.06} × × {Ca _{5.93} Y _{0.07} } _{26.00} {Fe _{0.58} {Fe _{0.40} Mn _{1.40} } _{21.92} {Zr _{2.99} Nb _{0.07} Ti _{0.34} } _{23.00} {Si(7) _{1.13} Nb _{0.87} } _{22.00} ...	Johnsen, Grice, 1999
20	Eudialyte-R $\bar{3}m$ No 13 Amrdupfjord, Kangerdluarsuq E. Greenland It was approved by the CNMNC as new mineral <i>Kentbrooksite</i>	$Na_{15.6}K_{0.3}Ca_{3.5}Sr_{0.2}REE_{1.1}Y_{0.4}Fe_{0.7}Mn_{1.8}Mg_{0.1}Zr_{3.0}Hf_{0.1}Ti_{0.2}Nb_{0.6}Al_{0.1}Si_{25.1}Cl_{0.3}F_{1.5}H_{1.2}$... [Σ anions = 78.10] {Na(1) _{2.90} REE _{0.10} } _{23.00} Na(2) _{2.37} {Na(3) _{2.82} REE _{0.18} } _{23.00} {Na(4) _{1.86} REE _{0.68} K _{0.30} Sr _{0.16} } _{23.00} Na(5) _{3.02} × × {Ca _{3.37} Mn _{1.79} REE _{0.41} Y _{0.43} } _{26.00} {Fe _{0.29} {Fe _{0.45} Mn _{1.00} Al _{0.41} } _{22.58} × × {Zr _{2.82} Hf _{0.05} Ti _{0.13} } _{23.00} Si(7) _{0.85} Si(7a) _{0.26} {Nb _{0.55} Zr _{0.15} Ti _{0.08} } _{20.76} ... Na _{15.3} K _{0.3} Ca _{3.5} Sr _{0.2} La _{0.5} Ce _{0.5} Nd _{0.1} Y _{0.4} Fe _{0.7} Mn _{1.8} Mg _{0.1} Zr _{3.0} Hf _{0.1} Ti _{0.2} Nb _{0.6} Al _{0.1} Si _{24.6} Cl _{0.3} F _{1.5} H _{1.6} [Zr+Nb+Ti = 3.77] {Na _{14.99} REE _{0.44} Y _{0.42} K _{0.30} Sr _{0.15} } _{23.24} {Ca _{3.27} Mn _{1.78} REE _{0.62} Na _{0.33} } _{26.00} {Mn _{1.90} Fe _{0.72} Al _{0.13} Mg _{0.05} } _{22.89} × × {Zr _{2.80} Hf _{0.06} Ti _{0.13} } _{23.00} Si _{0.60} {Nb _{0.35} Zr _{0.12} Ti _{0.10} } _{20.77} {Si _{0.92} } _{22.00} {Si _{0.72} O ₂ (F _{1.5} Cl _{0.27} OH _{0.27})} _{20.23} H ₂ O [Σ anions = 78.30] {Na(1),Na(2),Na(3),Na(5)} _{21.46} {Na(4)=Na _{1.69} REE _{0.44} Y _{0.42} K _{0.30} Sr _{0.15} } _{23.00} {M(1)=Ca _{3.27} Mn _{1.78} REE _{0.62} Na _{0.33} } _{26.00} × × {M(2)=Mn _{1.90} Fe _{0.52} Al _{0.13} Mg _{0.05} } _{23.00} {M(2a)=Fe _{0.27} Cl _{0.73} } _{23.00} {Zr=Zr _{2.81} Hf _{0.06} Ti _{0.13} } _{23.00} × × {M(3)=Nb _{0.55} Ti _{0.10} Zr _{0.12} O ₂ } _{21.00} {M(4)=Si _{0.84} Cl _{0.16} } _{21.00} {M(4a)=Si _{0.26} Cl _{0.74} } _{21.00} {Si ₂ O ₇ } ₂ O ₂ (F _{1.5} Cl _{0.27} OH _{1.17}) (Na,REE) ₁ (Ca,REE) ₈ Mn ₃ Zr ₃ NbSi ₂₅ O ₇₄ F ₂ ·2H ₂ O	Johnsen <i>et al.</i> , 1998; Johnsen, Grice, 1999
21	Eudialyte-R $\bar{3}m$ No 4 Mont Saint-Hilaire Quebec, Canada	$Na_{15.3}K_{0.2}Ca_{1.6}Sr_{0.1}REE_{0.9}Y_{0.1}Fe_{1.1}Mn_{1.4}Zr_{2.7}Ti_{0.1}Nb_{0.7}Ta_{0.0}Al_{0.0}Si_{25.4}Cl_{0.4}H_{1.1}$... [Σ anions = 76.63] Na(1) _{2.95} Na(2) _{2.76} {Na(3) _{2.91} REE _{0.09} } _{23.00} {Na(4) _{2.31} REE _{0.34} K _{0.23} Sr _{0.12} } _{23.00} Na(5) _{3.20} {Ca _{7.00} REE _{0.29} Mn _{1.88} Y _{0.12} } _{26.00} × × Fe _{0.50} {Fe _{0.55} Mn _{1.56} } _{22.11} {Zr _{2.76} Ti _{0.13} Nb _{0.11} } _{23.00} {Si(7) _{1.33} Nb _{0.67} } _{22.00} ...	Johnsen, Grice, 1999
22	Eudialyte-R $\bar{3}m$ No 2 Mont Saint-Hilaire Quebec, Canada	$Na_{14.5}K_{0.3}Ca_{4.4}Sr_{0.1}REE_{0.9}Y_{0.2}Fe_{2.3}Mn_{1.3}Zr_{3.0}Hf_{0.0}Ti_{0.1}Nb_{0.6}Ta_{0.1}Al_{0.1}Si_{25.1}Cl_{0.8}H_{2.5}$... [Σ anions = 77.67] Na(1) _{2.77} Na(2) _{2.93} {Na(3) _{2.87} REE _{0.13} } _{23.00} {Na(4) _{1.66} REE _{0.67} K _{0.30} Ca _{0.24} Sr _{0.13} } _{23.00} Na(5) _{2.76} × × {Ca _{4.46} Mn _{1.23} REE _{0.14} Y _{0.17} } _{26.00} {Fe _{0.32} Mn _{0.69} } _{21.12} {Zr ₃ } _{23.00} {Nb _{0.62} Ti _{0.06} Ta _{0.04} } _{20.72} {Si _{0.12} }... × {Fe _{0.55} {Fe _{1.55} Mn _{0.80} } _{22.35} {Zr _{2.96} Si(7) _{0.62} Si(7a) _{0.42} {W _{0.52} Nb _{0.31} } _{20.83} ...	Johnsen, Grice, 1999
23	Eudialyte-R $\bar{3}m$ No 6 Mont Saint-Hilaire Quebec, Canada It was approved by the CNMNC as new mineral: <i>Khomaykovite</i>	$Na_{17.2}K_{0.4}Ca_{6.6}Sr_{2.3}REE_{0.1}Fe_{2.1}Mn_{0.8}Mg_{0.0}Zr_{2.7}Hf_{0.0}Ti_{0.1}Nb_{0.3}W_{0.6}Al_{0.1}Si_{24.8}Cl_{0.6}F_{1.3}$... [Σ anions = 78.70] Na(1) _{2.88} Na(2) _{3.28} {Na(3) _{2.03} K _{0.37} Ca _{0.40} Sr _{0.13} REE _{0.08} } _{23.00} {Na(4) _{0.40} Sr _{0.20} } _{23.00} Na(5) _{2.99} {Ca _{6.08} } × {Fe _{0.55} {Fe _{1.55} Mn _{0.80} } _{22.35} {Zr _{2.96} Si(7) _{0.62} Si(7a) _{0.42} {W _{0.52} Nb _{0.31} } _{20.83} ... {Na _{12.26} Ca _{0.33} K _{0.38} Sr _{0.13} REE _{0.08} } _{23.05} {Sr _{2.78} Na _{0.22} } _{23.00} {Ca ₄ {Fe _{0.28} Mn _{0.78} Mg _{0.03} } _{22.84} {Zr _{2.94} Hf _{0.03} Ti _{0.03} } _{23.02} × × {W _{0.56} Nb _{0.34} } _{20.90} {Si _{2.78} Al _{0.06} } _{22.74} {O ₂ (OH,H ₂ O)} _{23.70} {OH _{1.36} Cl _{0.64} } _{22.00} ... [Σ anions = 78.70] Na ₁₅ Sr ₂ Ca ₆ Fe ₉ Zr ₃ W(Si ₂₅ O ₇₃)(O,OH,H ₂ O) ₃ (OH) ₂	Johnsen <i>et al.</i> , 1999
24	Eudialyte-R $\bar{3}m$ No 3 Mont Saint-Hilaire Quebec, Canada	$Na_{14.9}K_{0.2}Ca_{4.7}Sr_{0.1}REE_{1.3}Y_{0.2}Fe_{1.5}Mn_{1.3}Zr_{2.9}Hf_{0.0}Nb_{0.8}Ta_{0.0}Al_{0.1}Si_{25.1}Cl_{1.1}H_{1.7}$... [Σ anions = 77.90] Na(1) _{2.76} Na(2) _{2.99} {Na(3) _{2.92} REE _{0.08} } _{23.00} {Na(4) _{1.50} REE _{1.20} K _{0.24} Sr _{0.06} } _{23.00} Na(5) _{2.91} × × {Ca _{4.84} Mn _{0.88} REE _{0.10} Y _{0.18} } _{26.00} {Fe _{0.68} {Fe _{0.77} Mn _{1.43} } _{22.22} {Zr _{2.99} Si(7) _{0.80} Si(7a) _{0.09} } _{23.00} {Nb _{0.78} Ta _{0.07} } _{20.85} ...	Johnsen, Grice, 1999
25	Eudialyte-R $\bar{3}$ No 5 Mont Saint-Hilaire Quebec, Canada It was approved by the CNMNC as new mineral: <i>Oneillite</i>	$Na_{15.0}K_{0.2}Ca_{1.8}Sr_{0.0}REE_{2.1}Y_{0.2}Fe_{1.4}Mn_{1.7}Zr_{3.2}Hf_{0.0}Nb_{0.9}Ta_{0.0}Al_{0.1}Si_{24.8}Cl_{0.7}H_{2.4}$... [Σ anions = 78.09] Na(1) _{2.80} Na(2) _{3.02} {Na(3) _{2.82} REE _{0.18} } _{23.00} {Na(4) _{1.44} REE _{1.35} K _{0.19} } _{23.98} Na(5) _{2.87} × × {Mn _{2.75} Y _{0.25} } _{23.00} {Ca _{1.77} REE _{0.57} Na _{0.66} } _{23.00} Fe _{0.28} {Fe _{1.13} Mn _{0.95} Zr _{0.24} } _{22.32} {Zr _{2.93} Nb _{0.05} } _{22.98} Si(7) _{0.80} Si(7a) _{0.20} Nb _{0.87} {Na(1)=Na _{2.80} } {Na(2)=Na _{3.02} } {Na(3)=Na _{2.82} REE _{0.18} } _{23.00} {Na(4)=Na _{1.44} REE _{1.35} K _{0.19} } _{23.98} {Na(5)=Na _{2.87} } × {M(1a)=Mn _{2.75} Y _{0.25} } _{23.00} {M(1b)=Ca _{1.77} REE _{0.57} Na _{0.66} } _{23.00} {M(2,4)=Fe _{0.28} } {M(2,5)=Fe _{1.13} Mn _{0.95} Zr _{0.24} } _{22.35} × × {Zr=Zr _{2.91} Nb _{0.05} } _{22.98} {M(3)=Nb _{0.87} } {Si(7)=Si _{0.80} } {Si(7a)=Si _{0.20} }... {Na _{14.37} REE _{1.58} K _{0.30} Sr _{0.03} } _{21.63} {Ca _{1.77} REE _{0.59} Na _{0.66} } _{23.02} {Mn _{2.76} Y _{0.24} } _{23.00} {Fe _{1.43} Mn _{0.96} Zr _{0.25} } _{22.64} × × {Zr _{2.99} Nb _{0.05} Hf _{0.03} } _{23.01} {Nb _{0.85} Ta _{0.02} } _{20.87} {Si _{2.77} Al _{0.12} } _{22.89} O ₇₃ (O,OH,H ₂ O) _{23.09} OH _{1.27} Cl _{0.73} (Σ anions = 78.09) Na ₁₅ Ca ₃ Mn ₃ Fe ₃ Zr ₃ Nb(Si ₂₅ O ₇₃)(O,OH,H ₂ O) ₃ (OH) ₂	Johnsen <i>et al.</i> , 1999
26	Eudialyte-R $\bar{3}m$ No 16 Khibiny Kola Peninsula	$Na_{14.5}K_{0.3}Ca_{5.1}Sr_{0.7}Ba_{0.0}REE_{1.1}Y_{0.2}Fe_{1.1}Mn_{2.5}Zr_{2.9}Hf_{0.0}Ti_{0.0}Nb_{0.9}Ta_{0.0}Si_{24.0}Cl_{0.4}H_{2.7}$... [Σ anions = 78.53] Na(1) _{2.94} Na(2) _{2.79} Na(3) _{3.15} {Na(4) _{0.96} REE _{0.74} K _{0.33} Sr _{0.72} Y _{0.25} } _{23.00} Na(5) _{2.99} {Ca _{4.95} Mn _{0.67} REE _{0.38} } _{26.00} × × Fe _{0.26} {Fe _{0.79} Mn _{1.33} } _{22.62} {Zr _{2.96} Si(7) _{0.82} Si(7a) _{0.11} Nb _{0.95} ...	Johnsen, Grice, 1999
27	Eudialyte-R $\bar{3}m$ No 17 Burlapa massif N. Baikal region	$Na_{12.9}K_{0.3}Ca_{3.4}Sr_{0.6}Ba_{0.0}REE_{1.2}Y_{0.3}Fe_{1.3}Mn_{2.2}Mg_{0.1}Zr_{3.1}Hf_{0.0}Ti_{0.4}Nb_{0.5}Al_{0.8}Si_{24.9}Cl_{0.9}F_{1.3}$... [Σ anions = 78.09] {Na(1) _{2.90} REE _{0.05} } _{22.95} Na(2) _{2.51} {Na(3) _{2.84} REE _{0.16} } _{23.00} {Na(4) _{1.69} K _{0.28} REE _{0.43} Sr _{0.56} Ba _{0.04} } _{23.01} Na(5) _{3.0} × × {Ca _{3.50} Mn _{1.51} REE _{0.49} Y _{0.50} } _{26.00} Fe _{0.14} {Fe _{0.37} Mn _{0.66} Al _{0.42} Ti _{0.24} } _{21.69} {Zr _{2.89} Ti _{0.11} } _{23.00} {Fe _{1.93} Nb _{0.45} Al _{0.42} Zr _{0.20} } _{22.00} ...	Johnsen, Grice, 1999
28	Fe,Sr-analogue of <i>kentbrooksite</i> R $\bar{3}m$ Alluaiv Mt.	$Na_{13.3}K_{0.2}Ca_{4.4}Sr_{1.3}Fe_{2.0}Mn_{1.4}REE_{0.3}Zr_{3.1}Hf_{0.0}Ti_{0.2}Nb_{0.7}Si_{25.4}O_{76.8}Cl_{0.9}$ [Σ cations = 53] Na ₁₂ {Sr _{1.80} Na _{0.96} K _{0.24} } _{23.00} {Fe _{1.99} Mn _{0.67} Ti _{0.20} Zr _{0.10} Hf _{0.04} } _{23.00} {Ca _{4.85} Mn _{0.83} REE _{0.30} } _{26.00} {Zr ₃ } _{23.00} {Si(Si _{0.5} Nb _{0.7} } _{21.00} × × {Si _{0.9} } ₂ {[Si _{0.24} (OH,O) ₃]OH _{1.92} Cl _{1.1} H ₂ O}	Ekimenkova <i>et al.</i> , 2000

29	<i>Ferrokennbrooksit</i> R3m Mont Saint-Hilaire Quebec, Canada	$\{Na_{13.05}REe_{0.99}K_{0.32}Ca_{0.23}Sr_{0.15}\}_{\Sigma 14.74}\{Ca_{4.59}Mn_{1.2}Y_{0.17}\}_{\Sigma 6.00}\{Fe_{2.39}Mn_{0.61}\}_{\Sigma 3.00}\{Zr_{3.06}Ti_{0.04}Hf_{0.03}\}_{\Sigma 3.07} \times$ $\times \{Nb_{0.64}Si_{0.23}Zr_{0.07}Ta_{0.02}\}_{\Sigma 0.96}\{Si_{2.93}Al_{0.07}\}_{\Sigma 2.00}O_{73}\{O, OH, H_2O\}_{\Sigma 22.47}\{Cl_{0.99}F_{0.77}OH_{0.40}\}_{\Sigma 2.00} (\Sigma \text{ anions} = 77.47)$ $Na_{15}Ca_6(Fe, Mn)_3Zr_3NbSi_2O_{73}(O, OH, H_2O)_3(Cl, F, OH)_2$	Johnsen <i>et al.</i> , 2003 ²
30	<i>Manganokhomyakovite</i> R3m Mont Saint-Hilaire Quebec, Canada	$\{Na_{11.51}Ca_{0.25}K_{0.30}Sr_{0.04}REe_{0.07}\}_{\Sigma 12.17}\{Sr_1\}\{Ca_2\}\{Mn_{2.04}Fe_{1.23}\}_{\Sigma 3.27}\{Zr_{2.91}Hf_{0.03}Ti_{0.01}\}_{\Sigma 2.95}\{W_{0.66}Nb_{0.41}Ta_{0.01}\}_{\Sigma 1.08} \times$ $\times \{Si_{24.60}Al_{0.01}\}_{\Sigma 24.61}O_{73}\{O, OH, H_2O\}_{\Sigma 23.76}\{OH_{1.19}Cl_{0.81}\}_{\Sigma 2.00} \dots (\Sigma \text{ anions} = 78.70)$ $Na_{12}Sr_3Ca_3Mn_3Zr_3W(Si_{25}O_{73})(O, OH, H_2O)_3(OH)_2$	Johnsen <i>et al.</i> , 1999 ²
31	<i>Carbokenbrooksit</i> R3m Dara-i-Pioz, Tajikistan	$Na_{10.8}K_{0.4}Ca_{6.2}Sr_{0.5}Fe_{1.0}Mn_{2.5}La_{0.4}Ce_{0.6}Pr_{0.1}Nd_{0.2}Y_{0.1}Zr_{3.0}Ti_{0.2}Nb_{0.9}Si_{25.0}O_{77.6}Cl_{0.3}(CO_3)_{0.6} \cdot 4.5H_2O [Si = 25]$ $\{N_1=Na_{2.41}\}\{N_2=Na_{2.31}Ca_{0.45}K_{0.18}\}_{\Sigma 2.94}\{N_3=Na_{2.37}Ca_{0.45}K_{0.18}\}_{\Sigma 2.67}\{N_4=La_{0.36}Ce_{0.60}Pr_{0.05}Nd_{0.15}Na_{1.39}Sr_{0.45}\}_{\Sigma 3.00} \times$ $\times \{N_5=Na_{2.34}\}\{M_1=Ca_{5.34}Mn_{0.54}Y_{0.12}\}_{\Sigma 6.00}\{M_2=Mn_{1.98}Fe_{1.02}\}_{\Sigma 3.00}\{Zr_{2.96}Ti_{0.04}\}_{\Sigma 3.00}\{M_3=Nb_{0.88}Ti_{0.13}\}_{\Sigma 1.01} \times$ $\times \{M_4=Si_1\}\{Si_3O_9\}_2\{Si_6O_{27}\}_2\{O, OH, H_2O\}_3\{X_1=C_{0.38}Cl_{0.30}\}\{X_2=O\}$ $(Na, Cl)_{12}(Ca, Ce)_3Ca_6Mn_3Zr_3Nb(Si_{25}O_{73})(OH)_3(CO_3) \cdot H_2O$	Khomyakov <i>et al.</i> , 2003
32	<i>Zirsilitte-Ce</i> R3m Dara-i-Pioz, Tajikistan	$Na_{10.1}K_{0.3}Ca_6.2Sr_{0.4}Fe_{0.9}Mn_{2.6}La_{0.5}Ce_{0.8}Pr_{0.1}Nd_{0.2}Y_{0.1}Zr_{2.8}Ti_{0.2}Nb_{0.9}Si_{25.0}O_{79.9}Cl_{0.3}(CO_3)_{0.4} \cdot 5.5H_2O [Si = 25]$ $\{N_1=Na_{2.68}\}\{N_2=Na_{2.27}Ca_{0.42}K_{0.17}\}_{\Sigma 2.89}\{N_3=Na_{2.12}Ca_{0.40}K_{0.15}\}_{\Sigma 2.67}\{N_4=La_{0.47}Ce_{0.76}Pr_{0.05}Nd_{0.16}Na_{1.12}Sr_{0.43}\}_{\Sigma 3.00} \times$ $\times \{N_5=Na_{1.94}\}\{M_1=Ca_{5.36}Mn_{0.50}Y_{0.34}\}_{\Sigma 6.00}\{M_2=Ti_{1.3}Fe_{0.87}\}_{\Sigma 3.00}\{Zr_{2.80}Ti_{0.18}\}_{\Sigma 2.98}\{M_3=Nb_{0.93}\}\{M_4=Si_1\} \times$ $\times \{Si_3O_9\}_2\{Si_6O_{27}\}_2\{O, OH, H_2O\}_3\{X_1=C_{0.43}Cl_{0.30}\}\{X_2=O\}$ $(Na, Cl)_{12}(Ce, Na)_3Ca_6Mn_3Zr_3Nb(Si_{25}O_{73})(OH)_3(CO_3) \cdot H_2O$	Khomyakov <i>et al.</i> , 2003
33	<i>Taseqite</i> Ilimaussaq S. Greenland	$\{Na_{8.8}Sr_{4.8}K_{2.0}Ce_{0.2}\}_{\Sigma 13.78}\{Ca_{5.17}Mn_{0.59}Y_{0.09}\}_{\Sigma 5.85}\{Fe_{1.93}Mn_{0.92}\}_{\Sigma 2.85}\{Ti_{0.24}Nb_{0.11}Hf_{0.05}\}_{\Sigma 3.00} \times$ $\times \{Nb_{1.06}Ta_{0.04}Sn_{0.03}\}_{\Sigma 1.13}\{Si_{24}O_{73}\}\{O_{1.65}(OH)_{0.75}(H_2O)_{0.74}\}_{\Sigma 3.14}\{Cl_{1.91}(OH)_{0.09}\}_{\Sigma 2.00} (\Sigma \text{ anions} = 78.14)$ $Na_{12}Sr_3Ca_6Fe_3Zr_3NbSi_{25}O_{73}(O, OH, H_2O)_3Cl_2$	Petersen <i>et al.</i> , 2004
34	<i>Feklichevite</i> R3m Kovdor massif Kola Peninsula	$Na_{11.1}Ca_{8.4}Sr_{1.0}Fe^{3+}_{1.2}Mn_{0.2}La_{0.0}Ce_{0.0}Zr_{2.9}Hf_{0.1}Ti_{0.1}Nb_{0.6}Si_{25.3}O_{74.1}(OH)_{2.4}Cl_{0.5}F_{0.2} \cdot 1.7H_2O$ $[Si+Zr+Hf+Ti+Nb+Mn = 29]$ $Na_{10.80}\{Ca_{2.35}Na_{0.33}Sr_{0.08}Ce_{0.03}La_{0.02}\}_{\Sigma 2.81}\{Ca_6\}\{Fe^{3+}_{1.21}Fe^{2+}_{0.87}\}_{\Sigma 2.08}\{Zr_{2.85}Hf_{0.09}Ti_{0.05}\}_{\Sigma 2.99}Nb_{0.55} \times$ $\times \{Si_{25.25}Mn_{0.21}\}_{\Sigma 25.46}O_{73}\{(OH)_{1.12}O_{2.6}(H_2O)_{1.67}\}_{\Sigma 2.05}\{(OH)_{1.29}Cl_{0.32}F_{0.19}\}_{\Sigma 2.00}$ $\{Na(1)=Na_{1.80}\}\{Na(2)=Na_3\}\{Na(3)=Na_3\}\{Na(4)=Ca_{2.35}Na_{0.33}Sr_{0.08}REe_{0.05}\}_{\Sigma 2.81}\{Na(5)=Na_3\} \times$ $\times \{Ca_6\}\{M(2,4)=Fe_{0.92}\}\{M(2,6)=Fe_{1.16}\}\{Zr-Zr_{2.85}Hf_{0.09}Ti_{0.05}\}\{M(3)=Nb_{0.55}\}\{M(3a)=Si_{0.45}\} \times$ $\times \{Si(7)=Si_{0.75}\}\{Si(7a)=Mn_{0.21}Si_{0.03}\}_{\Sigma 0.26} \dots$ $Na_{11}Ca_9(Fe^{3+}, Fe^{2+})_2Zr_3Nb(Si_{25}O_{73})(OH)_3(CO_3)(H_2O)_5$	Rastsvetaeva <i>et al.</i> , 1999 ¹ ; Pekov <i>et al.</i> , 2001
35	<i>Golyshhevite</i> R3m Kovdor massif Kola Peninsula	$\{Na_{9.87}Ca_{4.05}K_{0.24}Ce_{0.06}La_{0.03}\}_{\Sigma 14.25}\{Ca_6\}\{Fe^{3+}_{1.69}Fe^{2+}_{0.50}Mn_{0.29}\}_{\Sigma 2.48}\{Zr_{2.97}\}\{Nb_{0.60}Si_{0.66}Al_{0.08}\}_{\Sigma 1.34}\{Si_{24}O_{72}\} \times$ $\times (OH)_{2.37}(CO_3)_{1.05}Cl_{0.21} \cdot 1.0H_2O [Si = 24.66]$ $(Na, Ca)_{10}Ca_9(Fe^{3+}, Fe^{2+})_2Zr_3Nb(Si_{25}O_{73})(OH)_3(CO_3)(H_2O)$	Chukanov <i>et al.</i> , 2005 Rozenberg <i>et al.</i> , 2005
36	<i>Mogovidite</i> R3m Kovdor massif Kola Peninsula	$\{Na_{9.02}Ca_{0.43}K_{0.30}\}_{\Sigma 9.75}\{Ca_{5.92}Ce_{0.05}La_{0.03}\}_{\Sigma 6.00}\{Fe^{3+}_{1.48}Fe^{2+}_{0.58}Mn_{0.30}\}_{\Sigma 2.36}\{Zr_{3.02}Ti_{0.09}\}\{Nb_{0.40}Si_{0.71}\}_{\Sigma 1.11}\{Si_{24}O_{72}\} \times$ $\times (OH)_{2.86}(CO_3)_{1.03}Cl_{0.46} \cdot 0.74H_2O [Si = 24.71]$ $Na_9(Ca, Na)_6Ca_6(Fe^{3+}, Fe^{2+})_2Zr_3NbSi_{25}O_{72}(CO_3)(OH, H_2O)_4$	Chukanov <i>et al.</i> , 2005
37	<i>High-tantalum eudialyte-R3m</i> Poços de Caldas Brazil	$Na_{11.9}K_{0.7}Ca_{5.3}Sr_{0.3}Ba_{0.1}Fe_{1.3}Mn_{1.3}REe_{0.1}Zr_{3.3}Hf_{0.1}Ti_{0.2}Nb_{0.05}Ta_{0.8}W_{0.15}Si_{24.7}Al_{0.3}O_{73.4}Cl_{1.0}$ $\{Na_{1.9}K_{0.6}Mn_{0.3}Ba_{0.1}Ce_{0.1}\}\{Na_{2.7}Sr_{0.3}\}\{Na_8\}\{Ca_{5.28}Mn_{0.72}\}\{Fe_{1.35}Ti_{1.14}Ta_{0.51}\}\{Zr_{2.85}Hf_{0.15}\} \times$ $\times \{Si_{10.78}^{VI}Nb_{0.13}^{VI}W_{0.09}\}\{Si_{0.5}Al_{0.3}Ti_{0.2}\}\{Si_{24}O_{72}\}\{O, (OH)_{3.54}\}\{Cl_{0.8}\} \cdot 1.2H_2O$ $\{Na(1)=^{VIII}Na_{3.3}\}\{Na(2a)=^{IX}Na_{1.8}\}\{Na(2b)=^{VIII}Na_{1.2}\}\{Na(3a)=^VNa_{0.6}\}\{Na(3b)=^{IV}Na_{1.38}\} \times$ $\times \{Na(4)=^{VI}(Na_{1.9}K_{0.6}Mn_{0.3}Ba_{0.1}Ce_{0.1})\}_{\Sigma 3}\{Na(5)=^{XII}(Na_{2.7}Sr_{0.3})\}\{^{VI}(Ca_{5.28}Mn_{0.72})\}\{^{IV}Ta_{0.51}\}\{^{VI}Fe_{1.35}\} \times$ $\times \{Zr=^{VI}(Zr_{2.85}Hf_{0.15})\}\{M(3)=^{VI}(Nb_{0.13}W_{0.09})\}\{Si(7a)=^{IV}(Si_{0.5}Al_{0.3})\}\{Si(7a)=^{IV}Si_{0.35}Si(7b)=^{IV}Si_{0.45}\}\{^{VI}Ti_{0.2}\} \times$ $\times \{Si_{24}O_{72}\}\{(OH)_{3.54}Cl_{0.8}\} \cdot 1.2H_2O$	Rastsvetaeva <i>et al.</i> , 2003
38	<i>Hyperzirconium eudialyte-R3m</i>	$\{Na_{15.87}K_{0.30}Sr_{0.33}\}\{Ca_{2.7}Mn_{1.1}Fe_{1.8}Na_{0.85}Ce_{0.35}Ti_{0.12}\}_{\Sigma 22.6}\{Zr_{1.2}Fe_{0.3}Na_{0.87}(OH)_{1.5}\}\{Zr_3\} \times$ $\times \{Si_{0.5}Al_{0.5}\}\{Si_{0.5}(Ti_{0.3}Nb_{0.2})\}\{Si_3O_9\}_2\{Si_6O_{27}\}_2\{O, OH\}_{1.5}(OH)_{2.5}Cl_{0.5} \cdot H_2O$	Rastsvetaeva, Khomyakov, 2000 ²
39	<i>Alluaivite</i> R 3m, 2c Alluaiv Mt. Lovozero	$Na_{17.5}K_{0.2}Ca_{4.5}Sr_{0.3}Ba_{0.1}Mn_{1.5}La_{0.0}Ce_{0.1}Zr_{0.5}Ti_{2.2}Nb_{0.9}Si_{25.8}O_{73.7}Cl_{0.7} \cdot 5.5H_2O (\Sigma \text{ cations} = 53)$ $\{Na_{17.47}K_{0.12}Sr_{0.28}Ba_{0.1}La_{0.03}Ce_{0.14}\}_{\Sigma 18.15}\{Ca_{4.46}Mn_{1.47}\}_{\Sigma 5.93}\{Ti_{2.18}Nb_{0.85}Zr_{0.05}\}_{\Sigma 3.08}\{Si_{25}O_{72}\}_{\Sigma 24.6}\{Cl_{0.66} \cdot 2H_2O$ $\{Na_{1.9}, Sr_{0.3}, REe_{0.1}\}_{\Sigma 19.5}\{Ca_{4.5}, Mn_{1.5}\}_{\Sigma 6}\{Ti_{2.2}, Nb_{0.7}\}_{\Sigma 3}\{Si_3O_9\}_2\{Si_{10}O_{28}\}_2\{Cl_{0.8}(H_2O)_{1.6}K_{0.1}\}_{\Sigma 4.45}$ $Na_{19}(Ca, Mn)_6(Ti, Nb)_3Si_{26}O_{74}Cl_2 \cdot 2H_2O$ $Na_{38}(Ca, Mn)_{12}(Ti, Nb)_6Si_{52}O_{148}Cl_2 \cdot 4H_2O$	Khomyakov <i>et al.</i> , 1990 ¹ ; Khomyakov <i>et al.</i> , 2007
40	<i>Ti-eudialyte</i> R3m, 2c Alluaiv Mt. Lovozero	$Na_{34.4}Ca_8.5Sr_{0.8}Ce_{1.1}Mn_{2.1}Fe_{0.9}Zr_{3.6}Ti_{2.4}Si_{50.7}Al_{0.4}O_{144}Cl_{0.9}(OH)_{5.7} \cdot 1.5H_2O (Nb_{0.8} \text{ omitted})$ Modular structure (two blocks): $\{Na_{14.4}Sr_{0.4}\}_{\Sigma 14.8}\{Na_{1.3}(Ti, Fe)_{0.3}\}_{\Sigma 1.6}\{Ca_{4.8}Mn_{1.2}\}_{\Sigma 6}\{Zr_{2.3}Ti_{0.7}\}\{Si_{1.6}Al_{0.4}\}_{\Sigma 2}\{Si_3O_9\}_2\{Si_6O_{27}\}_2\{Cl_{0.2}(OH)_{0.2}\} +$ $+ \{Na_{14.5}Ce_{0.5}\}_{\Sigma 15}\{Na_{2.1}Sr_{0.4}Fe_{0.5}Ce_{0.2}\}_{\Sigma 3}\{Ca_{3.7}Na_{1.9}Ce_{0.4}\}\{Ti_{1.7}Zr_{1.3}\}\{Si_{1.1}Mn_{0.9}\}_{\Sigma 2}\{Si_3O_9\}_2\{Si_6O_{27}\}_2\{Cl_{0.7}(OH)_{0.2}\} \cdot 1.5H_2O$ In General: $\{Na(1)Na(2)Na(3)Na(4)Na(5)Na(6)Na(7)Na(8)Na(9)Na(10)Na(11)Na(12)Na(13)Na(14)Na(15)Na(16)Na(17)Na(18)Na(19)Na(20)Na(21)Na(22)Na(23)Na(24)Na(25)Na(26)Na(27)Na(28)Na(29)Na(30)Na(31)Na(32)Na(33)Na(34)Na(35)Na(36)Na(37)Na(38)Na(39)Na(40)Na(41)Na(42)Na(43)Na(44)Na(45)Na(46)Na(47)Na(48)Na(49)Na(50)Na(51)Na(52)Na(53)Na(54)Na(55)Na(56)Na(57)Na(58)Na(59)Na(60)Na(61)Na(62)Na(63)Na(64)Na(65)Na(66)Na(67)Na(68)Na(69)Na(70)Na(71)Na(72)Na(73)Na(74)Na(75)Na(76)Na(77)Na(78)Na(79)Na(80)Na(81)Na(82)Na(83)Na(84)Na(85)Na(86)Na(87)Na(88)Na(89)Na(90)Na(91)Na(92)Na(93)Na(94)Na(95)Na(96)Na(97)Na(98)Na(99)Na(100)Na(101)Na(102)Na(103)Na(104)Na(105)Na(106)Na(107)Na(108)Na(109)Na(110)Na(111)Na(112)Na(113)Na(114)Na(115)Na(116)Na(117)Na(118)Na(119)Na(120)Na(121)Na(122)Na(123)Na(124)Na(125)Na(126)Na(127)Na(128)Na(129)Na(130)Na(131)Na(132)Na(133)Na(134)Na(135)Na(136)Na(137)Na(138)Na(139)Na(140)Na(141)Na(142)Na(143)Na(144)Na(145)Na(146)Na(147)Na(148)Na(149)Na(150)Na(151)Na(152)Na(153)Na(154)Na(155)Na(156)Na(157)Na(158)Na(159)Na(160)Na(161)Na(162)Na(163)Na(164)Na(165)Na(166)Na(167)Na(168)Na(169)Na(170)Na(171)Na(172)Na(173)Na(174)Na(175)Na(176)Na(177)Na(178)Na(179)Na(180)Na(181)Na(182)Na(183)Na(184)Na(185)Na(186)Na(187)Na(188)Na(189)Na(190)Na(191)Na(192)Na(193)Na(194)Na(195)Na(196)Na(197)Na(198)Na(199)Na(200)Na(201)Na(202)Na(203)Na(204)Na(205)Na(206)Na(207)Na(208)Na(209)Na(210)Na(211)Na(212)Na(213)Na(214)Na(215)Na(216)Na(217)Na(218)Na(219)Na(220)Na(221)Na(222)Na(223)Na(224)Na(225)Na(226)Na(227)Na(228)Na(229)Na(230)Na(231)Na(232)Na(233)Na(234)Na(235)Na(236)Na(237)Na(238)Na(239)Na(240)Na(241)Na(242)Na(243)Na(244)Na(245)Na(246)Na(247)Na(248)Na(249)Na(250)Na(251)Na(252)Na(253)Na(254)Na(255)Na(256)Na(257)Na(258)Na(259)Na(260)Na(261)Na(262)Na(263)Na(264)Na(265)Na(266)Na(267)Na(268)Na(269)Na(270)Na(271)Na(272)Na(273)Na(274)Na(275)Na(276)Na(277)Na(278)Na(279)Na(280)Na(281)Na(282)Na(283)Na(284)Na(285)Na(286)Na(287)Na(288)Na(289)Na(290)Na(291)Na(292)Na(293)Na(294)Na(295)Na(296)Na(297)Na(298)Na(299)Na(300)Na(301)Na(302)Na(303)Na(304)Na(305)Na(306)Na(307)Na(308)Na(309)Na(310)Na(311)Na(312)Na(313)Na(314)Na(315)Na(316)Na(317)Na(318)Na(319)Na(320)Na(321)Na(322)Na(323)Na(324)Na(325)Na(326)Na(327)Na(328)Na(329)Na(330)Na(331)Na(332)Na(333)Na(334)Na(335)Na(336)Na(337)Na(338)Na(339)Na(340)Na(341)Na(342)Na(343)Na(344)Na(345)Na(346)Na(347)Na(348)Na(349)Na(350)Na(351)Na(352)Na(353)Na(354)Na(355)Na(356)Na(357)Na(358)Na(359)Na(360)Na(361)Na(362)Na(363)Na(364)Na(365)Na(366)Na(367)Na(368)Na(369)Na(370)Na(371)Na(372)Na(373)Na(374)Na(375)Na(376)Na(377)Na(378)Na(379)Na(380)Na(381)Na(382)Na(383)Na(384)Na(385)Na(386)Na(387)Na(388)Na(389)Na(390)Na(391)Na(392)Na(393)Na(394)Na(395)Na(396)Na(397)Na(398)Na(399)Na(400)Na(401)Na(402)Na(403)Na(404)Na(405)Na(406)Na(407)Na(408)Na(409)Na(410)Na(411)Na(412)Na(413)Na(414)Na(415)Na(416)Na(417)Na(418)Na(419)Na(420)Na(421)Na(422)Na(423)Na(424)Na(425)Na(426)Na(427)Na(428)Na(429)Na(430)Na(431)Na(432)Na(433)Na(434)Na(435)Na(436)Na(437)Na(438)Na(439)Na(440)Na(441)Na(442)Na(443)Na(444)Na(445)Na(446)Na(447)Na(448)Na(449)Na(450)Na(451)Na(452)Na(453)Na(454)Na(455)Na(456)Na(457)Na(458)Na(459)Na(460)Na(461)Na(462)Na(463)Na(464)Na(465)Na(466)Na(467)Na(468)Na(469)Na(470)Na(471)Na(472)Na(473)Na(474)Na(475)Na(476)Na(477)Na(478)Na(479)Na(480)Na(481)Na(482)Na(483)Na(484)Na(485)Na(486)Na(487)Na(488)Na(489)Na(490)Na(491)Na(492)Na(493)Na(494)Na(495)Na(496)Na(497)Na(498)Na(499)Na(500)Na(501)Na(502)Na(503)Na(504)Na(505)Na(506)Na(507)Na(508)Na(509)Na(510)Na(511)Na(512)Na(513)Na(514)Na(515)Na(516)Na(517)Na(518)Na(519)Na(520)Na(521)Na(522)Na(523)Na(524)Na(525)Na(526)Na(527)Na(528)Na(529)Na(530)Na(531)Na(532)Na(533)Na(534)Na(535)Na(536)Na(537)Na(538)Na(539)Na(540)Na(541)Na(542)Na(543)Na(544)Na(545)Na(546)Na(547)Na(548)Na(549)Na(550)Na(551)Na(552)Na(553)Na(554)Na(555)Na(556)Na(557)Na(558)Na(559)Na(560)Na(561)Na(562)Na(563)Na(564)Na(565)Na(566)Na(567)Na(568)Na(569)Na(570)Na(571)Na(572)Na(573)Na(574)Na(575)Na(576)Na(577)Na(578)Na(579)Na(580)Na(581)Na(582)Na(583)Na(584)Na(585)Na(586)Na(587)Na(588)Na(589)Na(590)Na(591)Na(592)Na(593)Na(594)Na(595)Na(596)Na(597)Na(598)Na(599)Na(600)Na(601)Na(602)Na(603)Na(604)Na(605)Na(606)Na(607)Na(608)Na(609)Na(610)Na(611)Na(612)Na(613)Na(614)Na(615)Na(616)Na(617)Na(618)Na(619)Na(620)Na(621)Na(622)Na(623)Na(624)Na(625)Na(626)Na(627)Na(628)Na(629)Na(630)Na(631)Na(632)Na(633)Na(634)Na(635)Na(636)Na(637)Na(638)Na(639)Na(640)Na(641)Na(642)Na(643)Na(644)Na(645)Na(646)Na(647)Na(648)Na(649)Na(650)Na(651)Na(652)Na(653)Na(654)Na(655)Na(656)Na(657)Na(658)Na(659)Na(660)Na(661)Na(662)Na(663)Na(664)Na(665)Na(666)Na(667)Na(668)Na(669)Na(670)Na(671)Na(672)Na(673)Na(674)Na(675)Na(676)Na(677)Na(678)Na(679)Na(680)Na(681)Na(682)Na(683)Na(684)Na(685)Na(686)Na(687)Na(688)Na(689)Na(690)Na(691)Na(692)Na(693)Na(694)Na(695)Na(696)Na(697)Na(698)Na(699)Na(700)Na(701)Na(702)Na(703)Na(704)Na(705)Na(706)Na(707)Na(708)Na(709)Na(710)Na(711)Na(712)Na(713)Na(714)Na(715)Na(716)Na(717)Na(718)Na(719)Na(720)Na(721)Na(722)Na(723)Na(724)Na(725)Na(726)Na(727)Na(728)Na(729)Na(730)Na(731)Na(732)Na(733)Na(734)Na(735)Na(736)Na(737)Na(738)Na(739)Na(740)Na(741)Na(742)Na(743)Na(744)Na(745)Na(746)Na(747)Na(748)Na(749)Na(750)Na(751)Na(752)Na(753)Na(754)Na(755)Na(756)Na(757)Na(758)Na(759)Na(760)Na(761)Na(762)Na(763)Na(764)Na(765)Na(766)Na(767)Na(768)Na(769)Na(770)Na(771)Na(772)Na(773)Na(774)Na(775)Na(776)Na(777)Na(778)Na(779)Na(780)Na(781)Na(782)Na(783)Na(784)Na(785)Na(786)Na(787)Na(788)Na(789)Na(790)Na(791)Na(792)Na(793)Na(794)Na(795)Na(796)Na(797)Na(798)Na(799)Na(800)Na(801)Na(802)Na(803)Na(804)Na(805)Na(806)Na(807)Na(808)Na(809)Na(810)Na(811)Na(812)Na(813)Na(814)Na(815)Na(816)Na(817)Na(818)Na(819)Na(820)Na(821)Na(822)Na(823)Na(824)Na(825)Na(826)Na(827)Na(828)Na(829)Na(830)Na(831)Na(832)Na(833)Na(834)Na(835)Na(836)Na(837)Na(838)Na(839)Na(840)Na(841)Na(842)Na(843)Na(844)Na(845)Na(846)Na(847)Na(848)Na(849)Na(850)Na(851)Na(852)Na(853)Na(854)Na(855)Na(856)Na(857)Na(858)Na(859)Na(860)Na(861)Na(862)Na(863)Na(864)Na(865)Na(866)Na(867)Na(868)Na(869)Na(870)Na(871)Na(872)Na(873)Na(874)Na(875)Na(876)Na(877)Na(878)Na(879)Na(880)Na(881)Na(882)Na(883)Na(884)Na(885)Na(886)Na(887)Na(888)Na(889)Na(890)Na(891)Na(892)Na(893)Na(894)Na(895)Na(896)Na(897)Na(898)Na(899)Na(900)Na(901)Na(902)Na(903)Na(904)Na(905)Na(906)Na(907)Na(908)Na(909)Na(910)Na(911)Na(912)Na(913)Na(914)Na(915)Na(916)Na(917)Na(918)Na(919)Na(920)Na(921)Na(922)Na(923)Na(924)Na(925)Na(926)Na(927)Na(928)Na(929)Na(930)Na(931)Na(932)Na(933)Na(934)Na(935)Na(936)Na(937)Na(938)Na(939)Na(940)Na(941)Na(942)Na(943)Na(944)Na(945)Na(946)Na(947)Na(948)Na(949)Na(950)Na(951)Na(952)Na(953)Na(954)Na(955)Na(956)Na(957)Na(958)Na(959)Na(960)Na(961)Na(962)Na(963)Na(964)Na(965)Na(966)Na(967)Na(968)Na(969)Na(970)Na(971)Na(972)Na(973)Na(974)Na(975)Na(976)Na(977)Na(978)Na(979)Na(980)Na(981)Na(982)Na(983)Na(984)Na(985)Na(986)Na(987)Na(988)Na(989)Na(990)Na(991)Na(992)Na(993)Na(994)Na(995)Na(996)Na(997)Na(998)Na(999)Na(1000)Na(1001)Na(1002)Na(1003)Na(1004)Na(1005)Na(1006)Na(1007)Na(1008)Na(1009)Na(1010)Na(1011)Na(1012)Na(1013)Na(1014)Na(1015)Na(1016)Na(1017)Na(1018)Na(1019)Na(1020)Na(1021)Na(1022)Na(1023)Na(1024)Na(1025)Na(1026)Na(1027)Na(10$	

<p>41 <i>Eudialyte-R3 with Ca and Fe ordered</i> <i>Kedykverpakhk</i> <i>Lovozero</i></p>	$\text{Na}_{1.54}\text{K}_{0.2}\text{Ca}_{3.4}\text{Sr}_{0.2}\text{Fe}_{2.0}\text{Mn}_{0.9}\text{Mg}_{0.2}\text{Al}_{0.3}\text{REE}_{0.2}\text{Zr}_{3.8}\text{Hf}_{0.1}\text{Ti}_{0.1}\text{Nb}_{0.2}\text{Si}_{25}\text{O}_{73}(\text{OH})_{0.8}\text{Cl}_{1.1} [\text{Si} = 25]$ $\{\text{Na}(1a) = \text{VI}\text{Na}_{1.35}\} \{\text{Na}(1b) = \text{VIII}\text{Na}_{1.05}\} \{\text{Na}(2a) = \text{VIII}\text{Na}_{1.15}\text{Ca}_{0.20}\} \{\text{Na}(2b) = \text{VIII}\text{Na}_{1.65}\text{Ca}_{0.10}\} \{1.75 \times$ $\times [\text{Na}(3) = \text{IX}\text{Na}_{2.80}\text{Ca}_{0.20}\} \{2.25 [\text{Na}(4a) = \text{IX}\text{Na}_{1.20}\text{Sr}_{1.0}\text{K}_{0.15}\} \{1.50 [\text{Na}(4b) = \text{VIII}\text{Na}_{1.40}\text{Sr}_{0.8}\text{K}_{0.05}\} \} \{1.50 \times$ $\times \{\text{Na}(5) = \text{VIII}\text{Na}_{1.0}\} \{M(1a) = \text{VI}\text{Fe}_{2.2}\text{Ca}_{0.5}\text{Mn}_{0.3}\} \{2.25 [M(1b) = \text{VI}\text{Ca}_{2.7}\text{REE}_{0.3}\} \} \{2.25 [M(2,4) = \text{IV}\text{Zr}_{0.8}\text{Hf}_{0.1}\} \} \times$ $\times \{M(2,5a) = \text{VI}\text{Mn}_{0.6}\} \{M(2,5b) = \text{VI}\text{Na}_{1.5}\} \{M(3) = \text{VI}\text{Nb}_{0.20}\text{Ti}_{0.13}\text{Mg}_{0.15}\} \} \{2.0 \times$ $\times [M(3a) = \text{IV}\text{Si}_{0.4}\text{Al}_{0.1}\} \} \{2.0 \times \{\text{Si}(7) = \text{IV}\text{Si}_{0.3}\} \{\text{Si}(7a) = \text{IV}\text{Si}_{0.4}\text{Al}_{0.1}\} \} \{2.0 \times \{\text{Si}_{25}\text{O}_{73}\} \{(\text{O},\text{OH})_{2.6}\} \{\text{Cl}, \text{H}_2\text{O}\}_2$ $\{\text{Na}_{14.2}\text{Ca}_{0.4}\text{Sr}_{0.2}\text{K}_{0.2}\} \{2.25 [\text{Ca}_{2.7}\text{REE}_{0.3}\} \} \{2.25 [\text{Fe}_{2.2}\text{Ca}_{0.5}\text{Mn}_{0.3}\} \} \{2.25 [\text{Na}_{1.5}\text{Zr}_{0.8}\text{Hf}_{0.1}\text{Mn}_{0.6}\} \} \} \{2.25 [\text{Zr}_3 \times$ $\times \{\text{Si}_{0.4}\text{Al}_{0.1}\text{Nb}_{0.2}\text{Ti}_{0.13}\text{Mg}_{0.15}\} \} \{2.25 \text{O}_{73}\} \{(\text{O},\text{OH})_{2.6}\} \{\text{Cl}, \text{H}_2\text{O}\}_2$ $\text{Na}_{15}(\text{Ca}_3\text{Fe}_3)(\text{Na},\text{Zr}_3)(\text{Si},\text{Nb})(\text{Si}_{25}\text{O}_{73})(\text{OH},\text{H}_2\text{O})_3(\text{Cl},\text{OH})_2$	<p>Ekimenkova et al., 2000;</p> <p>Chukanov et al., 2003</p>
<p>42 <i>Mn,Ce-eudialyte-R3</i> <i>Alluiv Mt.</i> <i>Lovozero</i></p>	$\text{Na}_{17.0}\text{K}_{0.1}\text{Ca}_{2.6}\text{Sr}_{0.5}\text{Fe}_{0.15}\text{Mn}_{3.2}\text{L}_{0.3}\text{Ce}_{0.3}\text{Nd}_{0.2}\text{Y}_{0.1}\text{Zr}_{3.2}\text{Hf}_{0.05}\text{Ti}_{0.1}\text{Nb}_{0.4}\text{Si}_{25.6}\text{O}_{74.15}(\text{OH},\text{H}_2\text{O})_{3.35}\text{F}_{0.5}\text{Cl}_{0.3} \cdot n\text{H}_2\text{O}$ $\{\text{Na}_{14.2}\text{Sr}_{0.45}\text{REE}_{0.25}\text{K}_{0.1}\} \{\text{Mn}_3(\text{Ca}_2,1\text{REE}_{0.9})\} \{\text{Na}_{1.8}(\text{Mn}_{0.6}\text{Fe}_{0.15})\} \{\text{Zr}_{0.4}\text{Hf}_{0.05}\} \} \{\text{Zr}_{2.9}\text{Ti}_{0.1}\} \times$ $\times \{\text{Si}_{11}\text{Nb}_{0.4}\} \{\text{Si}_3\text{O}_9\} \{\text{Si}_9\text{O}_{27}\} \{(\text{O},\text{OH})_{3.35}\text{F}_{0.5}\text{Cl}_{0.3} \cdot 0.65\text{H}_2\text{O}\}$ $\{\text{Na}(1a) = \text{VI}\text{Na}_{1.50}\} \{\text{Na}(1b) = \text{VIII}\text{Na}_{1.50}\} \{\text{Na}(2a) = \text{VIII}\text{Na}_{1.10}\text{REE}_{0.25}\} \{2.1 \cdot 44 [\text{Na}(2b) = \text{VIII}\text{Na}_{1.56}\} \} \{1 \times \text{Sr}_{0.30}\} \times$ $\times \{\text{Na}(3) = \text{IX}\text{Na}_{2.70}\} \{\text{Na}(4) = \text{VI}\text{Na}_{1.80}\} \{\text{Na}(5a) = \text{VIII}\text{Na}_{1.50}\} \{\text{Na}(5b) = \text{IX}\text{Na}_{1.35}\text{Sr}_{0.15}\} \} \{2.1 \cdot 50 [\text{Na}(6) = \text{IX}\text{Na}_{2.90}\text{K}_{0.10}\} \} \times$ $\times [M(1) = \text{VI}\text{Mn}_3] \{M(1a) = \text{VI}\text{Ca}_{2.10}\text{REE}_{0.90}\} \} \{2.25 [M(2) = \text{VI}\text{Mn}_{0.60}\text{Fe}_{0.15}\} \} \{Zr(2) = \text{VI}\text{Zr}_{0.40}\text{Hf}_{0.05}\} \} \{Zr = \text{VI}\text{Zr}_{2.90}\text{Ti}_{0.10}\} \} \times$ $\times \{T(1a) = \text{IV}\text{Si}_{0.51}\} \{T(1b) = \text{IV}\text{Si}_{0.49}\} \} \{T(2) = \text{IV}\text{Si}_{0.60}\} \} \{T(2b) = \text{IV}\text{Nb}_{0.40}\} \} \{\text{Si}_3\text{O}_9\} \{\text{Si}_9\text{O}_{27}\} \{(\text{O},\text{OH})_{3.35}\text{F}_{0.5}\text{Cl}_{0.3} \cdot 0.65\text{H}_2\text{O}\}$	<p>Rastsvetayeva et al., 1999;</p> <p>Rastsvetayeva, Khomyakov, 2000;</p>
<p>43 <i>Mn,Na-ordered eudialyte-R3</i> <i>Alluiv Mt.</i> <i>Lovozero</i></p>	$\{\text{Na}_{14}\text{Sr}_{0.4}\text{K}_{0.2}\} \{2.25 [\text{Na}_{0.58}\text{Ca}_{1.05}\text{Ce}_{0.45}\text{Sr}_{0.15}\} \} \{Mn_{12}\text{Ca}_{0.72}\text{Ce}_{0.18}\} \} \{Zr_3\} \{\text{Fe}_{1.55}\text{Zr}_{0.40}\text{Nb}_{0.50}\text{Ti}_{0.13}\text{Nb}_{0.12}\} \} \{\text{Si}_{9.9}\text{Al}_{0.1}\} \times$ $\times \{\text{Si}_3\text{O}_9\} \{2 [\text{Si}_9\text{O}_{27}\} \} \{(\text{O},\text{H},\text{F},\text{Cl})_{0.7} \cdot 1.1 \text{H}_2\text{O}\}$ $\{\text{Na}_{2a} = \text{Na}_{1.2}\text{K}_{0.18}\} \{\text{Na}_{5b} = \text{Na}_{1.26}\text{Sr}_{0.15}\} \} \{M(1a) = \text{Mn}_{12}\text{Ca}_{0.72}\text{Ce}_{0.18}\} \} \{M(1b) = \text{Na}_{1.35}\text{Ca}_{0.5}\text{Ce}_{0.45}\text{Sr}_{0.15}\} \} \{3.00 \times$ $\times [M(2a) = \text{Zr}_{0.65}\text{Nb}_{0.57}\} \} \{1.20 [M(2b) = \text{Ti}_{0.17}\text{Nb}_{0.13}\} \} \{2.30 [\text{Fe}_{1.55}\} \} \{\text{Si}_{18b} = \text{Si}_{0.65}\text{Al}_{0.1}\} \} \{\text{Cl}_{1a} = \text{Cl}_{0.6}(\text{H}_2\text{O})_{0.3}\} \} \{3.00 \dots$ $\text{Na}_{16.3}\text{K}_{0.3}\text{Sr}_{0.6}\text{Ba}_{0.6}\text{Ca}_{4.3}\text{Mn}_{1.6}\text{Fe}_{0.2}\text{REE}_{0.4}\text{Zr}_{2.9}\text{Ti}_{0.2}\text{Nb}_{0.4}\text{Si}_{25.3}\text{O}_{73.3}\text{Cl}_{0.6} \cdot n\text{H}_2\text{O}$ $\text{Na}_{36}\{\text{Na}_{6.3}\text{Sr}_{1.8}\text{K}_{0.9}\} \{\text{Ca}_{12.8}\text{Mn}_{3.3}\text{Ce}_{1.5}\text{Na}_{0.4}\} \{\text{Na}_{12}\} \{\text{Nb}_{0.9}\text{Ti}_{0.6}\text{Fe}_{0.5}\} \} \{Zr_3\} \{\text{Si}_3\} \{\text{Mn}_{15}\text{Si}_{12}\text{Al}_3\} \times$ $\times \{\text{Si}_3\text{O}_9\} \{6 [\text{Si}_9\text{O}_{27}\} \} \{(\text{OH})_{10}\text{Cl}_{2.4} \cdot 9\text{H}_2\text{O}\}$	<p>Rastsvetayeva, Khomyakov, 1998</p>
<p>44 <i>Low-ferriferous eudialyte-R3m</i> <i>Alluiv Mt.</i> <i>Lovozero</i> <i>(Authors consider Z = 1 otherwise another specimens)</i></p>	$\{\text{Na}_{1a}\}_{4.5}\{\text{Na}_{1b}\}_{4.5}\{\text{Na}_{2a}\}_{6.75}\{\text{Na}_{2b}\}_{2.25}\{\text{Na}_{3a}\}_{1.9}\{\text{Na}_{3b}\}_{1.6}\{\text{Na}_{5a}\}_{6.75}\{\text{Na}_{5b}\}_{2.25}\{\text{Na}_{6}\}_{9.0} \times$ $\times \{M_3 = \text{Na}_{2.8}\text{Sr}_{1.8}\text{K}_{0.9}\} \{M_1 = \text{Ca}_{12.8}\text{Mn}_{3.3}\text{Ce}_{1.5}\text{Na}_{0.4}\} \{\text{Na}_{12} = \text{Na}_{12}\} \{(\text{OH})_{1.5}\} \{\text{Na}_{4b} = \text{Na}_{1.5}\} \{\text{Na}_{4b} = \text{Na}_{1.5}\} \{\text{Na}_{4b} = \text{Na}_{1.5}\} \{e^{+}\}_{0.3}\} \{Zr_3\} \times$ $\times \{T_1 = \text{Si}_{3.0}\} \{T_2a = \text{Al}_{0.3}\} \{T_2b = \text{Si}_{1.2}\} \{T_2c = \text{Mn}_{1.5}\} \{\text{Si}_3\text{O}_9\} \{6 [\text{Si}_9\text{O}_{27}\} \} \{(\text{OH})_{10}\text{Cl}_{2.4} \cdot 9\text{H}_2\text{O}\}$	<p>Rastsvetayeva, Khomyakov, 2001;</p>
<p>45 <i>High-sodium eudialyte R3 2c</i> <i>Eveslogchorr</i> <i>Khibiny</i></p>	$\text{Na}_{33.30}\text{K}_{1.45}\text{Ca}_{11.7}\text{Sr}_{0.74}\text{Ce}_{0.10}\text{Fe}^{2+}_{2.19}\text{Mn}_{0.47}\text{Zr}_{5.94}\text{Ti}_{0.52}\text{Si}_{26.0}\text{Al}_{44.48}(\text{OH})_{34.80}\text{Cl}_{2.93}\text{F}_{0.36} \cdot 3\text{H}_2\text{O}$ <p>Modular structure (three blocks, once two of them are considered):</p> $\text{Na}_{36}\{\text{Na}_{7.1}\text{K}_{1.9}\} \{\text{Ca}_{18}\} \{\text{IV}\text{Fe}_{6.66}\text{Mn}_{2.34}\} \{Zr_3\} \{\text{Si}_{16}\text{Ti}_{1.56}\} \{\text{Si}_{17}\text{O}_{216}\} \{(\text{OH})_{5.06}(\text{H}_2\text{O})_{3.96}\text{Cl}_{2.22}\text{ClF}\} +$ $+ \{\text{Na}_{5.94}\text{K}_{2.6}\text{Sr}_{0.6}\} \{\text{Na}_{33.2}\text{Sr}_{0.8}\} \} \{\text{IV}\text{Na}_{3.69}\} \{\text{IV}\text{Na}_{4.83}\text{Sr}_{1.0}\} \} \{\text{VII}\text{Na}_{4.2}\text{Sr}_{2.0}\text{Ce}_{0.15}\} \} \{\text{Ca}_{9}\} \{\text{Ca}_{8.55}\text{Sr}_{0.45}\} \times$ $\times \{Zr_3\} \{\text{Si}_6\} \{\text{Si}_{17}\text{O}_{216}\} \{(\text{OH})_{6}(\text{H}_2\text{O})_{4.5}\text{Cl}_6$	<p>Rastsvetayeva, Khomyakov, 2006;</p>
<p>46 <i>High-potassic eudialyte-R3m, 2c</i> <i>Rasvumchorr</i> <i>Khibiny</i></p>	$\text{Na}_{27.1}\text{K}_{7.9}\text{Ca}_{1.1}\text{Sr}_{0.7}\text{Ce}_{0.9}\text{Fe}_{2.3}\text{Mn}_{0.4}\text{Zr}_{7.5}\text{Hf}_{0.7}\text{Ti}_{0.3}\text{Nb}_{0.2}\text{Si}_{51.5}\text{Al}_{0.2}\text{O}_{146.1}(\text{OH})_{19}\text{Cl}_{23} \cdot 1.71 \text{H}_2\text{O} [\Sigma \text{ anions} = 152]$ <p>Modular structure (three blocks, once two of them are considered):</p> $\text{K}_9\text{Na}_{36}\{\text{Ca}_{18}\} \{\text{IV}\text{Fe}_{5.7}\text{Fe}_{0.9}\text{Mn}_{1.1}\text{V}\text{Na}_{1.3}(\text{OH})_{0.6}\} \{Zr_3\} \{\text{Hf},\text{Ta},\text{O}_{18}\} \} \{\text{Si}_{4.5}(\text{OH})_{4.5}\text{V}\text{Al}_{0.6}\text{Nb}_{0.3}\text{Cl}_{0.6}\text{O}_{2.6}\} \} \{(\text{OH})_{0.7}\} \times$ $\times \{\text{Si}_{17}\text{O}_{216}\} \{(\text{H}_2\text{O})_{3.4}\text{Cl}_{1.65} +$ $+ \{\text{Na}_{41.6}\text{K}_{2}\text{Sr}_{1.4}\} \{\text{Ca}_{17}\text{Sr}_{0.9}\text{Ce}_{0.1}\} \} \{\text{IV}\text{Na}_3\text{V}\text{K}_6\text{V}\text{K}_6\} \{Zr_7\text{Ti}_{1.2}\} \} \{\text{Si}_{25}\text{O}_{75}\} \{(\text{OH})_{5.5}\} \} \{\text{Si}_{72}\text{O}_{216}\} \{(\text{H}_2\text{O})_{1.6}\text{Cl}_{1.6}\} \times$ $\{N(1) = \text{Na}_{2.34}\text{K}_{0.66}\} \} \{2.25 [N(1) = \text{Na}_3]\} \{N(2) = \text{Na}_3\} \} \{N(2) = \text{Na}_3\} \} \{N(3) = \text{Na}_3\} \} \{N(3) = \text{Na}_3\} \} \{N(4) = \text{Na}_{2.55}\text{Sr}_{0.47}\} \} \{2.25 \times$ $\times \{N(4) = \text{K}_3\} \} \{N(5) = \text{Na}_3\} \} \{N(5) = \text{Na}_3\} \} \{N(6) = \text{K}_{2.01}\} \} \{N(7) = \text{K}_{2.01}\} \} \{M(1) = \text{Ca}_{5.67}\text{Sr}_{0.30}\text{Ce}_{0.03}\} \} \{2.6 [M(1) = \text{Ca}_6]\} \times$ $\times \{M(2) = \text{Na}_{0.99}\} \} \{M(2) = \text{Fe}_{2.19}\text{Mn}_{0.47}\text{Nb}_{0.45}\} \} \{2.25 [\text{Zr} = \text{Zr}_{7.5}\text{Hf},\text{Ta},\text{O}_{18}\} \} \} \{2.25 [\text{Zr} = \text{Zr}_{7.5}\text{Hf},\text{Ta},\text{O}_{18}\} \} \} \{M(3) = \text{Si}_{0.87}\text{Nb}_{0.10}\} \} \{2.0 \times$ $\times \{M(3) = \text{Si}_{0.81}\text{Al}_{0.19}\} \} \} \{M(4) = \text{Si}_{0.83}\text{Cl}_{0.17}\} \} \} \{2.1 [M(4) = \text{Si}_{1.00}\} \} \dots$ $\times \{\text{VI-VIII}(\text{Na}_{7.0}\text{K}_{2.0})\} \} \{\text{VI}(\text{Na}_{7.6}\text{Sr}_{1.4})\} \} \} \{\text{VIII}\text{K}_6\} \} \} \{\text{VI}(\text{Ca}_{17}\text{Sr}_{0.9}\text{Ce}_{0.1})\} \} \} \{\text{VII}\text{Ca}_{18}\} \} \} \{\text{VII}\text{K}_6\} \} \} \{\text{VII}\text{K}_6\} \} \} \times$ $\times \{\text{IV}\text{Fe}_{5.7}\text{Na}_{1.3}\text{V}\text{Mn}_{1.1}\text{Fe}_{0.9}\} \} \} \{\text{VI}(\text{Zr}_{7.5}\text{Ti}_{1.2})\} \} \} \{\text{VI}(\text{Zr}_{8.8}\text{Hf},\text{Ta},\text{O}_{18})\} \} \} \{\text{IV}\text{Si}_{2.6}\text{Nb}_{0.3}\text{Cl}_{0.1}\text{V}\text{Si}_{2.4}\text{Al}_{0.6}\} \} \} \{\text{IV}\text{Si}_{2.6}\text{Cl}_{0.5}\text{V}\text{Si}_{3.0}\} \times$ $\times \{\text{Si}_3\text{O}_9\} \} \} \{2 [\text{Si}_9\text{O}_{27}\} \} \} \{1.2 \text{O}_2(\text{OH})_{11.35}(\text{H}_2\text{O})_{17}\text{Cl}_7$	<p>Rastsvetayeva, Khomyakov, 2001;</p> <p>Khomyakov et al., 2006;</p>
<p>It was approved by the CNMNC as new mineral: <i>Rastsvetayevite</i></p>	$\text{Na}_{27}\text{K}_6\text{Ca}_{12}\text{Fe}_5\text{Zr}_6\text{Si}_9\text{O}_{73}(\text{OH},\text{H}_2\text{O})_6\text{Cl}_2$	<p>Sokolova et al., 1991;</p> <p>Rastsvetayeva et al., 1990;</p> <p>Ekimenkova et al., 2000;</p>
<p>47 <i>K,HfO'-eudialyte R3m</i> <i>Rasvumchorr</i> <i>Khibiny</i></p>	$\text{Na}_3\text{K}_2\text{Sr}_{0.3}\text{Ca}_5\text{REE}_{0.1}\text{Mn}_{1.1}\text{Fe}_{1.1}\text{Zr}_4\text{Ti}_{0.3}\text{Nb}_{0.1}\text{Si}_{25.2}\text{Al}_{0.8}\text{Si}_{0.85}(\text{H}_2\text{O})_{7.4}\text{Cl}_{1.6} [\text{V } 1755 \text{ \AA}^3; \text{d } 2.69]$ $\text{Na}_{28}\text{K}_{2.2}(\text{H}_3\text{O})_7\{\text{Ca},\text{Sr},\text{Mn}\}_6\{\text{Fe}^{3+}_{1.2}\text{Zr},\text{Ti},\text{Al},\text{Nb}\}_{0.8}\text{Cl}_{1.0}\} \{Zr_3\} \{\text{Si}_{10}\text{Na}_{1.0}\} \times$ $\times \{\text{Si}_3\text{O}_7(\text{O},\text{OH})_2\} \} \{\text{Si}_9\text{O}_{24}(\text{O},\text{OH})_2\} \} \} \text{Cl}_1 \cdot 5(\text{O},\text{OH})_6$	<p>Sokolova et al., 1991;</p> <p>Rastsvetayeva et al., 1990;</p> <p>Ekimenkova et al., 2000;</p>
<p>48 <i>Oxonium eudialyte-R3m</i> <i>Karnasurt</i> <i>Lovozero</i></p>	$\text{Na}_8\text{K}_{0.3}\text{Sr}_{0.5}\text{Ca}_{3.3}\text{REE}_{0.5}\text{Mn}_{1.4}\text{Fe}^{3+}_{2.1}\text{Zr}_4\text{Ti}_{1.0}\text{Nb}_{0.1}\text{Si}_{24}\text{O}_{68.3}\text{Cl}_{0.3} \cdot 10\text{H}_2\text{O} [\text{Si} = 24]$ $\{\text{VIII}\text{X}(\text{Na}_{28.2}\text{K}_{0.30}\text{Sr}_{0.15})\} \} \{2.8 \cdot 73 \text{VII-X}(\text{H}_3\text{O})_{1.27}\} \} \{\text{Ca}_{3.3}\text{Mn}_{1.4}\text{REE}_{0.5}\text{Na}_{0.45}\text{Sr}_{0.35}\} \} \} \{2.10 [\text{V}\text{Fe}^{3+}_{2.10}\text{Na}_{90}\} \} \} \{2.25 [\text{Zr}_3 \times$ $\times \{\text{VI}(\text{Zr}_{0.32}\text{Nb}_{0.07}\text{Ti}_{0.07})\} \} \} \{2.0 \cdot 46 [\text{IV}\text{Si}_{3.0}\text{O}_3]\} \} \} \{\text{Zr}_{0.08}\text{Nb}_{0.05}\text{Ti}_{0.03}\} \} \} \{2.0 \cdot 44 [\text{Si}_3\text{O}_9]\} \} \} \{\text{Si}_9\text{O}_{24}(\text{OH},\text{O})_3\} \} \} \{2(\text{OH})_{3.16}\text{Cl}_{0.26}\text{H}_2\text{O}\}$	<p>Chukanov et al., 2003;</p> <p>Rastsvetayeva, Chukanov, 2003</p>
<p>It was approved by the CNMNC as new mineral: <i>Ikanite</i></p>	$(\text{Na},\text{H}_3\text{O})_3(\text{Ca},\text{Mn},\text{REE})_6\text{Fe}^{3+}_3\text{Zr}_3(\text{Cl},\text{Zr})(\text{Cl},\text{Si})\text{Si}_{24}\text{O}_{66}(\text{O},\text{OH})_6\text{Cl} \cdot n\text{H}_2\text{O}$	<p>Rastsvetayeva, Chukanov, 2003</p>
<p>49 <i>Na,Fe-decatonized eudialyte-R3</i> <i>Inagly</i> <i>S. Yakutia</i></p>	$\text{Na}_{2.7}\text{K}_{1.2}\text{Sr}_{0.5}\text{Ba}_{0.5}\text{Ca}_{5.8}\text{REE}_{0.2}\text{Mn}_{1.1}\text{Fe}_{2.0}\text{Zr}_{2.9}\text{Ti}_{0.3}\text{Nb}_{0.8}\text{Si}_{25.6}\text{Al}_{0.2}\text{O}_{66.8}\text{Cl}_{1.2} \cdot 16\text{H}_2\text{O}$ $(\text{H}_3\text{O})_{20.9}\text{Na}_{65}\text{K}_{3.5}\text{Ba}_{1.6}\text{Sr}_{1.3}\text{Ce}_{0.2}\} \} \{2.2 [\text{Ca}_{17.4}\text{Ce}_{0.36}\} \} \} \{2.18 (\text{H}_3\text{O})_{4.4}\} \} \} \{2.1 [\text{Fe},\text{Mn}]_{0.8}\} \} \} \{Zr_3\} \times$ $\times \{\text{IV}\text{Si}_3\} \} \} \{\text{IV}\text{Si}_{1.5}\text{Ti}_{0.75}\text{V}\text{Al}_{0.65}\text{V}\text{Nb}_{0.1}\} \} \} \{2.25 [\text{Si}_{17}\text{O}_{51}\} \} \} \{2.25 [\text{Si}_{17}\text{O}_{51}\} \} \} \{(\text{OH})_{17.3}\} \} \} \{(\text{OH})_{0.6}\text{Cl}_{0.9}(\text{H}_2\text{O})_{1.6}\} \} \} \{(\text{SO}_4)_{0.6}$ $\{A(1) = \text{IX}(\text{H}_3\text{O})_3\} \} \} \{A(2a) = \text{IX}(\text{Na}_{4.7}\text{Ba}_{1.6})\} \} \} \{A(2b) = \text{VII}(\text{H}_3\text{O})_{2.5}\text{Ce}_{0.2}\} \} \} \{A(3a) = \text{IX}(\text{H}_3\text{O})_{4.9}\text{Sr}_{0.3}\} \} \} \{A(3b) = \text{IX}\text{K}_{3.6}\} \} \times$ $\times \{A(4a) = \text{VIII}(\text{Na}_{1.9}\text{Sr}_{0.2})\} \} \} \{A(4b) = \text{VIII}(\text{H}_3\text{O})_{4.5}\} \} \} \{A(5a) = \text{IX}(\text{H}_3\text{O})_{1.0}\} \} \} \{A(5b) = \text{VIII}(\text{H}_3\text{O})_{2.5}(\text{OH})_{1.0}\} \} \} \times$ $\times \{\text{VI}\text{Ca}_9\} \} \} \{\text{IV}\text{Ca}_{6.6}\text{Ce}_{0.30}\} \} \} \{M = \text{IV}(\text{Na}_{2.2}\text{Fe},\text{Mn}_{1.0})\} \} \} \{\text{Si}(7a) = \text{IV}\text{Si}_{1.66}\} \} \} \{\text{Si}(7b) = \text{IV}\text{Si}_{1.35}\} \} \} \{\text{Si}(8) = \text{IV}\text{Si}_{1.5}\} \times$ $\times \{\text{VI}\text{Ti}_{0.75}\} \} \} \} \{\text{Al}_{0.65}\text{Nb}_{0.1}\} \} \} \dots$	<p>Rastsvetayeva, Khomyakov, 2002</p>
<p>It was approved by the CNMNC as new mineral: <i>Aqualite</i></p>	$(\text{H}_3\text{O})_9\text{Na}_2(\text{K},\text{Ba},\text{Sr})_2\text{Ca}_2\text{Zr}_3\{\text{Si}_{26}\text{O}_{66}(\text{OH})_6\}(\text{OH})_6\text{Cl} \cdot \text{H}_2\text{O}$ $(\text{H}_3\text{O})_8(\text{Na},\text{K},\text{Sr},\text{Ca})_2\text{Zr}_3\text{Si}_{26}\text{O}_{66}(\text{OH})_9\text{Cl}$	<p>Rastsvetayeva, Khomyakov, 2002</p>

Notes: For every unit-cell of table:
 First line (in blue) contains chemical formula resulted from analyses (most by EMPA).
 Second line contains approximate structural formula with detrialization (inside of square brackets - [] - carcass elements are printed; inside of braces - { } - "extracarcass" atoms).
 Last line (in red) contains structural formula for individual mineral species (Johnsen et al,20031; Khomyakov et al.,20061).
 ** After Dorfman M.D. et al., 1967; 1968.

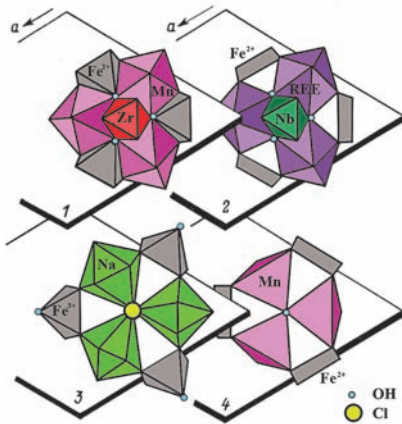


Fig. 3. Statistically possible well-ordered distribution of "additional" cations in M_1 , M_2 and M_3 polyhedra in the structurally maximum ordered eucolite (by the example of barsanovite). 1 – rigid cluster consists of: Zr^{8+} -octahedron, Fe^{3+} -apex polyhedron and Na 8-apex polyhedron occupied with Mn^{2+} in the lower "zeolite" chamber; 2 – the same cluster in case when M_1 -octahedron is occupied with Nb^{5+} , "iron"-position – with $^{14}Fe^{2+}$ "square", and M_3 -polyhedron – with REE^{3+} ; 3, 4 – construction of similar, combined pseudo-centrosymmetrical domain in the upper "zeolite" chamber. After R.K. Rastsvetaeva et al. (1990). Ordering is resulted in acentric eucolite structures.

16a, 16b, 17a, 17b, 18 – 20) and respective "additional" positions with new nomenclature:

1) For $R\bar{3}m$. $M(1)$ – octahedral of 6-member Ca-rings with local symmetry 2; $M(2,4)$ and $M(2,5)$ – cations in "iron" positions in 4- and 5-coordination⁶; Si(7) and Si(7a) – for "additional" tetrahedron position that transforms the upper ring $[Si_9O_{27}]$ to the "platform" $[Si_{10}O_{28}]$; $M(3)$ – for "additional" octahedron that centres lower 9-member ring $[Si_9O_{27}]$ ⁷; three sodium positions: Na(1), Na(4) and Na(5), where the first one is split to Na(1a), Na(1b), between which 6 Na atoms are statistically distributed; Na(4) position bonded with $M(2,4)$, $M(3)$ and $[Si_9O_{27}]$, – the most capacious which may be occupied with K, Ca, Sr, REE; and also six anion positions: $X(1a)$, $X(1b)$, $X(1c)$, $X(1d)$,

$X(1e)$, $X(1f)$, occupied with Cl, F and OH-groups, bonded with Na only (31 positions in total).

2) For $R\bar{3}m$. $M(1)$ – $[M(1)O_6]$ -octahedra atoms which are distorted due to partial substitution of Ca for Mn, REE and Y; above mentioned $M(2,5)$ и $M(2,4)$; Si(7) and Si(7a); $M(3)$ ⁸; five sodium positions: Na(1a), Na(1b), Na(2), originated from Na(1) and also Na(3a), Na(3b), Na(4), originated from Na(4) and Na(5) due to the centre of symmetry. Positions Na(1), Na(2) and Na(5) are occupied only with sodium (except sample No 11, where Ca was determined in Na(1) and sample No 13, with REE in this position); positions Na(3) and Na(4) contain isomorphous impurities (Ramiza K. Rastsvetaeva consider them as $M(4)$ and $M(3)$ polyhedra bonded with a pseudocentre of symmetry), that can be more than sodium: in Na(3) – K, REE, Sr and Ba, in Na(4) – K, REE, Y, Ca, Sr, Ba, (to be mentioned that in sodium positions no manganese was determined). Also eight anion positions were determined: $X(1a)$, $X(1b)$, $X(1c)$, $X(1d)$, $X(2a)$, $X(2b)$, $X(2c)$, $X(2d)$ (48 positions in total).

3) For $R\bar{3}$. $M(1a)$ and $M(1b)$ – are "split" positions in case of planes of symmetry absence; above mentioned $M(2,5)$ and $M(2,4)$, Si(7) and Si(7a); $M(3)$; six sodium positions: Na(1a), Na(1b), Na(2), Na(3), Na(4) and Na(5); Na(3) can be occupied with REE, and Na(4) – REE and K; and seven anion positions: $X(1a)$, $X(1b)$, $X(1c)$, $X(2a)$, $X(2b)$, $X(2c)$, $X(2d)$ (56 positions in total).

These authors' conclusions about the possible isomorphous substitutions in series of structural positions means it is therefore competent to consider eudialyte as a MVCVS. According to (Johnsen, Grice, 1999), the isomorphous impurities content in 6-member Ca-rings may be up to 0.69 and 0.79 cpfu (atom coefficient per formula unit) for Y (samples No 7 and No 8 from Kipawa – table 1, No 16 and 18), 0.25 cpfu for iron (together with Mn, REE and Y) (sample No 15 from Ilimaussak – table 1, No 13), 0.18 cpfu Zr (together with Mn, REE and Y) (sample No 9 from Saint-Amable sill – table 1, No 11). The higher contents of impurities become ordered. For example, in oneillite (table 1, No 25) smaller octahedra $M(1a)$ are completely occupied with Mn and Y, and larger octahedra $M(1b)$ are occupied with Ca, REE and Na.

⁶ – According to (Johnsen, Grice, 1999), the "square" $^{14}M(2,4)$ is bonded with oxygen atoms O(14) and O(17) of Ca-octahedra from two nearest 6-member rings; and "5-apex polyhedron" $^{15}M(2,5)$ is to be completed to half-octahedron with O(19) (OH-group according to Ramiza K. Rastsvetaeva) – the only "additional" oxygen atom that is not bonded with Si. Fe^{2+} predominantly occupies $M(2,4)$, although it might be occupied with Mn^{2+} , which preferably has 5-coordination $M(2,5)$. These authors claim that Ti and Zr $M(2)$ occupy $^{15}M(2,5)$ position but not octahedron (what was discovered by Ramiza K. Rastsvetaeva).

⁷ – In the centre-symmetry group the substitution: $2^{14}Si_7 \leftrightarrow ^{16}M(3) + ^{14}Si_7$ with disordered distribution of "additional" atoms over positions Si(7), Si(7a), $M(3)$, $M(3a)$ and $M(3b)$ was observed. As the centre-symmetry of the structure does weaken "additional" silicon gets displaced by octahedral cations: $Si_{1.89}Nb_{0.11}$ in the sample No 9, $Si_{1.88}Nb_{0.12}$ in the sample No 14, $Si_{1.85}Nb_{0.15}$ in the sample No 15, $Si_{1.84}Nb_{0.16}$ in the sample No 10, $Si_{1.73}Nb_{0.27}$ in the sample No 12, $Si_{1.71}Nb_{0.29}$ in the sample No 7, $Si_{1.67}Nb_{0.33}$ in the sample No 1, $Si_{1.63}Ti_{0.21}Nb_{0.16}$ in the sample No 8, (table 1).

⁸ – In acentric group the substitution $2^{14}Si_7 \leftrightarrow ^{16}M(3) + ^{14}Si_7$ occurs within the same positions as in $R\bar{3}m$: Si(7), Si(7a), $M(3)$, $M(3a)$ and $M(3b)$, with $3m$ symmetry; however "additional" octahedron in the lower 9-member ring, normally occupied with Nb, is very well pronounced. It is formed with three O(9) atoms from $[SiO_4]$ -tetrahedra inwards-directed and with three "additional" O(19) atoms. The following position occupancy, resulted in increasing in niobium content in "additional" octahedra, was determined: $[Si(7,7a), M(3,3a,3b)] = Si_{1.37}Nb_{0.63}$ in the sample No 11, $[Si(7,7a), M(3,3a,3b)] = Si_{1.33}Nb_{0.67}$ in the sample No 4, $[Si(7,7a), M(3,3a)] = Si_{0.93}Nb_{0.45}Al_{0.42}Zr_{0.20}$ in the sample No 17, $Si(7) = 0.67$, $Si(7a) = 0.33$, $M(3,3a) = Nb_{0.62}Ta_{0.04}Ti_{0.06}$, $M(3b) = Si_{0.12}$ in the sample No 2, $Si(7) = 0.85$, $Si(7a) = 0.26$, $M(3) = Nb_{0.55}Zr_{0.13}Ti_{0.08}$ in the sample No 13, $Si(7) = 0.62$, $Si(7a) = 0.42$, $M(3) = W_{0.52}Nb_{0.31}$ in the sample No 6, $Si(7) = 0.84$, $Si(7a) = 0.09$, $M(3,3a) = Nb_{0.78}Ta_{0.07}$ in the sample No 3, $Si(7) = 0.82$, $Si(7a) = 0.11$, $M(3) = Nb_{0.95}$ in the sample No 16, (table 1).

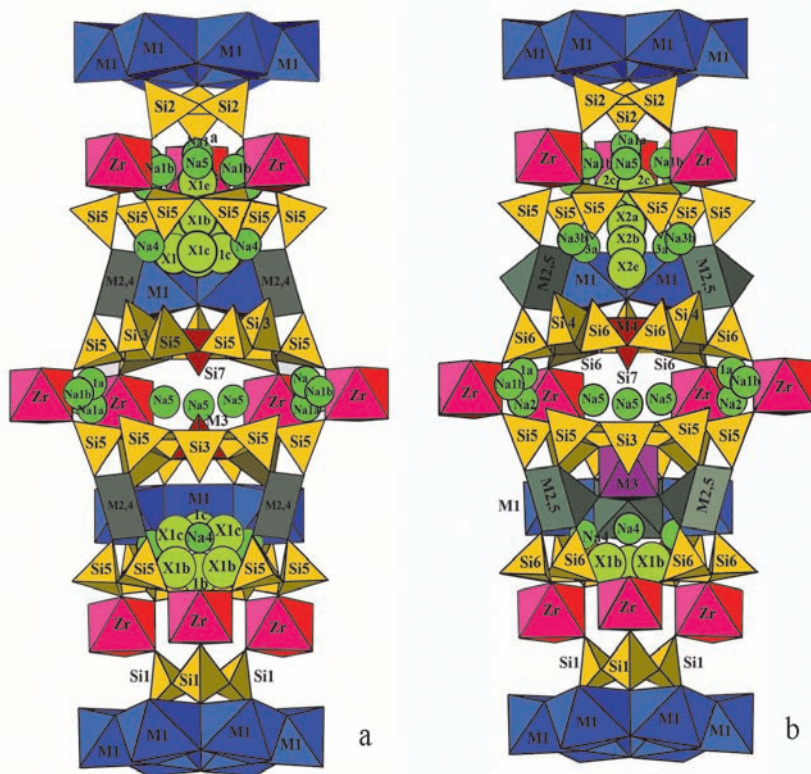


Fig. 4. Crystal structures of centrosymmetrical $R\bar{3}m$ (a) and acentrical $R3m$ (b) eudialytes. After O. Johnsen and, J.D. Grice (1999).

Unification and new labelling of the atom positions in crystal structure. Later these authors marked position Si(7) as M_7 and Na positions as N_1 , N_2 , N_3 , N_4 and N_5 . Euclites are characterized with change of a symmetry from $R\bar{3}m$ to $R3m$ i.e. increasing of being acentric due to statistically distributed atoms occupying acentric structure motif.

All the studied specimens were named as *eudialytes* although they are already subdivided into «eudialytes *sensu lato*» and «eudialytes *sensu stricto*». Special attention is drawn to “eudialyte No 13” (table 1, No 20), registered as the new mineral species – *kentbrooksie* (Johnsen *et al.*, 1998). But that is another story and it deserves a separate chapter.

Eudialyte and mineral species and varieties determination problem

«Nothing grew in tundra before the Great October Revolution...»

From the Lokal lore hand-book of Kola peninsula (1930s).

The “Great Eudialyte Revolution” began from Ole Johnsen, Joel D. Grice and R.A. Gault research works (Johnsen *et al.*, 1998), who registered with the CNMNC “eudialyte No 13” (table 1, No 20) from Kangerlussuaq, Greenland enriched in Nb, Mn, REE, Sr and F and described earlier (Johnsen, Gault, 1997), as a new mineral species *kentbrooksie*. These authors did not bother to refer either to the data on the similar euclite from the Yenisei range studied in detail (Sveshnikova, Burova, 1965) or in connection to its later investigation by means of x-ray, physical and spectroscopic methods or barsanovite revision

(Borutzky *et al.*, 1968), or to the complete refinement of this TR,Mn-euclite that resulted in the same crystallochemical conclusions (Rastsvetaeva, Borutzky, 1990). Reference to our last paper appeared only after 13 years (Johnsen *et al.*, 2003,) with the postscript “for completeness”, meaning they know about work done but do not want to discuss it. Obviously the point is not in the absence of reference, but in precedent – without mentioning the 150-years long history of eudialyte and euclite studies, and the term *euclite*, with no reference to the previous papers and its criticism, they decidedly replaced the *eudialyte-euclite* isomorphous series by *eudialyte-kentbrooksie* one, pretending they do not understand it is one and the same and that they commit “scientific forgery” (Johnsen, Gault, 1997; Johnsen, Grise, 1999; Johnsen *et al.*, 2003.).

Of course, the appearance of *kentbrooksie* could be explained in that its authors studied eudialyte fairly recently and were not familiar with the corresponding literature, history of this mineral investigation and had never heard of *euclite*. Perhaps they did not know that the first analysis of euclite from Langesundfjorden (Norway) by V.S. Brögger (Brögger, 1890) revealed a high niobium (3.52% Nb_2O_5) content, rare earth elements (4.80% Ce_2O_3 and 0.32% Y_2O_3) and manganese (3.60% MnO), and low content of chlorine (0.55% Cl), i.e. that they highlighted in *kentbrooksie* composition. They did not want to see that regularities they “disco-

vered" conform in full with conclusions obtained by E.E. Kostyleva (1929, 1936), V.G. Feklichev (1963, 1965, 1979), S.M. Kravchenko and E.G. Proshenko (1966), B.Ye. Borutzky *et al.* (1968), J.B. Dawson and T. Frisch, (1971), I.D. Borneman-Starynkevich (1975), A.P. Khomyakov *et al.* (1975), E.E. Kostyleva-Labuntsova *et al.*, (Mineralogy..., 1978), H.J. Bollingberg *et al.*, (1983), R.K. Rastsvetaeva *et al.* (1987, 1988, 1990), R.K. Rastsvetaeva and B.Ye. Borutzky (1990), E.V. Pol'shin *et al.* (1991), R.K. Rastsvetaeva (1992). It is incredulous that it was possible not to notice 150-years long epoch of the study of this mineral. If these researchers found out about that only after 10 years why did not they try to compare their data with the previous one, but content themselves with a "for completeness" postscript? It is absolutely obvious that this deplorable "eudialyte revolution" is first of all disrespect for those Russian and foreign scientists who contributed a lot to this unique mineral study, and attempt to dictate a "one-sided" formalized crystallochemical ideology to mineralogy which emasculates its geological essence. Great Archimedes told: "Give me a place to stand on, and I will move the Earth". In this case as a place to stand on they chose kentbrooksitite, and the authors persistently "push" their "new" minerals – khomyakovite, manganokhomyakovite, oneillite (Johnson *et al.*, 1999₂) into eudialyte-kentbrooksitite series.

In any case, to throw down the gauntlet and since then "structurists" started to tear eudialyte to pieces i.e. mineral species competing with one another in crowning with laurels of a new mineral discoverer. It is not very difficult because being familiar with the CNMNC rules one can see it with the "naked eye" like fungi in tundra. Alexander E. Fersman bantered at his companions in Khibiny – if you cannot find minerals you can busy yourself with "fungicology", i.e. fungi picking. In fact in the presence of that lot of structural positions, any new structure refinement might result in new senseless minerals by means of simplifying or "correct" chemical analysis, drawing special attention to the symmetry or unit cell parameters deviations, or applying the modular structure concept.

Fairly speaking kentbrooksitite is not the first such attempt. Let us recall history with barsanovite. When it became clear that it was not new zirconium silicate but eucolite (Borutzky *et al.*, 1968; Rastsvetaeva *et al.*, 1987, 1990₁) some scientists wished to replace the eudialyte-eucolite series with eudialyte-barsanovite. When the "structurists" threw the term eucolite into the litterbin, someone decided to resurrect it under a new name – firstly as "Fe,Cl-analogue of kentbrooksitite" (Ekimenkova *et al.*, 2000₄) (table 1, No 9) and later – as georgbarsanovite (Khomyakov *et al.*, 2007) (table 1, No 10). Repeated investigation of the type specimen – "yellowish-green barsanovite" from the Fersman Mineralogical Museum RAS resulted in the higher Nb⁹ and Si content, and therefore its structure was reinterpreted; "additional" octahedron in the lower 9-member

ring was completed with silicon and all excess Zr "transferred" into the "iron" position M(2). In other words, georgbarsanovite appeared to be not as *highly ordered* as its predecessor barsanovite and must give "old haunt" place on the side of isomorphous series to the other eucolites, for example to the sample No 325 (table 1, No 5) and No 1008 (table 1, No 6). Discussion on the subject was already published (Khomyakov and Rastsvetaeva, 2005; Borutzky, 2007).

If considering niobium content as a speciation property according to the nomenclature and systematization of the eudialyte minerals group developed by (Johnsen *et al.*, 2003_; Khomyakov, 2004; Khomyakov *et al.*, 2006₁) then the chemical composition of minerals examined is quite bewildering. According to Ole Johnsen and Joel D. Grice (Johnsen, Grice, 1999), the highest Nb content in M(3) position 0.95 cpfu was detected not in kentbrooksitite (0.55 cpfu), but in the unnamed (not specified geologically) eudialyte-R3m No 16 from Khibiny (table 1, No 26). Nb M(3) content in barsanovite is 0.67 cpfu (Rastsvetaeva *et al.*, 1990₁), in georgbarsanovite – 0.80 cpfu (Ekimenkova *et al.*, 2000₄; Khomyakov *et al.*, 2007). Three years after the paper (Ekimenkova *et al.*, 2000₄) was published, the new mineral ferrokentbrooksitite appeared abroad (Johnsen *et al.*, 2003₂) (table 1, No 29), which by chemical composition and properties is similar to the "Fe,Cl-analogue of kentbrooksitite" and therefore, barsanovite containing Nb_{0.64}Si_{0.23} in M(3). Before that Irina A. Ekimenkova *et al.* (2000₃) refined the structure of the "Fe,Sr-analogue of kentbrooksitite" (table 1, No 28), containing Nb_{0.7}Si_{0.3} in M(3). The niobium content in these specimens is higher than in kentbrooksitite. If that is so kentbrooksitite has the right to be the end-member in the isomorphous series reviewed?

Thus, the "newest" methodology was demonstrated: once one of eucolites was named *kentbrooksitite* soon its analogues "poured down from a horn of plenty". The authors of these "new" minerals both foreign and Russian did everything to wipe away from the memory the great contribution to the eudialyte-eucolite problem made by our predecessors_; the term *eucolite* is no longer mentioned in the structural literature, and all "newly-made" minerals are compared only with the *proper eudialyte* end-member. Because of this "crafty" technology eucolite was secretly cloned into more than 20 "new" mineral species.

We consider that eudialyte is one mineral species and not twenty!

In the past Alexander E. Fersman wrote (1943): "In mineralogy of the XVIII century, in papers of our coryphaeus Nikolay I. Koksharov, Pavel V. Eremeev and the majority of the German school the mineral was self-sufficing as an independent mineral species, as something permanent, stable and that already existed. Modern science comprehends "mineral" in other way; it is not abstract and independent natural matter, not an abstract geometric figure with typical crystal habit

⁹ – It is easy to perform: niobium is indistinguishable from zirconium in x-ray absorption spectrum.

and not a physical body according to theoretical physicists. Mineral for us is that part of the environment closely and directly related within its history – past, present and future... Mineral is that part of the complex chemical processes that take place independently of the human being". This is how mineralogy was taught in the Soviet Higher School and which our science was proud of. At present the CNMNC ideology throw us back to the 18th century even being equipped with structural analysis. It is a pity that methods work against science and not in the interests of it. The "structuralists" obviously decided that modern mineralogy is a synonym of crystallochemistry and raise the undoubtedly interesting but "intimate" structural peculiarities into the main speciation criteria rank. The structural features fit as the *structural varieties* character but not the *mineral species* ones.

We will not return to *more* and *less considerable* features. Geologists are less interested in whether it is left or right quartz that they have than what form of SiO₂ is it – quartz, cristobalite or tridymite. In our case is it important which positions Mn is distributed in, does it occupy several positions simultaneously or "seclude" itself in one, is it "spread" over the structure or "predominate" somewhere? The most important is that eudialyte is manganous and it can reflect its specific conditions of formation. Why is the "additional" position in the centre of the lower 9-member ring featured so much? Why does niobium has a privileged role? Andrey G. Bulakh (2004) rightly mentioned that the "content of exotic elements – Nb (or W) constitute nearly 1 at.% and its presence or absence does not principally affect either the structure topology of eudialyte or physical properties".

There are 31 – 48 – 56 positions in the eudialyte structure depending on symmetry, and 16 – 22 – 22 without consideration of oxygen and framework silicon positions. Ole Johnsen and Joel D. Grice (Johnsen, Grice, 1999) insist the other anions positions might be cancelled too and the Nomenclature sub-commission of the CNMNC approved (11 – 14 – 15 positions). What is the reason for such a discrimination – in their kentbrooksite one of the species-forming elements was fluorine, and other eudialytes contain (CO₃), S, OH, H₂O, H₃O⁺ – whether it is uninteresting or does not specify mineral-forming process? In eudialytes with a doubled 60 Å unit cell the number of positions is also doubled, i.e. 22 – 28 – 30. When considering that eudialyte contains approximately ten components simultaneously which are distributed over several positions, then we will get countless number of variants. Therefore, almost every structural refinement using the "dominance rule", symmetry change, structural ordering, unit cell reduplication, modular structure models might result in new mineral species; here we agree with Alexander P. Khomyakov that the number

of "discoveries" becomes limitless. However, do geologists need such a structural systematization? Does it reflect the real interrelations between eudialytes in nature?

In most cases chemical elements present in eudialyte are multiple micro-impurities resulting from simultaneous chemical reactions. Considering that the "dominance rule" or "50% rule" by the CNMNC application to a multi-component system will transform into "33.3%" rule in 3-component system (Nikel, 1992; Bokiy, 1997), into 25% in 4-system, into 16.6% in 5-one etc. Eudialyte contains more than 10 components at once and the "% rule" becomes meaningless. Eudialyte chemical analyses ranking by atomic percentage (Bulakh, Petrov, 2003; Bulakh, Petrov, 2004) showed that the most significant combinations next to oxygen, Si and Na are Ca and Mn (4th rank), Fe and Mn (5th rank), Mn, Fe, Sr and K (6th rank) and therefore there are only four mineral species: "*Ca,Fe-eudialyte*", "*Ca,Mn-eudialyte*", "*Mn,Ca,-eudialyte*" and "*hydro-eudialyte*" (Bulakh, 2004). The rest of them are only their chemical varieties. V.G. Feklichev (1963) determined three types of eudialytes from Khibiny: *feriferous series*, where Fe>Mn, 2) *manganous series* with Mn>Fe and 3) *hydrous and hydrous-potassic series* eudialyte which contain considerable amount of water and decreased amount of alkali. Later Feklichev, (1979) distinguished 5 types of eudialyte: 1) enriched in alkali (generally, in Na, less in K), 2) enriched in Mn, *REE*, Nb, 3) enriched in Mn, Fe³⁺, Nb and OH, 4) enriched in Mn, Nb, Fe³⁺, H₃O⁺, OH, 5) enriched in K and H₃O⁺. That investigation is an example of a chemical approach to the speciation problems, however eudialyte species (or types) detected are controlled by their natural occurrence statistics.

It is frequently discussed: what is the principal property – chemical composition, structure or genesis of a mineral? The answer is – all of them are the main property, because they all reflect different parts of the nature of a mineral substance: a mineral cannot be without composition or structure, or not be the result of a natural geological processes. Unfortunately, physical-chemical conditions of eudialyte existence are not studied in full. According to L.N. Kogarko *et al.* (1980; 1981) eudialyte crystallizes at temperatures below 903°C in the Na₂O-SiO₂-Al₂O₃-ZrO₂ system modelling magmatic apatitic melt, at 903°C and at higher temperatures it melts incongruently resulting in keldyshite. Paragenesis of eudialyte, keldyshite, nepheline, sodalite and melt is stable within the boundary area. And in such a system the variations of eudialyte chemical composition obviously could not be studied. Previously it was synthesised hydrothermally from a Ca-bearing system and it was shown that it can exist without iron content (Christophe-Michel-Levy, 1961)¹⁰.

¹⁰ – According to the nomenclature offered (Johnsen *et al.*, 20031; Khomyakov, 2004; Khomyakov *et al.*, 2006), iron in a proper eudialyte Na₁₃Ca₆Fe₃Zr₃Si₂(Si₂₅O₇₃)(O,OH,H₂O)₃(Cl,OH)₂ is essential component.

Thus there are no data about phase transitions or individual phase appearance within the eudialyte stability field and this is the reason to consider eudialyte as a single mineral species, and as an *MVCVS* in particular. Chemical and structural changes within its stability field due to ion-exchange substitutions are gradual, continuous and reflecting changes of mineral-forming conditions during its crystallization and later which conforms with interpretation of the facts. There is no data on individual stability fields of the "new" minerals of "eudialyte group" discovered and approved by the IMA. In our opinion while there is no such data they are to be considered as *mineral varieties* – chemical, structural and chemically-structural.

In our opinion the term *eucolite* should be resurrected. Eucolite is a term comprehending structural-chemical varieties of eudialyte which occur in a natural changing environment due to the zeolite-like ion-exchanging ability of the structure of this mineral. And this is the reason to consider it as a *MVCVS*. Eudialyte and eucolite could be separated by the symmetry change $R\bar{3}m$ into $R3m$ (and not by optical sign). The boundary is conditional because crystal structure changes are statistical and the piezoeffect intensity changed in the specimens studied (Borutzky *et al.*, 1968) due to the "block" structure of centre-symmetrical and asymmetrical fragments.

Therefore the viewpoint of the CNMNC of the IMA and its nomenclature sub-commissions is rather surprising. We got used to double standards in politics and it is a pity that they involve science. On one hand they persist on the re-naming of *ramsayite* into *lorenzenite*, *karpinskiite* into *leifite* – after the type-locality despite scandalous mistakes in the chemical analyses¹¹ of the prototypes. On the other hand they silently observe how the long-standing and genetically understood term *eucolite* is substituted by new term *kentbrooksites* which became an individual mineral species for no reason; they reduce the eudialyte-eucolite problem to a eudialyte-kentbrooksites series with no significant arguments or discussions with specialists in this area. Change of chemical composition, structure of minerals and their related properties is a normal occurrence in the mineral "life" due to changes in physical-chemical conditions. If these changes do not affect the mineral stability field then there is no reason of the new mineral species discovery.

"Dolly the sheep" and introduction in "DNA-eudialytology"

The first approved "Dolly the sheep" became *kentbrooksites* (Johnsen *et al.*, 1998), "gene" material

for that was eucolite in general and "REE, Mn-eucolite" from the Yenisei range in particular (Rastsvetaeva, Borutzky, 1990). Previously Russian researchers created something similar i.e. *barsanovite*, but unfortunately surpassed the times. Nowadays on the "eudialyte pasture" there is the whole "flock" of *baby-kentbrooksites*: *ferrokentbrooksites* (Johnsen *et al.*, 2003), *Fe,Cl-analogue of kentbrooksites* (Ekimenkova *et al.*, 2000), *Fe,Sr-analogue of kentbrooksites* (Ekimenkova *et al.*, 2000), *K-kentbrooksites* (Rastsvetaeva, Khomyakov, 2005), *georgbarsanovite* (Khomyakov *et al.*, 2007), *carbokentbrooksites* (Khomyakov *et al.*, 2003). The same "sheep" is *zirsilite-Ce*¹² (Khomyakov *et al.*, 2003) which differs from *carbokentbrooksites* only with switched positions of N_4 Na and Ce. The total sum of REE in *carbokentbrooksites* is 1.16 cpfu, in *zirsilite* is 1.45 cpfu; whether it is the reason for the new mineral species "zirsilite" determination? It does not meet even the formal "dominance rule", as REE content does not occupy the half of N_4 position. *Khomyakovite*¹³ and *manganokhomyakovite* (Johnsen *et al.*, 1999,) "grazing" on the same field, but the "birth-marks" on their skin are made of tungsten and niobium – the unique fact but insufficient to change the "sheep" into the "goat". However, they seriously discuss about determination of *sodio-khomyakovite* and *strontio-ferri-khomyakovite* (Johnsen *et al.*, 2003). Strontium impurity gives no rest to the "selectionists" therefore the strontium "sheep" *taseqite* (Peterson *et al.*, 2004) joined the "flock". We assume that it would be more correct to name all these minerals *Fe,Cl-, Fe,Sr-, Ce-, Sr-, W-, Mn,W-, Nb-, carbonate-* etc. *eucolites* and not *Fe,Cl-, Fe,Sr-kentbrooksites*. It is typical for all of them that their "speciation" components are represented with micro-impurity playing no part in chemical individuality of eudialyte. Therefore the problem of "speciation" comes to the retrieval of non-equivalent position occupied by someone's majority.

Apart of them there are *feklichevite* (Pekov *et al.*, 2001), *golyshveite*¹⁴ (Chukanov *et al.*, 2005; Rozenberg *et al.*, 2005) and *mogodivite* (Chukanov *et al.*, 2005) – eudialytes enriched in calcium and carbonate-ion (table 1, No 34 – 36), from the Kovdor massif. Occupying "communal flats" N_3 and N_4 , calcium prevails as a mineral-forming component composing 6-member rings of a framework; and there is no difficulty in understanding Andrey G. Bulakh (2004) who considered "*Ca,Fe-eudialyte*" as an individual mineral species according to the main chemical components. We assume it is potentially an individual mineral species.

¹¹ – In *lorenzenite* from Narsarsuk analysis instead of titanium they detected 11% ZrO_2 , and in *leifite* – beryllium was missed.

¹² – The authors themselves point out that the crystal structures of *carbokentbrooksites* and *zirsilite* do not differ from *kentbrooksites* one. The only distinction is (CO_3) -group, although "lawmakers" (Johnsen *et al.*, 2003) agreed that anions would not be considered for the systematization of eudialyte group minerals.

¹³ – Tungsten content in *khomyakovite* is only 0.56 cpfu, but it does not stop the authors to "stretch" it to one write its formula as: $Na_{15}Ca_6Mn_3Zr_3W(Si_{25}O_{73})(O,OH,H_2O)_3(Cl,F)_2$.

¹⁴ – It was proved by means of Nuclear Gamma Resonance – NGR (Mossbauer effect) that Fe^{3+} in the "iron" position in *golyshveite* and *mogodivite* is predominant over Fe^{2+} and occupies octahedron which corresponds to the similar conclusion for *eucolites* (Pol'shin *et al.*, 1991). Besides these minerals are (CO_3) – dominant in X_1 position.

However "structurists" were busy not only with "sheep breeding" and did not discover anything significant. One extraordinary example was *alluaivite* – titanium analogue of eudialyte with the double 60 Å unit cell, discovered by Alexander P. Khomyakov in the Lovozero massif (Khomyakov *et al.*, 1990; Rastsvetaeva *et al.*, 19903). This one is not "Dolly the sheep". Zr-octahedra in the framework of alluaivite are completely substituted by titanium ones; this is the only case among "new" eudialyte minerals when the end-members exist in reality: normally "dominant" components represented with micro-impurity hardly reach 50% or more of position occupancy. The identity of alluaivite was proved genetically as its aggregates were grown on eudialyte crystals and there is a gap in chemical composition between them. Later the same scientists published new data on the crystal structure of "Ti-eudialyte" – future *dualite*¹⁵, an intermediate member between eudialyte and alluaivite (Rastsvetaeva *et al.*, 1999). After 12 years alluaivite was found in Khibiny forming 1) grains overgrowth over eudialyte and 2) in the eudialyte crystals rims as a result of substitution of Zr, K, Sr, Fe and Cl for Ti, Nb, Si, Na and S. Thus it is similar to the alkali feldspars story: in some conditions they represent a continuous isomorphous series (one mineral species), in other conditions they are two natural end-members (two mineral species).

Incidentally, the authors of dualite (Khomyakov *et al.*, 2007) did not notice the existence of all intermediate eudialyte-alluaivites, and insist on the gap within the isomorphous series and at the same time consider dualite as an ordered member with Zr:Ti = 1:1 (similar to dolomite). An intermediate member of an isomorphous series is not an individual mineral species even according to the IMA CNMNC instructions, therefore dualite is just another "Dolly the sheep". Its regular modular composition is likely to reveal the block isomorphism which resulted from its late metasomatic replacement due to high-alkaline solutions.

The modular 24-layer model of «Ti-eudialyte» should consist of "eudialyte" – Zr(Ti),Ca(Mn),Ti(Fe),Si(Al) and "alluaivite" – Ti(Zr),Ca(NaCe),Na,Si(Mn) blocks, which double the unit cell along the *c* axis. However it is surprising that the authors "lost" niobium whose content is 1.67–3.74 wt.% Nb₂O₅ (from 0.76 to 1.70 *cpfu*) and that should affect the structure model suggested. During dualite approval by the CNMNC as a new mineral species this mistake was removed. (Khomyakov *et al.*, 2007). For similar structures (Johnsen *et al.*, 20031; Khomyakov *et al.*, 2006; 2007) the universal structural formula

$$[N(1)_3N(1^*)_3N(2)_3N(2^*)_3N(3)_3N(3^*)_3N(4)_3N(4^*)_3 \times N(5)_3N(5^*)_3][N(6)_3][N(7)_3][M(2)_3M(2^*)_3] \times [M(3)M(3^*)][M(4)M(4^*)][M(1)_6M(1^*)_6][Z_3Z^*_3]$$

¹⁵ – Scientists registered it as a new mineral species – *dualite* (Khomyakov *et al.*, 2007), considering its structure as the modular one i.e. combined with eudialyte and alluaivite modules. The similar cases occur within the plagioclase series when albite blocks alternate with anorthite ones, which result in number of "super-structural" X-ray reflections. However there are no scientists who tried to register homogenous intermediate members of plagioclase series as new mineral species.

¹⁶ – It is interesting that in this mineral all the Fe "moved" to the 6-member ring octahedra, and "iron squares" *M(2,4)* were occupied with excessive Zr together with Mn and Na in 5-apex polyhedra. The similar unusual tetrahedral coordination was detected in high-tantalum eudialyte from Brazil (table 1, No 37) (Rastsvetaeva *et al.*, 2003).

$[Si_3O_9]_2[Si_3O_9]^*{}_2[Si_9O_{27}]_2[Si_9O_{27}]^*{}_2[O,OH,H_2O]_4 \times [O,OH,H_2O]^*{}_4]X_2X^*{}_2$, was suggested, where positions in the second half of the doubled unit cell are marked with * and where *N(1–7)* and *N(1*–5*)* – Na, *N(4 and 4*)* Na, K, H₃O⁺, Ca, Sr, Mn, REE, *N(6)* and *N(7)* – K, Sr, *M(2 and 2*)* – Fe²⁺, Fe³⁺, Mn, REE, Na, *M(3 and 3*)* – Si, Nb, Ti, Zr, Mn, W, *M(4 and 4*)* – Si, *M(1 and 1*)* – Ca, Mn, Sr, REE, Y, Na, Z and Z* – Zr, Ti, Nb, X and X* – Cl, F, S, SO₄, CO₃, H₂O, OH. Unfortunately is remained unclear (Khomyakov *et al.*, 2007) what the conclusions were: – either Z positions are occupied with ordered Zr and Ti with additional Nb (Zr_{2.0}Ti_{0.7}Nb_{0.3} and Ti_{1.7}Zr_{1.0}Nb_{0.3}) (p. 37), which was mentioned before without Nb being taken into account (Rastsvetaeva *et al.*, 1999); or zirconium and titanium are completely separated in these positions (p. 34, abstract and approximated the formula of the approved new mineral *dualite*). Obviously this detail might be conclusive for the interpretation of eudialyte-alluaivite series in nature. Interestingly the alluaivite module contains Mn in tetrahedron in *M(3)* position within the 9-member ring centre.

However, the model of *dualite* presented looks like syntactical co-growth of these minerals on the elementary level, which is quite common in the metasomatic rocks. This was described for epistolite, murmanite and shkatulkaite intergrowths (Nemeth *et al.*, 2005) or bornemanite, combined with seidozerite and lomonosovite modules (Ferraris *et al.*, 2001). The same was detected in some labuntsovites. In particular additional reflexes along *a** which double the unit cell and result in symmetry *I2/m*, was interpreted microdomains (~2 μm, parallel to (100) of *D*-occupied *Mn-labuntsovite* and *D*-vacant *Ba-lemmleinite*, occurring due to irregular growth or later solid-phase transformations in the mineral (Organova *et al.*, 2007).

The second essential event was undoubtedly the discovery of eudialytes with isomorphous substitutions within the 6-member framework rings. The significant substitution of Ca for Mn was observed in alluaivite (Khomyakov *et al.*, 1990; Rastsvetaeva *et al.*, 1990₃), substitution of Ca for Mn and Ca for Na – in different modules of dualite (Rastsvetaeva *et al.*, 1999; Khomyakov *et al.*, 2007). However the researchers were not particularly interested in that because this substitution becomes dominant only when more than 3 *cpfu* of 6 *cpfu* of Ca are substituted. This was found in *oneillite* (table 1, No 25) (Johnsen, Grice, 1999), where half of the Ca is substituted by Mn which resulted in the plane of symmetry loss and space group decreasing to *R3* (fig. 5).

Later there appeared: (1) "eudialyte with ordered calcium and iron"¹⁶ (Ekimenkova *et al.*, 2000,) future

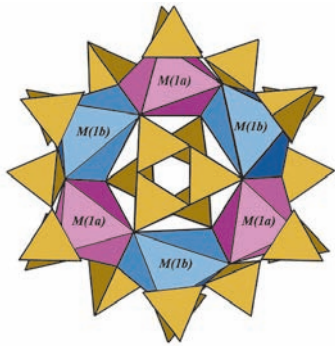


Fig. 5. In the 6-member ring in oneillite crystal structure octahedra $M(1a)$ are smaller ($M-O$ distance 2.227 Å) and occupied with Mn. Octahedra $M(1b)$ are bigger (2.431 Å) and occupied with Ca and REE. After O. Johnsen & J.D. Grice (1999)

and O. Johnsen (1999,) it is sufficient for the symmetry has been lowered to $R3$ due to plane of symmetry loss. The similar effect is due to iron occupying octahedra of the 6-member ring ($M(1a) = Fe_{2,2}Ca_{0,5}Mn_{0,3}$, $M(1b) = Ca_{2,7}REE_{0,3}$ – Ekimenkova *et al.*, 2000₁), and also sodium and other elements ($M(1a) = Mn_{2,1}Ca_{0,72}Ce_{0,18}$, $M(1b) = Na_{1,35}Ca_{1,05}Ce_{0,48}Sr_{0,15}$ – Rastsvetaeva *et al.*, 1999₂).

raslakite (Chukanov *et al.*, 2003) (table 1, No 41), where one half of the 6-member ring octahedra is occupied with $Ca_{2,7}$ and $REE_{0,3}$ and the other half – $Fe_{2,2}$ with $Ca_{0,5}$ and $Mn_{0,3}$; (2) "Mn,Ce-eudialyte with ordered calcium and manganese" (Rastsvetaeva *et al.*, 1999₂) (table 1, No 42), where one half of octahedra is occupied with Mn and the other half – $Ca_{2,1}$ and $REE_{0,90}$; and (3) "eudialyte with ordered sodium and manganese" (Rastsvetaeva, Khomyakov, 2000₁) (table 1, No 43), where $M(1a) = Mn_{2,1}Ca_{0,72}Ce_{0,18}$ и $M(1b) = Na_{1,35}Ca_{1,05}Ce_{0,45}Sr_{0,15}$.

Thus calcium – the second major component of the eudialyte framework – might be substituted by manganese, iron and sodium. Zirconium, when excess is present, finds a place besides Zr-octahedra (Rastsvetaeva, Borutzky, 1990; Johnsen *et al.*, 1999₂; Ekimenkova *et al.*, 2000₁). In "hyper-zirconium eudialyte" (Rastsvetaeva, Khomyakov, 2000₂) (table 1, No 38), with "unknown" geological occurrence and chemical analysis, Zr almost completely occupies Fe-position and forms octahedra on the basis of the "iron" square. At the same time Ca-octahedra of the 6-member ring are more than half substituted by Mn, Fe, Na, Ce and Sr (fig. 6).

Also, despite symmetry decreasing to $R3m$ and $R3$ the latter minerals are *proper eudialytes*, i.e. *MVCVS* formation is not typical for eucolites. The *proper eudialytes* as *MVCVS* reveal even greater diversity. The modular structure deserves special attention, but they are not understood genetically. Alexander P. Khomyakov launching "the new chapter" of "eudialytology" compares these objects with DNA-molecules probably considering their inconvenience. However they do not resemble DNA either with molecule torsion or with genetic information enclosed.

In the modular structure of *high-potassic eudialyte* with the doubled c period – future *rastsvetaevite* (table 1, No 46) three modules were distinguished:

"eudialyte", "alluaivite" and "barsanovite-kentbrooksite" (Rastsvetaeva, Khomyakov, 2001₂; Khomyakov *et al.*, 2006₁), although later only the first two were considered. It has features of *potassic eucolite* ($R3m$) in rischorrites from the Khibiny massif. The formation conditions of these eudialytes are described in detail by Olga A. Ageeva (Ageeva, 1999; 2002; Ageeva *et al.*, 2002₂), who showed that they occur during K-metasomatism when replaced primary eudialyte-eucolites are later replaced by potassium-oxonyc eudialyte which dissociate to wadeite and zircon. In our opinion the "alluaivite module" was unsuccessfully named because the alluaivite term is related to titanium and here the only "alluaivite" feature is substitution of Fe and Mn by Na-polyhedra in the "iron" position (Rastsvetaeva, Andrianov, 1987; Rastsvetaeva, Borutzky, 1988; Rastsvetaeva, Khomyakov, 2000; 2000₁; 2000₂; Ekimenkova *et al.*, 2000₂). For the high-potassic eudialyte the explanation of the occurrence of the large potassium ions is more essential. Similar to dualite it is possible to assume that there is block isomorphism i.e. transformation of eudialyte takes place. Potassic varieties are no less diverse than titanium and therefore there is no ground to distinguish only *rastsvetaevite*?

In the modular structure of *high-sodium eudialyte* with doubled c -period and $R3$ symmetry the future *labyrinthite* (Rastsvetaeva, Khomyakov, 2001₃; Khomyakov *et al.*, 2006₂) (table 1, No 45) there are eudialyte (together with kentbrooksite) and alluaivite alternation modules. In the alluaivite module rich in sodium there are three Na-polyhedra near the "iron position": two 7-apex polyhedra Na(12) and Na(13) and "square" Na(11). In the eudialyte module "additional" titanium occupies the $M(3)$ centre of 9-member Si-O ring (Ti-dominant analogue of barsanovite or kentbrooksite). Thus *labyrinthite* is to be considered as "titanium eudialyte".

Hydro-eudialytes are formed during hydrothermal alteration. During hydration sodium is mainly leached as well as some other components. Charge compensation demands H_3O^+ ions. There are structurally studied: "*potassic-oxonium eudialyte*"- $R3m$ from Rasvumchorr (Khibiny) (Sokolova *et al.*, 1991; Rastsvetaeva *et al.*, 1990₂), sodium "*oxonium eudialyte*"- $R3m$ from Karnasurt (Lovozero) (Ekimenkova *et al.*, 2000₂; Chukanov *et al.*, 2003; Rastsvetaeva, Chukanov, 2003) and "*Na,Fe-decatonized eudialyte*"- $R3$ from Inagly (S. Yakutia) (Rastsvetaeva, Khomyakov, 2002) (table 1, No 47–49). The latter two are already approved as "new" mineral species, two more "Dolly the sheep": *ikranite* (in honour of the Crystallographic Institute RAS) and *aqualite*. Several leached and hydrated eudialytes were studied by Ksenia A. Rozenberg (Rozenberg *et al.*, 2004), where oxonium ion content was calculated on a valency balance basis. The H_3O^+ -ion normally occupies sodium positions $N(1-4)$: in $N(2)$ and $N(3)$ in all eudialytes studied. $N(1)$ and $N(4)$ positions are main-

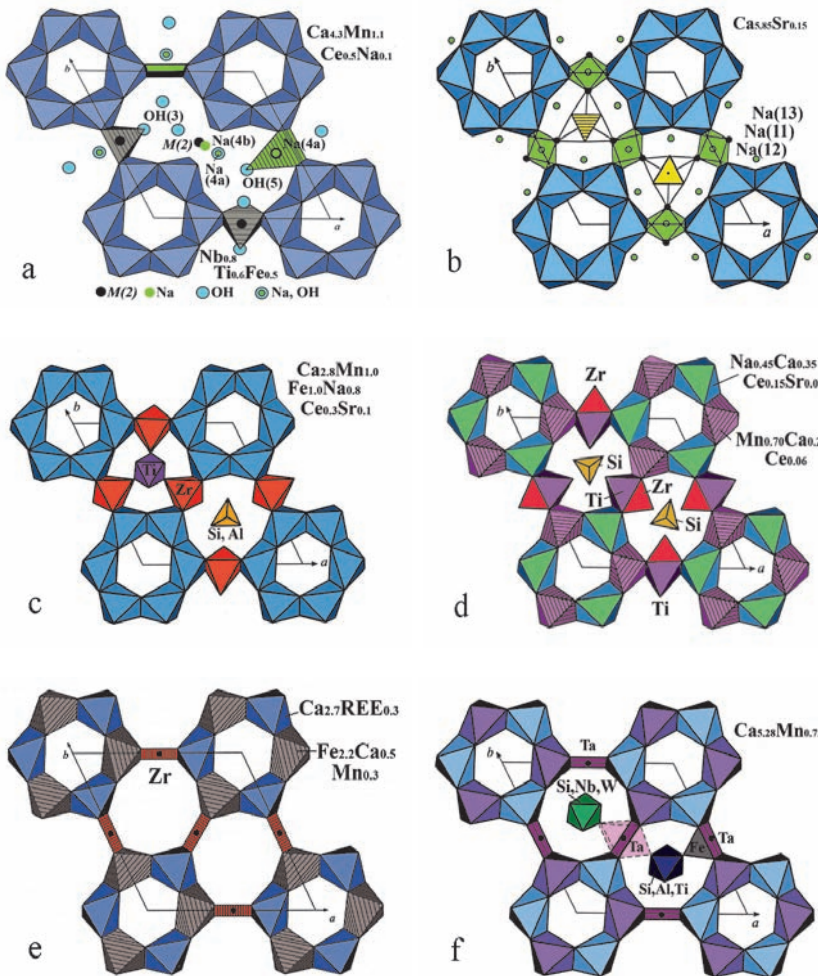


Fig. 6. Occupation of the "iron" position with impurities of different composition and valency. After A.P. Khomyakov (1998), (2001₃), (2002₂), (2000₁), I.A. Ekimenkova et al. (2000₃) and R.K. Rastsvetaeva et al. (2003) respectively. A – various occupancy in the low-ferriferous eudialyte: flat square Fe^{2+} (position $^{14}\text{Fe}^{2+}$) occupied with sodium (Na4b), 5-apex polyhedra M(2) (half-octahedra) with additional OH(3)-group, occupied with Fe^{3+} or Mn ($^{13}\text{Fe}^{3+}$, ^{15}Mn), octahedra M(2) with two additional OH-groups, occupied in general with Nb and Ti, and Na-half-octahedra (Na4a) with additional OH(5)-group. B – statistical position occupancy: Na(11) ("square") and Na(12) and Na(13) (7-apex polyhedra) in "alluvite" module of high-sodium eudialyte. C – zirconium octahedra in M(2) positions in hyperzirconium eudialyte. D – statistical occupancy of "squares" ^{14}Fe (cpfu 1.55) and two types of 5-apex polyhedra: $M(2a) = \text{Zr}_{0.65}\text{Na}_{0.57}$ and

$M(2b) = \text{Ti}_{0.17}\text{Nb}_{0.13}$ in Mn,Na-ordered analogue of eudialyte-R3. E – zirconium occupancy of distorted "square" M(2,4) ($\text{Zr}_{0.8}\text{Hf}_{0.1}$), manganese – in 5-apex polyhedra M(2,5a) ($\text{Mn}_{0.6}$) and sodium – in 5-apex polyhedra M(2,5b) ($\text{Na}_{1.5}$) in eudialyte-R3 with ordered distribution of calcium and iron. F – tantalum occupancy in "square" ($^{14}\text{Ta}_{0.51}$) (octahedral coordination is also possible) and iron – in 5-apex polyhedra ($^{15}\text{Fe}_{1.35}$) in high-tantalum eudialyte from Brazil.

ly occupied and N(5), N(6) and N(7) – only with (OH)-groups and with H_2O which coordinates additional M(3)- and M(4)-cations in $[\text{Si}_9\text{O}_{27}]$ rings. In ikranite that might be considered as the final stage of hydrothermal alteration of eudialyte, 9-member rings are free of additional cations, Fe^{3+} in the "iron position" iron reveals its oxidation, and the H_3O^+ -ion is determined in eight positions. In aquilite almost all sodium is substituted with oxonium. Returning to the problem of speciation the "species-forming" features in this case are "holes" from substituted cations of the original eudialyte, in other words we systematize "sheep" by "torn fleece flocks".

Eudialyte as a MCVCS continues to surprise us with possible compositional variations. Already found

were: S-containing variety of "titanium eudialytes" (Ageeva et al., 2002₁; 2002₂), "hyper-zirconium analogue of eudialyte" (Rastsvetaeva et al., 2006), "Nb-deficient carbonate analogue of feklitchevite" (Rozenberg et al., 2005₂) and other (Rastsvetaeva, 2007).

Conclusions

1. Individual mineral species separation should be based not on the difference determination between mineral individuals, but on the isolation of natural entities which occupying a definite place in geology-geochemical processes, with analysis of chemical composition and crystal structure varia-

tions during changes of the mineral-forming and mineral-retentive environment.

2. Criterion for mineral species independence is a single *stability field* existence where the gradual changes in chemical composition and structural features are allowed, with no phase transition, dissolution or structure type distortion. Accordingly the continuous isomorphous series (at certain physical-chemical conditions) is to be considered as a single mineral species. Its dissolution or phase transition products (also at the certain conditions) are to be considered as individual mineral species.

3. Crystallochemical criteria recommended by the CNMNC of the IMA for new mineral species approval and the "dominance rule" in particular applied to the separate structurally non-equivalent positions, are *formalized and genetically unjustified*. They do not consider the importance of components occupying these positions (for chemical individuality of a mineral within geochemical processes), do not subdivide them into major and minor, do not analyze the reasons for the structural characteristics changes (symmetry, unit cell parameters, "super-structural" x-ray reflections). Mineral species approved on their basis are torn apart from certain geological processes, are not applicable to geology and useless for the analysis of mineral-forming conditions. For reliable genetic data, in obtaining it, it is more logical to consider "newly-discovered" mineral species as *chemical, structural and structural-chemical varieties* i.e. as original material for future scientific analysis and not as a supreme final achievement of mineralogy.

4. Eudialyte is the most outstanding example of *MVCVS*. Their formation is a special phenomenon in mineralogy consisting in the ability of compounds to form from a multi-component natural system. These compounds contain a great number of isomorphous impurities (of different composition, atomic size and charge) in the appropriate structure positions resulting in coordinates displacement, coordination polyhedra transformation, splitting positions into "subpositions" with incomplete occupancy. Having no data on the stability field of separate individuals with variations in micro-impurities composition or symmetry deviation, enables us to consider eudialyte as a *single mineral species*.

5. It is required to resurrect the forgotten term *euclolite*. Replacement of the comprehensive term euclolite with special terms – *kentbrooksite, georgbarsanovite* and the introduction of *eudialyte-kentbrooksite, eudialyte-barsanovite* or *eudialyte-georgbarsanovite* series instead of *eudialyte-euclolite* are disrespectful to predecessors contributions to the eudialyte problem study. The eudialyte-euclolite series cannot come to dual, triple, quadruple etc. isomorphous series because substitutions occur simultaneously between multiple components. It would be logical to consider *kentbrooksite, georgbarsanovite*

and like "new" minerals as *varieties of euclolite* and apply "rational" systematization: «CaMnNbF-euclolite», «CaFeNbCl-euclolite» etc. Intensive "cloning" of a number of mineral species within the so-called eudialyte group is an attempt to reduce nomenclature and systematization to formalized structural and structural-chemical variations in the crystal structure unrelated with natural geological processes.

6. The titanium analogue of eudialyte – *alluaivite* is an individual mineral species, because it corresponds to the end-member of eudialyte-euclolite isomorphous series that reflects *essential substitutions* of the main components (Zr and Ti) within the structure framework (therefore we consider them as zirconium silicates and titanium silicates respectively) and also it is founded genetically. However there is another mineral species occurring in nature – "*Ti-eudialyte*", that corresponds to all the continuous isomorphous series between eudialyte and alluaivite, whose members form as a result of gradual metasomatic replacement due to eudialytes zeolite-like structural ability for low-temperature ion-exchange substitutions.

7. Fantastic progress of structural analysis and investigation of eudialyte made this rare mineral from alkaline massifs one of the most interesting objects in mineralogy and gives structural understanding of a unique phenomenon – possibility of logically disadvantageous but energetically stable *minerals of variable composition and variable structure* occurrence, which are sensitive to mineral-forming conditions changes. The author hopes that "nomenclature games" involved in mineralogy at present would change into detailed investigation of the phenomenon by means of physical-chemical analysis that allows real genetically explained mineral species of eudialytes.

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International Scientific Conference "Fersman Days" and its youth session "Fersmaniada" devoted to the 125th anniversary of academician Alexander E. Fersman

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On the 10–12th November 2008 International scientific conference "Fersman Days" devoted to the 125th anniversary of academician Alexander Fersman, organized by Fersman Mineralogical Museum RAS and IGEM RAS supported by Russian Geological Society and Russian Mineralogical Society took place in Moscow. The conference was hosted by Fersman Mineralogical Museum RAS and IGEM RAS – the scientific institutions that showed allegiance to principles founded by academician Alexander Fersman, an outstanding Russian scientist and public figure.

At the conference the problems of development trends of academician Alexander Fersman's ideas, their urgency in the modern science, importance and timeliness of his discoveries within Kola Peninsula, Ural Mountains and Middle Asia investigations were discussed, and also particular questions of mineralogy and geochemistry of natural and men-caused processes were considered.

At the Fersman Mineralogical museum the new exhibition "Amusing mineralogy in stones" using Alexander Fersman own mineral collection and archive materials was put on display. For the first time within the conference the youth session "Fersmaniada" was organized.

Delegates from many cities and regions of Russia took part in the meeting, they came from Moscow, Miass, Apatity, Chita, Vladivostok, Murzinka. Young mineralogists arrived from Apatity, Rybinsk, Arkhangelsk, Perm, Moscow, Orsk and Energetik town (Orsk region). International delegates came from Bulgaria and Ukraine.

The first day of a conference was consecrated to plenary lectures by outstanding scientists from Russia and foreign countries and was held in the IGEM RAS. Peculiar attention was concentrated on the talks by academician Vladislav S. Urusov on "the natural selection of the mineral species", professor Igor V. Pekov on the unusual new minerals and pro-

fessor Ernst M. Spiridonov on the pegmatites problems.

The second day was held in the Fersman Mineralogical Museum RAS and was devoted to particular questions of mineralogy such as agate genesis (lecturer – professor Mikhail N. Maleev), aesthetic crystallochemistry (lecturer – professor Alexander P. Khomyakov), mineralogy of Darai-Pioz alkaline complex (lecturer – Leonid A. Pautov).

On the third day the youth session "Fersmaniada" supported by Russian Geological Society (RosGeo) took place at the Fersman Mineralogical Museum. The auditorium listened to twelve talks by young geologists and mineralogists who reported about their own and team results. The most interesting topics were represented by schoolchildren from Apatity, Perm, Orsk and Bogotol.

As a result young scientists got first, second and third awards. The first award was granted to Nina Sinitsina paper on the educational "Fersman Route" in Apatity region. The second award was shared between Pavel Maerkov from Bogotol, Olesya Vidischeva and Angelina Dolganova from Orsk. The third award shared between Ekaterina Sentsova, Vladlena Syrvacheva from Perm and Tatiana Gatalova, Elizaveta Kramkova from Energetik town. Besides, all the young participants were awarded with RosGeo diploma and Fersman museum certificates.

Also, the abstracts of the conference published comprised ones of professional and young mineralogists in one magazine.

The conference united different people together, both mineralogists, museum professionals and young geologists who became interested in science recently. Everybody were united with the passion to mineralogy and academitian Alexander Fersman heritage. The fact the youth session was well-attended revealed the genuine interest of the young generation in the Earth sciences and hopefully will help revive professional specialists in the industry.

Manuscript preparation guide for the journal "New Data on Minerals"

1. General statements

- 1.1. The journal "New Data on Minerals" publishes original papers (including short communications in the section "Mineralogical Notes"), compilations, historical materials, discussions, reviews, personal notes and chronicles of current events (exhibits, conferences, jubilees, etc.) related to mineralogy, crystallography, crystal chemistry, museum activities, and mineralogical collections.
- 1.2. All manuscripts submitted to the Editor must be accompanied by Agreement on the copyright transfer for publishing the paper in the journal "New Data on Minerals" (one copy) signed by all authors. The Agreement form can be found on Fersman Mineralogical Museum RAS website www.fmm.ru/public.html.
- 1.3. All papers submitted to the Editor are subject to peer-review. Based on the reviewer's recommendations, the paper can be rejected or returned to the authors for revision. In the latter case, the authors should answer all reviewer's comments in the second submission.
- 1.4. The Editor reserves the right to adjust the style and size of the submitted materials when necessary. The date of submission is considered to be the date when the final version of the manuscript is received by the Editor.
- 1.5. The Editor will send the corrected proof of a manuscript to the authors, and only minor modifications in the proof will be allowed.
- 1.6. If the paper contains data on new mineral species, these must have been approved by the Commission on New Minerals, Nomenclature and Classification of the International Mineralogical Association (CNMNC IMA) prior to submission.
- 1.7. The paper size (including references, figures, and tables) must not exceed 1 printed unit (i.e. 22 pages, 1800 symbols per page).

2. Format requirements

- 2.1. Submitted manuscripts should be printed on the paper size A4 by Times New Roman, 12 pt. The text should be double-spaced and justified with the left margin of 3 cm. Pages should be numbered. Two hard copies and/or an electronic copy (MS Word Windows file) of a manuscript must be submitted. The manuscript should follow the format of the journal "New

Data on Minerals". The title should be typed bold. Do not use all caps. The names of the authors and the title of the paper should be given in both Russian and English, with each author's affiliation given under the name (including organization, city, and e-mail).

- 2.2. Subheadings can be used for paper structuring. Subheadings should be bold in low-case letters and separated from the body text with an extra line. No period is used after subheadings.
- 2.3. References should be provided in the section **References** in the end of the text. Do not use numbers and indent the first line of each reference. The authors' names should be typed in italic. The references should be arranged in the alphabetic order. If several references of the same author are included, they are arranged in the chronological order, with the author's name repeated; publications with the same year are numbered with subscript indexes. The references should include the following information: for books – authors' last names and initials, book title, place of publication (city), publisher, year, and total number of pages (for example: *Godovikov A.A.* Mineralogy. Moscow: Nedra, **1983**. 647 p.); for journal papers – authors' last names and initials, paper title, journal title, year, volume, number or issue, and the first and the last pages (for example: *Chukhrov F.V.* Ephemeral minerals // Nature. **1973**. No. 9. P. 64–69.); for book articles – authors' last names and initials, paper title, book title, place of publication (city), publisher, year, and the first and the last pages (for example: *Lebedev L.M., Cherkashev G.A., Tsepina A.I.* New data on the mineralogy of sulfide ores of the Atlantis II Trench (Red Sea) // Modern hydrothermal mineral formation. Moscow: Nauka. **1988**. P. 110–123.
- 2.4. In the text, references are given in parenthesis, for example: (Fersman, 1953).
- 2.5. The journal uses the terminology and nomenclature adopted by the International Mineralogical Association. Such terms as *Li-tiosudite* should be avoided (should be replaced by *Li-bearing* or *lithium-bearing*, etc.). When applying the mineral names to their synthetic analogs, one should use quote marks or the adjective *synthetic*.

- 2.6. For the mineral formulae calculated from the analytical data, calculation base should be given (for example: $O = 6$ or the number of charges = 22). When referring to the atomic coefficients in mineral formulae in the text, one can use abbreviations such as apfu etc. The formulae may be typed using specialized editors such as Microsoft Equation. The variables in the formulae and in the text given by Latin or Russian letters should be typed in italic, and the greek letters should be typed in regular font. Regular font is also used for the symbols of chemical elements and mineral formulae. Italic font should be used for the letters in the crystallographic point group notations. Bold and underlines are only used for specially defined cases.
- 2.7. In decimals, the integer part is separated from the fraction part with a decimal point (for example: 0.98). For Miller indices, inversion axes in the symmetry class notations, a line above a symbol should be used (rather than a minus sign near the symbol).
- 2.8. All abbreviations must be explained when first mentioned. Shortened words in the text are not allowed (except for commonly accepted terms, such as wt.%. When shortening is needed for tables, explanations should be provided in the Note.

3. Requirements to illustrations and tables

- 3.1. All illustrational materials and tables should be provided on separate pages. Both grayscale and color illustrations can be used. The decision to print illustrations in color is taken by the Editor in each individual case. Usually, the space ratio between the color illustrations and text (with exception of articles in the rubric "Mineralogical Museums and Collections") should not exceed 4 pictures per 16 typed pages.
- 3.2. The electronic versions of illustrations should be submitted as TIF or JPG files with the following parameters: (a) scheme or drawing in color – color scheme: RGB, resolution 300 dpi; (b) scheme or drawing without color – color scheme: grayscale, resolution 300 dpi; (c) black and white line drawing – color scheme: bitmap, resolution 800–1200 dpi. The dimensions of an illustration should not less than those intended for the final publication. The original files in the format of the graphic editor or other software used should be also provided. If the authors decide to add

any elements (e.g. arrows, text, etc.) to the illustrations in the final submission, this should be done using a graphic editor or manually on the hard copy of the picture (using the MS Word editor in this case is not appropriate).

- 3.3. Maps, profiles, and microphotographs must be accompanied by linear scale. The size of objects on the microphotographs should be indicated in the figure caption. All symbols on figures must be explained either in the caption or in the text. The list of figure captions is provided on a separate page. The figure captions and table titles are needed in both Russian and English.
- 3.4. References to figure and tables in the text are given in parenthesis with a space before the number, for example: (Fig. 1) or (Table 3). When letters are used in figure numeration, those should follow the number; for example: (Fig. 2a). When referring to a figure or a table in the text, one should use full spelling (for example: "As shown in the Figure 3, ...").

4. Abstract

- 4.1. All manuscripts must be submitted with an abstract in the beginning of the text. The size of the abstract must not exceed 1 page typed with line spacing 1.5. A note mentioning the number of figures, tables, and references in the paper should be given in the end of the abstract as a separate line aligned on the left margin, for example: 2 tables, 4 figures, 10 references. Keywords (no more than 10) should be listed separated by commas at the end of the abstract as a separate left aligned paragraph, (for example: "Keywords: pertsevite, new find, mineral species, holotype, Gonochan Deposit, Far East, Titov Deposit, Upper Verkhoyan Region, kotoite-bearing rocks").

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