

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.

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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,Na-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

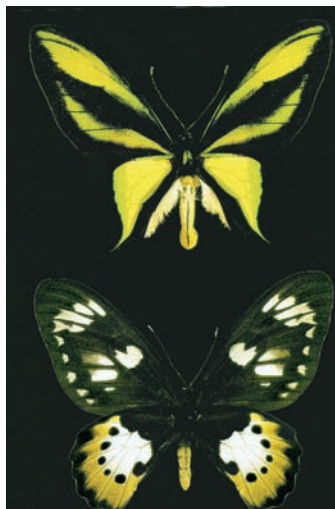


Fig. 1. These formally resemble butterflies were attributed to different biological species until it was discovered that the upper one is shining male of *Ornithoptera paradisea*, and the lower is his modest female partner in *paranja*. If genetic aspect of a speciation is not taken into account one 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 $C \bar{1}$ — instead of $P \bar{1}$. "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 $Fm\bar{3}m$ 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 ($P6_322$; $P6_622$). 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 Langesundsfjorden (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 Langesundsfjorden 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. Muschnug, 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-eucolites 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 eucolite 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-eucolites belong to Ekaterina E. Kostyleva-Labuntsova (Kostyleva, 1929; 1936). Systematic investigation of eudialyte-eucolites from the Kola peninsula, eudialyte from Kangerdluarssuq and Narsarsuk (Greenland) and eucolite 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 eucolite enriched in Ca, Mn, Fe, Mg. Specific gravity and refractive indices increase from eudialyte to eucolite, 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 eucolite 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 eudialytes (" - "). 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 eucolite 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 *ferriferrous 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_o / n_e " with fields for " + " and " - " varieties, and therefore assumed that optical sign does not depend directly on refraction of light; nevertheless the most abundant ferriferrous 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 *eucolite* 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 %): SiO_2 43.4–52.5, ZrO_2 9.1–16.4, TiO_2 0–4.0, $(\text{Nb,Ta})_2\text{O}_5$ 0–3.7, Al_2O_3 0–2.9, Fe_2O_3 0–6.7, FeO 0–7.3, MgO 0–1.8, MnO 0.2–11.1, $(\text{Ca,Sr})\text{O}$ 3.5–15.9, REE_2O_3 0–8.2, Na_2O 7.5–15.9, K_2O 0–3.8, Cl 0–2.4, H_2O 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 $(\text{Na}_2\text{ZrSi}_3\text{O}_9 + \text{Na}_3\text{Si}_3\text{O}_6(\text{OH})_3)$ for $(\text{NaCeFeSi}_3\text{O}_9 + \text{Ca}_2\text{FeSi}_3\text{O}_9)$. 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 \AA^3 – Golyshev *et al.*, 1971 or 1793 \AA^3 – 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 aluminosilicates – minerals with a permanent Si,Al-radical. Coefficients at A group (Na, K, Ca, Sr, REE, Mn) and B group (Zr, Fe^{3+} , Fe^{2+} , 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 $(\text{Na,K,Ca,Sr,Ba,REE,Mn})_5(\text{O,OH,Cl})_{10}$ (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: TiO_2 – up to 6.0 and Nb_2O_5 – up to 3.9, HfO_2 – up to 0.75, Ta_2O_5 – up to 6.3, WO_3 – up to 1.3, SrO – up to 8.9, La_2O_3 – up to 2.5, Ce_2O_3 – up to 3.9, Nd_2O_3 – up to 0.8, Pr_2O_3 – up to 0.3, Y_2O_3 – up to 1.6, F – up to 1.2, CO_2 – up to 0.8, SO_3 – 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 eucolite remained unclear.

Structural-chemical study of eudialyte-eucolites 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-eucolite series* determination with a concrete definition of isomorphous replacements taking place during *eucolitization* 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 extra-lattice 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 [Si_9O_{27}] are to be centered simultaneously both with “additional” Si-tetrahedra and “additional” octahedral, with different orientation. “Additional” silicon was “spread” over Si_7 and new Si_9 positions (with occupancy coefficient *o.c.* 0.53 and 0.37) in the upper ring and also Si_8 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 Fe^{3+} or Mn^{2+}) and octahedron (in case of Ti^{4+} or its statistical substitution by Na_7 and Na_{15} octahedra away from the ^{41}Fe 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: Na_4 on the plane of symmetry (7-apex polyhedra) and Na_{12} and Na_6 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: Na_2 (9-apex polyhedron), Na_5 distant from it for 0.93 Å, and K (10-apex polyhedron); two positions Na_9 and Na_{10} distant from the K one for 0.50 and 0.40 Å; and also Na_{14} position distant from Na_7 along the c_3 axis for 0.51 Å. Found in the lower chamber were: Na_1 (10-apex polyhedron), with split from it (0.51 Å) Na_{11} position (might be occupied with Sr) and Na_3 (7-apex polyhedron), related with Cl_1 atom and with split from it (0.70 Å) Na_8 position; and Na_{13} position on the c_3 axis close to Na_{15} . All the eudialyte varieties could be described on the basis of this structure.

³ — In Italian version the content of the cell $\text{Na}_{12}\text{Ca}_6\text{Fe}_3\text{Zr}_{3.36}\text{Si}_{24}\text{O}_{72}\text{Cl}_{0.68}(\text{Z} = 3)$ was calculated for 24 atoms of Si distributed by three tetrahedral positions: Si_1 in 3-member rings [Si_3O_9], Si_2 and Si_3 in 9-member rings [Si_9O_{27}], the excess of zirconium is placed by authors to the centre of 9-member ring. In Russian version of structure, the cell content $\text{Na}_{14}\text{Ca}_6\text{Zr}_3\text{Si}_{25}\text{O}_{80}\text{Cl}_{1.6}(\text{Z} = 3)$ is calculated for 25 atoms of Si and distributed among positions split according to acentric group $R3m$. Eight positions of Si were determined: Si_1 and Si_2 in 3-member rings [Si_3O_9], Si_3 , Si_4 , Si_5 and Si_6 in 9-member rings [Si_9O_{27}] and two “additional” atoms Si_7 and Si_8 with *o.c.* (occupancy coefficient) = 0.5 each, occupying centres of 9-member rings as radicals [$\text{Si}_9\text{O}_{24}(\text{OH})_3$].

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-feriferous 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 Petrelus 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 Petrelus 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

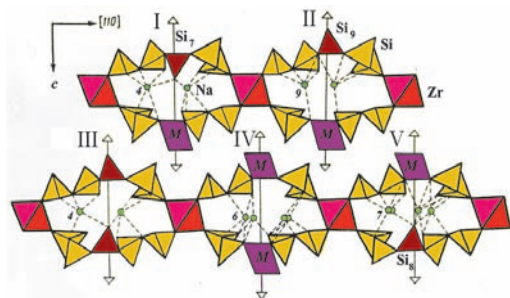
(o.c. 0.71) — in the M_1 position of the lower ring. Sodium is distributed over four positions: Na_4 (7-apex polyhedron, o.c. 0.13), Na_9 (o.c. 0.19), Na_6 (5-apex polyhedron, o.c. 0.23) and Na_7 (o.c. 0.09). Similar distribution of “additional” cations was determined in other eucolites (table 1, No 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*-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 $Zr^{IV}Fe^{2+}Mn$ or $Nb^{IV}Fe^{2+}REE$ atoms are formed, and in the upper one — structurally identical groups $Cl^{IV}Fe^{3+}Na$ or $(OH)^{IV}Fe^{2+}Mn$.

A number of refinements preformed by Ramiza K. Rastsvataeva using our material demonstrated structural changes occurring during eucolization 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* 3*m*, *R*3*m* и *R*3) 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-sited octahedron. Displaced $Si(3s)$ position in case of *R*3*m* reveals central symmetry deviation which however does not reach $Si(3)$ and $Si(4)$ atomic positions in *R*3*m*. Positions $Si(5)$ and $Si(6)$ are getting split in case of *R*3.

	Mineral	Chemical and structural information*	References
1	Eudialyte-R Naujakasit Greenland	$\text{Na}_{12}\text{yK}_0\text{Ca}_5\text{sREE}_0\text{Fe}^{2+}_{2.6}\text{Fe}^{3+}_{0.2}\text{Mn}_{0.2}\text{Zr}_3\text{Nb}_{20}\text{Si}_{24}\text{O}_{723}\text{Cl}_{10}\text{H}_{3.6}$ [Si = 24] $\text{Na}_{12}[\text{Ca}, \text{REE}]_6(\text{Fe}^{2+})_6(\text{Fe}^{3+})_2(\text{Mn}, \text{Mg})_2[\text{Zr}]_3(\text{Zr}, \text{Nb})_2[\text{Si}_9\text{O}_{27-y}(\text{OH})_y]_2\text{Cl}_2$ ($x = 0.1-0.9$; $y = 1-3$; $z = 0.7-1.4$) $\text{Na}_{12}[\text{Ca}]_6\text{Fe}_3[\text{Zr}]_3\text{Si}_9\text{O}_{27}[\text{Si}_9\text{O}_{27}][\text{Si}_9\text{O}_{27}]\text{Cl}_2$ $\text{Na}_{15}\text{Ca}_6\text{Fe}_3\text{Zr}_3\text{Si}(\text{Si}_2\text{O}_7)_3(\text{O}, \text{OH}, \text{H}_2\text{O})_3(\text{Cl}, \text{OH})_2$	Giuseppi et al., 1970; 1971
2	Eudialyte-R3m Yukspor Khbinsy	$\text{Na}_{13}\text{yK}_0\text{Ca}_6\text{Sr}_0\text{IREE}_0\text{Fe}^{2+}_{2.5}\text{Fe}^{3+}_{0.2}\text{Mn}_{0.3}\text{Mg}_{0.2}\text{Zr}_2\text{Tl}_0\text{Si}_{25}\text{O}_{73}\text{Cl}_{1.6}$.4.H ₂ O [V 1760 Å ³ ; d 2.87] $\text{Na}_{12}[\text{Ca}]_6\text{Fe}_3[\text{Zr}]_3\text{Si}(\text{Si}_3\text{O}_9)_2[\text{Si}_9\text{O}_{27}][\text{Si}_9\text{O}_{27}(\text{OH})] + (\text{Na}, \text{K}, \text{Ca}, \text{S}, \text{OH})$ $\text{Na}_{15}\text{Ca}_6\text{Fe}_3\text{Zr}_3\text{Si}(\text{Si}_2\text{O}_7)_3(\text{O}, \text{OH}, \text{H}_2\text{O})_3(\text{Cl}, \text{OH})_2$	Dorfman, 1962; Golyshv et al., 1971; 1972;
3	Eudialyte-R3m No 817/M Rasmuchor Khbinsy	$\text{Na}_{14}\text{K}_{1.3}\text{Ca}_5\text{Sr}_0\text{REE}_0\text{Fe}^{2+}_{1.8}\text{Fe}^{3+}_{0.2}\text{Mn}_{0.2}\text{Al}_0\text{Zr}_2\text{Tl}_0\text{Nb}_{0.0}\text{Si}_{24}\text{O}_{73}\text{Cl}_{1.7}$.7.H ₂ O [V 1758 Å ³ ; d 2.74] $\text{Na}_{14}\text{K}_{1.4}\text{Ca}_6\text{Sr}_0\text{REE}_0\text{Fe}^{2+}_{1.8}\text{Fe}^{3+}_{0.3}\text{Mn}_{0.2}\text{Al}_0\text{Zr}_3\text{Tl}_0\text{Nb}_{0.0}\text{Si}_{25}\text{O}_{73}\text{Cl}_{1.8}$.8 H ₂ O [Si = 25.3] $\{\text{Na}(2)_{1.2}\text{Na}(5)_{0.84}\}\text{Zr}_2\text{Na}(9)_{1.26}\text{Na}(10)_{0.57}\text{K}_{1.20}\text{Si}_{23}\text{O}_3\{\text{Na}(4)_{1.50}\text{Na}(6)_{1.26}\text{Na}(12)_{0.24}\}\text{Si}_{30} \times$ $\times [\text{Na}(1)_{2.26}\text{Na}(11)_{0.72}\text{Si}_{30}\{\text{Na}(3)_{2.10}\text{Na}(8)_{0.87}\}\text{Zr}_2\text{Na}(9)_{1.26}\text{Na}(10)_{0.57}\text{Fe}^{2+}_{1.92}\text{Mf}^{3+}=\text{Fe}^{2+}_{0.26}\text{Ti}_{0.31}\text{Si}_{20.57}\text{Si}_{22.40} \times$ $\times \{\text{Na}(7)_{0.21}\text{Na}(13)_{0.23}\text{Na}(14)_{0.33}\text{Na}(15)_{0.18}\text{Zr}_{0.93}\text{Zr}_3\{\text{Si}(9)_{0.37}\text{Si}(7)_{0.53}\}\text{Si}_{20.90}\{\text{Si}(8)_{0.43}\text{Al}_{0.30}\}\text{Si}_{20.73} \times$ $\times [\text{Si}(2)_3\text{O}_9][\text{Si}(5)_3\text{O}_9][\text{Si}(1)_{0.6}\text{Si}(4)_{0.27}][\text{Si}(3)_{0.6}\text{Si}(6)_{0.83}\text{Si}(10)_{0.16}\text{O}_{27}] \times$ $\times [\text{OH}(1)_{0.53}\text{OH}(2)_{0.37}\text{OH}(3)_{0.81}\text{OH}(4)_{0.43}\text{OH}(5)_{0.30}\text{Si}_{22.44}\text{Cl}(-1)_{-1.72}]$ $\times [\text{Na}_{14}\text{K}_{1.2}][\text{Ca}]_6[\text{Fe}_1(\text{Fe}, \text{Mn}, \text{Ti})_{0.3}][\text{Zr}]_3[\text{Si}_{10}\text{Al}_{0.3}][\text{Si}_{25}\text{O}_{73}]\text{Cl}_{1.7}$.2.4 H ₂ O $\text{Na}_{15}\text{Ca}_6\text{Fe}_3\text{Zr}_3\text{Si}(\text{Si}_2\text{O}_7)_3(\text{O}, \text{OH}, \text{H}_2\text{O})_3(\text{Cl}, \text{OH})_2$	Rastsvetova, Andrianov, 1987; Rastsvetova, Borutsky, 1988
4	Eucalite - R3m No 638 Chasnchor Khbinsy	$\text{Na}_{12}\text{yK}_0\text{Ca}_6\text{Sr}_0\text{REE}_0\text{Fe}^{2+}_{2.5}\text{Fe}^{3+}_{0.3}\text{Mn}_{0.6}\text{Mg}_{0.9}\text{Al}_{0.3}\text{Zr}_3\text{Tl}_0\text{Nb}_{0.0}\text{Si}_{24}\text{O}_{73}\text{Cl}_{1.2}$.3.OH ₂ O [V 1755 Å ³ ; d 3.00] $\{\text{Na}(2)_{1.86}\text{Na}(5)_{1.08}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Mf}(4)=(\text{Na}, \text{Sr}, \text{Mg})_{1.08}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Na}(6)_{1.38}\text{Na}(7)_{0.54}\text{Na}(9)_{0.57}\}\text{Si}_{28.8} \times$ $\times \{M(3)=(\text{Na}, \text{REE})_{1.3}\text{Na}(3)_{1.89}\text{Na}(8)_{0.81}\text{Na}(10)_{0.33}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Mf}(2)=\text{Fe}^{2+}_{1.32}\text{Mf}(2)=\text{Fe}^{2+}_{0.60}\text{Fe}^{3+}_{0.27}\text{Mn}_{0.76}\text{Ti}_{0.63}\}\text{Si}_{22.95} \times$ $\times [\text{Zr}]_3\{\text{Si}(9)_{0.21}\text{Ti}_{0.16}\text{Si}(7)_{0.60}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Mf}(1)=(\text{Nb}_{0.41}\text{Al}_{0.30})_{0.71}\text{Zr}_{0.99} \times$ $\times [\text{Si}_{24}\text{O}_{72}][\text{OH}(1)_{0.66}\text{OH}(2)_{0.30}\text{OH}(3)_{1.71}\text{OH}(4)_{0.27}\text{OH}(5)_{0.12}\}\text{Si}_{23.08}\{\text{Cl}(1)_{0.73}\text{Cl}(2)_{0.64}\}\text{Si}_{21.37}$ $\{\text{Na}_9\}\text{Na}, \text{K}, \text{Sr}, \text{REE}, \text{Mg}, \text{Ca}, \text{Fe}^{2+}_{1.2}\text{Fe}^{3+}_{1.2}(\text{Fe}^{3+}, \text{Fe}^{2+}, \text{Mn}), \text{Mn}\}\{\text{Zr}_3\{\text{Si}_{10}\}\{\text{Nb}, \text{Al}, \text{Ti}, \text{H}_2\text{O}\}\{\text{Si}_{25}\text{O}_{73}\}\{\text{OH}\}_3\text{Cl}_{1.4}$	Minerology of Khbinsy massif, 1978; Rastsvetova, et al., 1988
5	REE, Fe- Eucalite R3m No 325 Petrelus Mt. Khbinsy	$\text{Na}_{12}\text{yK}_0\text{Ca}_5\text{Sr}_0\text{REE}_0\text{Mg}_{0.5}\text{Fe}^{2+}_{2.3}\text{Fe}^{3+}_{0.4}\text{Mn}_{0.1}\text{Zr}_3\text{Tl}_0\text{Nb}_{0.6}\text{Al}_{0.2}\text{Si}_{24}\text{O}_{73}\text{Cl}_{0.9}$.5.H ₂ O [V 1765 Å ³ ; d = 3.04] $\{\text{Na}(9)=(\text{Na}_{1.36}\text{K}_{0.34})_{0.71}\text{Na}(10)_{1.03}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Mf}(4)=(\text{Na}_{1.04}\text{Sr}_{0.19})_{0.21}\text{Na}(3)_{1.63}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Na}(6)_{1.38}\text{Na}(7)_{0.54}\text{Na}(9)_{0.57}\}\text{Si}_{28.8} \times$ $\times \{M(3)=(\text{REE})_{0.71}\text{Mn}_{1.45}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Na}(10)_{0.24}\text{Na}(2)_{1.83}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Na}(6)_{1.38}\text{Na}(7)_{0.54}\text{Na}(9)_{0.57}\}\text{Si}_{28.8} \times$ $\times \{\text{Fe}^{2+}_{1.29}\text{Mf}(2)=\text{Fe}^{3+}_{1.28}\text{Zr}_{0.28}\text{Zr}_{1.56}\}\text{Zr}_3\{\text{Si}(7)_{0.73}\text{Si}(8)_{0.19}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Mf}(1)=(\text{Zr}_{0.27}\text{Nb}_{0.60})_{0.71}\text{Zr}_{0.99} \times$ $\times [\text{Si}_{24}\text{O}_{72}][\text{OH}(1)_{0.75}\text{OH}(2)_{0.29}\}\text{Si}_{21.04}\{\text{OH}(3)_{2.31}\text{OH}(4)_{0.22}\text{OH}(5)_{0.17}\text{OH}(6)_{0.61}\text{Cl}(1)_{0.60}\}\text{Cl}(2)_{0.70}\text{Ti}_{0.70}$ $\{\text{Na}_{12}\text{K}_{0.34}\text{Sr}_0\text{REE}_0\text{Mg}_{0.5}\}\text{Fe}^{2+}_{2.3}\text{Fe}^{3+}_{0.4}\text{Mn}_{0.1}\text{Zr}_3\{\text{Zr}_{0.76}\text{Ti}_{0.16}\text{Nb}_{0.6}\text{Al}_{0.1}\}\text{Si}_{24}\text{O}_{73}\text{Cl}_{0.9}$.5.H ₂ O	Minerology of Khbinsy massif, 1978; Rastsvetova, Borutsky, 1990
6	REE, Mn- Eucalite No 1008-6 R3m Sredne-Tatarsky massif Yenisei range	$\text{Na}_{12}\text{yK}_0\text{Ca}_6\text{Sr}_0\text{REE}_0\text{Fe}^{2+}_{1.1}\text{Fe}^{3+}_{0.6}\text{Mn}_{0.7}\text{Zr}_3\text{Tl}_0\text{Nb}_{0.6}\text{Al}_{0.3}\text{Si}_{25}\text{O}_{73}\text{Cl}_{0.9}$.3.OH ₂ O [V 1767 Å ³ ; d 3.03] $\{\text{Na}(9)=(\text{Na}_{0.99}\text{K}_{0.33}\text{H}_2\text{O})_{0.66}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Mf}(4)=(\text{Na}_{1.56}\text{Na}(3)_{1.41})_{0.71}\text{Zr}_{0.99} \times$ $\times \{\text{Na}(4)_{0.33}\text{Na}(5)_{1.77}\text{Na}(6)_{0.36}\text{H}_2\text{O}\}_{0.27}\text{Zr}_2\text{Na}(9)_{1.74}\text{Mf}(3)=(\text{REE})_{0.71}\text{Na}_{1.1}\text{Mn}_{0.57}\text{Zr}_{0.49}\text{Na}(1)_{0.33}\text{Na}(2)_{0.15}\}\text{Si}_{22.97} \times$ $\times \{\text{M}(3)=(\text{REE})_{0.71}\text{Mn}_{1.45}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Na}(10)_{0.24}\text{Na}(2)_{1.83}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Na}(6)_{1.38}\text{Na}(7)_{0.54}\text{Na}(9)_{0.57}\}\text{Si}_{28.8} \times$ $\times \{\text{Si}(7)_{0.55}\text{Si}(8)_{0.19}\text{Si}(9)_{0.27}\text{Zr}_{0.92}\text{Al}_{0.30}\text{Mf}(1)=(\text{Zr}_{0.13}\text{Nb}_{0.56})_{0.69}\text{Zr}_{0.99}\}\text{Si}_{24}\text{O}_{72} \times$ $\times \{\text{OH}(1)_{0.56}\text{OH}(2)_{0.43}\}\text{Ti}_{0.16}\{\text{OH}(3)_{2.16}\text{OH}(4)_{0.30}\text{OH}(5)_{0.12}\text{OH}(6)_{0.62}\text{OH}(7)_{0.84}\text{OH}(8)_{0.44}\}\text{Si}_{23.08} \times$ $\times \{\text{Ca}_2\text{Ba}_5\text{Sr}_0\text{K}_0\text{Ca}_6\text{Sr}_0\text{REE}_0\text{Fe}^{2+}_{0.7}\text{Fe}^{3+}_{0.3}\text{Mn}_{0.6}\text{Al}_{0.1}\text{Zr}_3\text{Tl}_0\text{Nb}_{0.7}\text{Si}_{24}\text{O}_{73}\text{Cl}_{1.2}\}\text{Si}_{21} \times$ ** $\text{Na}_{13}\text{yK}_0\text{Ca}_6\text{Sr}_0\text{REE}_0\text{Fe}^{2+}_{1.8}\text{Fe}^{3+}_{0.6}\text{Mn}_{0.6}\text{Al}_{0.2}\text{Zr}_3\text{Tl}_0\text{Nb}_{0.4}\text{Ta}_0\text{Si}_{25}\text{O}_{73}\text{Cl}_{1.3}$.2.OH ₂ O $\{\text{Na}(2)_{1.89}\text{Na}(5)_{1.11}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Na}(10)_{0.24}\text{Na}(2)_{1.83}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Na}(6)_{1.38}\text{Na}(7)_{0.54}\text{Na}(9)_{0.57}\}\text{Si}_{28.8} \times$ $\times \{M(3)=(\text{Na}, \text{REE})_{1.3}\text{Na}(3)_{1.89}\text{Na}(8)_{0.81}\text{Na}(10)_{0.33}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Mf}(2)=\text{Fe}^{2+}_{1.32}\text{Mf}(2)=\text{Fe}^{2+}_{0.60}\text{Fe}^{3+}_{0.27}\text{Mn}_{0.76}\text{Ti}_{0.63}\}\text{Si}_{22.95} \times$ $\times \{\text{Fe}^{2+}_{1.17}\text{Mf}(2)=\text{Fe}^{3+}_{0.66}\text{Fe}^{3+}_{0.57}\text{Mn}_{0.60}\text{Ti}_{0.83}\}\text{Zr}_3\{\text{Si}(9)_{0.21}\text{Al}_{0.09}\text{Si}(7)_{0.69}\}\text{Si}_{20.72} \times$ $\times \{\text{Si}(8)_{0.17}\text{Ti}_{0.07}\text{Mf}(1)=(\text{Zr}_{0.24}\text{Nb}_{0.36}\text{Al}_{0.13})_{0.73}\}\text{Zr}_{0.97}\text{Si}_{24}\text{O}_{72} \times$ $\times [\text{OH}(1)_{0.82}\text{OH}(2)_{0.22}\text{OH}(3)_{1.85}\text{OH}(4)_{0.27}\text{OH}(5)_{0.15}\text{OH}(6)_{0.62}\text{OH}(7)_{0.84}\text{OH}(8)_{0.44}\}\text{Si}_{23.08} \times$ $\times \{\text{OH}(1)_{0.82}\text{OH}(2)_{0.22}\text{OH}(3)_{1.85}\text{OH}(4)_{0.27}\text{OH}(5)_{0.15}\text{OH}(6)_{0.62}\text{OH}(7)_{0.84}\text{OH}(8)_{0.44}\}\text{Si}_{23.08} \times$ $(\text{Na}, \text{Ca})_9(\text{Mn}, \text{Fe})_2(\text{Zr}, \text{Nb})_2\text{Si}_{12}(\text{O}, \text{Cl}, \text{OH})_{37}$ **	Sveshnikova, Burova, 1965; Rastsvetova, Borutsky, 1990
7	Barsanovite «reddish-brown» R3m river Petrelus valley Khbinsy	$(\text{Ca}_2\text{Ba}_5\text{Sr}_0\text{K}_0\text{Ca}_6\text{Sr}_0\text{REE}_0\text{Fe}^{2+}_{0.7}\text{Fe}^{3+}_{0.3}\text{Mn}_{0.6}\text{Al}_{0.1}\text{Zr}_3\text{Tl}_0\text{Nb}_{0.7}\text{Si}_{24}\text{O}_{73}\text{Cl}_{1.2})\text{Si}_{21} \times$ ** $\text{Na}_{13}\text{yK}_0\text{Ca}_6\text{Sr}_0\text{REE}_0\text{Fe}^{2+}_{1.8}\text{Fe}^{3+}_{0.6}\text{Mn}_{0.6}\text{Al}_{0.2}\text{Zr}_3\text{Tl}_0\text{Nb}_{0.4}\text{Ta}_0\text{Si}_{25}\text{O}_{73}\text{Cl}_{1.3}$.2.OH ₂ O $\{\text{Na}(2)_{1.89}\text{Na}(5)_{1.11}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Na}(10)_{0.24}\text{Na}(2)_{1.83}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Na}(6)_{1.38}\text{Na}(7)_{0.54}\text{Na}(9)_{0.57}\}\text{Si}_{28.8} \times$ $\times \{M(3)=(\text{Na}, \text{REE})_{1.3}\text{Na}(3)_{1.89}\text{Na}(8)_{0.81}\text{Na}(10)_{0.33}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Mf}(2)=\text{Fe}^{2+}_{1.32}\text{Mf}(2)=\text{Fe}^{2+}_{0.60}\text{Fe}^{3+}_{0.27}\text{Mn}_{0.76}\text{Ti}_{0.63}\}\text{Si}_{22.95} \times$ $\times \{\text{Fe}^{2+}_{1.17}\text{Mf}(2)=\text{Fe}^{3+}_{0.66}\text{Fe}^{3+}_{0.57}\text{Mn}_{0.60}\text{Ti}_{0.83}\}\text{Zr}_3\{\text{Si}(9)_{0.21}\text{Al}_{0.09}\text{Si}(7)_{0.69}\}\text{Si}_{20.72} \times$ $\times \{\text{Si}(8)_{0.17}\text{Ti}_{0.07}\text{Mf}(1)=(\text{Zr}_{0.24}\text{Nb}_{0.36}\text{Al}_{0.13})_{0.73}\}\text{Zr}_{0.97}\text{Si}_{24}\text{O}_{72} \times$ $\times [\text{OH}(1)_{0.82}\text{OH}(2)_{0.22}\text{OH}(3)_{1.85}\text{OH}(4)_{0.27}\text{OH}(5)_{0.15}\text{OH}(6)_{0.62}\text{OH}(7)_{0.84}\text{OH}(8)_{0.44}\}\text{Si}_{23.08} \times$ $\times \{\text{OH}(1)_{0.82}\text{OH}(2)_{0.22}\text{OH}(3)_{1.85}\text{OH}(4)_{0.27}\text{OH}(5)_{0.15}\text{OH}(6)_{0.62}\text{OH}(7)_{0.84}\text{OH}(8)_{0.44}\}\text{Si}_{23.08} \times$ $(\text{Na}, \text{Ca})_9(\text{Mn}, \text{Fe})_2(\text{Zr}, \text{Nb})_2\text{Si}_{12}(\text{O}, \text{Cl}, \text{OH})_{37}$ **	Dorfman et al., 1963; 1965; Rastsvetova et al., 1987
8	Barsanovite R3m «yellowish-green» river Petrelus valley Khbinsy	$(\text{Ca}_2\text{Ba}_5\text{Sr}_0\text{K}_0\text{Ca}_6\text{Sr}_0\text{REE}_0\text{Fe}^{2+}_{0.7}\text{Fe}^{3+}_{0.3}\text{Mn}_{0.6}\text{Al}_{0.1}\text{Zr}_3\text{Tl}_0\text{Nb}_{0.7}\text{Si}_{24}\text{O}_{73}\text{Cl}_{1.2})\text{Si}_{21} \times$ ** $\text{Na}_{11}\text{yK}_0\text{Ca}_6\text{Sr}_0\text{REE}_0\text{Fe}^{2+}_{2.4}\text{Fe}^{3+}_{0.3}\text{Mn}_{1.7}\text{Al}_0\text{Zr}_3\text{Tl}_0\text{Nb}_{0.7}\text{Si}_{24}\text{O}_{73}\text{Cl}_{0.9}$.7.H ₂ O [V 1756 Å ³ ; d 3.07] $\{\text{Na}(2)_{1.59}\text{Na}(5)_{0.40}\text{Na}(3)_{1.11}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Mf}(3)=(\text{REE})_{0.71}\text{Na}_{1.1}\text{Mn}_{0.57}\text{Zr}_{0.49}\text{Na}(1)_{0.33}\text{Na}(2)_{0.15}\}\text{Si}_{22.97} \times$ $\times \{M(3)=(\text{Na}, \text{REE})_{1.3}\text{Na}(3)_{1.89}\text{Na}(8)_{0.81}\text{Na}(10)_{0.33}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Mf}(2)=\text{Fe}^{2+}_{1.32}\text{Mf}(2)=\text{Fe}^{2+}_{0.60}\text{Fe}^{3+}_{0.27}\text{Mn}_{0.76}\text{Ti}_{0.63}\}\text{Si}_{22.95} \times$ $\times \{\text{Fe}^{2+}_{0.60}\text{Mf}(2)=\text{Fe}^{3+}_{1.90}\text{Fe}^{3+}_{0.33}\text{Al}_{0.05}\text{Ti}_{0.06}\}\text{Zr}_3\{\text{Si}(7)_{0.95}\}\text{Mf}(1)=(\text{Zr}_{0.33}\text{Nb}_{0.67})_{0.71}\text{Zr}_{0.99}\}\text{Si}_{24}\text{O}_{72} \times$ $\times [\text{OH}(1)_{0.92}\text{OH}(2)_{0.15}\text{OH}(3)_{1.88}\text{OH}(4)_{0.83}\text{OH}(5)_{0.61}\text{Cl}(1)_{0.75}\text{Cl}(2)_{0.17}\}\text{Si}_{20.92}$ $(\text{Na}, \text{Ca})_9(\text{Mn}, \text{Fe})_2(\text{Zr}, \text{Nb})_2\text{Si}_{12}(\text{O}, \text{Cl}, \text{OH})_{37}$ **	Dorfman et al., 1963; 1965; Rastsvetova et al., 1990;
9	Fe, Cl-analogue of kentbrooksit R3m New investigation of «yellowish-green barsanovite»	$\text{Na}_{11}\text{yK}_0\text{Ca}_6\text{Sr}_0\text{REE}_0\text{Fe}^{2+}_{2.4}\text{Fe}^{3+}_{0.3}\text{Mn}_{1.7}\text{Al}_0\text{Zr}_3\text{Tl}_0\text{Nb}_{0.7}\text{Si}_{24}\text{O}_{73}\text{Cl}_{0.9}$.7.H ₂ O [V 1756 Å ³ ; d 3.07] $\{\text{Na}(2)_{1.59}\text{Na}(5)_{0.40}\text{Na}(3)_{1.11}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Mf}(3)=(\text{REE})_{0.71}\text{Na}_{1.1}\text{Mn}_{0.57}\text{Zr}_{0.49}\text{Na}(1)_{0.33}\text{Na}(2)_{0.15}\}\text{Si}_{22.97} \times$ $\times \{M(3)=(\text{Na}, \text{REE})_{1.3}\text{Na}(3)_{1.89}\text{Na}(8)_{0.81}\text{Na}(10)_{0.33}\}\text{Zr}_2\text{Na}(9)_{1.74}\text{Mf}(2)=\text{Fe}^{2+}_{1.32}\text{Mf}(2)=\text{Fe}^{2+}_{0.60}\text{Fe}^{3+}_{0.27}\text{Mn}_{0.76}\text{Ti}_{0.63}\}\text{Si}_{22.95} \times$ $\times \{\text{Fe}^{2+}_{0.60}\text{Mf}(2)=\text{Fe}^{3+}_{1.90}\text{Fe}^{3+}_{0.33}\text{Al}_{0.05}\text{Ti}_{0.06}\}\text{Zr}_3\{\text{Si}(7)_{0.95}\}\text{Mf}(1)=(\text{Zr}_{0.33}\text{Nb}_{0.67})_{0.71}\text{Zr}_{0.99}\}\text{Si}_{24}\text{O}_{72} \times$ $\times [\text{OH}(1)_{0.92}\text{OH}(2)_{0.15}\text{OH}(3)_{1.88}\text{OH}(4)_{0.83}\text{OH}(5)_{0.61}\text{Cl}(1)_{0.75}\text{Cl}(2)_{0.17}\}\text{Si}_{20.92}$ $(\text{Na}, \text{Ca})_9(\text{Mn}, \text{Fe})_2(\text{Zr}, \text{Nb})_2\text{Si}_{12}(\text{O}, \text{Cl}, \text{OH})_{37}$ **	Ekimenkova et al., 2002
10	Georgbarsanovite - new name of barsanovite It was approved by the CNMNC as new mineral	$\text{Na}_{11}\text{yK}_0\text{Ca}_6\text{Sr}_0\text{Ba}_{0.0}\text{Ca}_{0.2}\text{Ce}_{0.3}\text{Nd}_{0.1}\text{Y}_{0.1}\text{Fe}^{2+}_{2.6}\text{Mn}_{1.2}\text{Zr}_3\text{Hf}_{0.0}\text{Ti}_{0.1}\text{Nb}_{0.9}\text{Si}_{25}\text{O}_{73}\text{Cl}_{1.0}\text{F}_{0.6}$.1.4H ₂ O $\{\text{N}(1)=\text{Na}_3\}\{\text{N}(2)=\text{Na}_3\}\{\text{N}(3)=\text{Na}_3\}\{\text{N}(4)=\text{Mn}_{1.07}\text{Sr}_{0.72}\text{Ce}_{0.47}\text{Ca}_{0.3}\text{K}_{0.25}\text{Y}_{0.13}\text{Ba}_{0.03}\}\text{Si}_{23.00}\{\text{N}(5)=\text{Na}_3\} \times$ $\times [\text{M}(1)=\text{Ca}_6] \times \text{Fe}^{2+}_{2.55}\text{Zr}_{0.27}\text{Mn}_{0.13}\text{Ti}_{0.05}\}\text{Zr}_3\{\text{M}(3)=\text{Nb}_{0.8}\text{Si}_{0.2}\}\text{Si}_{21.00}\{\text{M}(4)=\text{Si}_{1.0}\} \times$ $\times [\text{Si}_3\text{O}_9]_2[\text{Si}_6\text{O}_{12}]_2\{\text{O}, \text{OH}, \text{F}\}\text{Cl}_2\text{H}_2\text{O}$ $\text{Na}_{12}(\text{Mn}, \text{Sr}, \text{REE})_3\text{Ca}_6\text{Fe}^{VI}_3\text{Zr}_3[\text{Si}_3\text{O}_9]_2[\text{Si}_9\text{O}_{27}(\text{OH})_3][\text{Si}_9\text{NbO}_{27}(\text{O}, \text{OH})_3](\text{O}, \text{OH}, \text{F})\text{Cl}_2\text{H}_2\text{O}$ $\text{Na}_{11}\text{yK}_0\text{Ca}_6\text{Sr}_0\text{Ba}_{0.0}\text{Ca}_{0.2}\text{Ce}_{0.3}\text{Nd}_{0.1}\text{Y}_{0.1}\text{Fe}^{2+}_{2.6}\text{Mn}_{1.2}\text{Zr}_3\text{Hf}_{0.0}\text{Ti}_{0.1}\text{Nb}_{0.9}\text{Si}_{25}\text{O}_{73}\text{Cl}_{1.0}\text{F}_{0.6}$.0.88H ₂ O [Σ cat. = 53] $\{\text{N}(1)=\text{Na}_3\}\{\text{N}(2)=\text{Na}_3\}\{\text{N}(3)=\text{Na}_3\}\{\text{N}(4)=\text{Mn}_{1.07}\text{Sr}_{0.72}\text{Ce}_{0.47}\text{Ca}_{0.3}\text{K}_{0.25}\text{Y}_{0.13}\text{Ba}_{0.03}\}\text{Si}_{23.00}\{\text{N}(5)=\text{Na}_3\} \times$ $\times [\text{M}(1)=\text{Ca}_6] \times \text{Fe}^{2+}_{2.55}\text{Zr}_{0.27}\text{Mn}_{0.13}\text{Ti}_{0.05}\}\text{Zr}_3\{\text{M}(3)=\text{Nb}_{0.8}\text{Si}_{0.2}\}\text{Si}_{21.00}\{\text{M}(4)=\text{Si}_{1.0}\} \times$ $\times [\text{Si}_3\text{O}_9]_2[\text{Si}_6\text{O}_{12}]_2\{\text{O}, \text{OH}, \text{H}_2\text{O}\}\{\text{Cl}, \text{F}\}_2$ $\text{Na}_{12}(\text{Mn}, \text{Sr}, \text{REE})_3\text{Ca}_6\text{Fe}^{3+}_3\text{Zr}_3\text{Nb}(\text{Si}_2\text{O}_7)_6\text{Cl}_2(\text{H}_2\text{O})$	Khomyakov et al., 2005
11	Eudialyte-R No 9 Saint-Amable sill Quebec, Canada	$\text{Na}_{15}\text{yK}_0\text{Ca}_3\text{Sr}_0\text{IREE}_0\text{Y}_{0.2}\text{Fe}_{1.3}\text{Mn}_{2.2}\text{Zr}_2\text{Tl}_0\text{Nb}_{0.1}\text{Al}_0\text{Si}_{25}\text{O}_{73}\text{Cl}_{0.4}\text{H}_{0.3}...$ [Σ anions = 75.39] $\text{Na}_{13}\text{yK}_0\text{Ca}_6\text{Sr}_0\text{IREE}_0\text{Y}_{0.2}\text{Fe}_{1.3}\text{Mn}_{2.2}\text{Zr}_2\text{Tl}_0\text{Nb}_{0.1}\text{Al}_0\text{Si}_{25}\text{O}_{73}\text{Cl}_{0.4}\text{H}_{0.3}...$ [Σ anions = 75.39] $\times [\text{Zr}_2\text{Si}_2\text{O}_{10}]_{0.30}\{\text{Si}_{1.89}\text{Nb}_{0.11}\}_{22.00}...$	Johnsen, Grice, 1999
12	Eudialyte-R No 14 Narsarsuk S. Greenland	$\text{Na}_{15}\text{yK}_0\text{Ca}_3\text{Sr}_0\text{IREE}_0\text{Y}_{0.2}\text{Fe}_{1.3}\text{Mn}_{2.2}\text{Zr}_2\text{Tl}_0\text{Nb}_{0.1}\text{Al}_0\text{Si}_{25}\text{O}_{73}\text{Cl}_{0.4}\text{H}_{0.3}...$ [Σ anions = 76.40] $\text{Na}_{13}\text{yK}_0\text{Ca}_6\text{Sr}_0\text{IREE}_0\text{Y}_{0.2}\text{Fe}_{1.3}\text{Mn}_{2.2}\text{Zr}_2\text{Tl}_0\text{Nb}_{0.1}\text{Al}_0\text{Si}_{25}\text{O}_{73}\text{Cl}_{0.4}\text{H}_{0.3}...$ [Σ anions = 76.40] $\times [\text{Zr}_2\text{Si}_2\text{O}_{10}]_{0.30}\{\text{Si}_{1.89}\text{Nb}_{0.11}\}_{22.00}...$	Johnsen, Grice, 1999

- 13 Eudialyte-R $\bar{3}m$
No 15
Ilimaussaq
S. Greenland
 $\text{Na}_{15.0}\text{K}_{0.3}\text{Ca}_{5.5}\text{Sr}_{0.0}\text{REE}_{0.4}\text{Y}_{0.1}\text{Fe}_{3.2}\text{Mn}_{0.2}\text{Zr}_{2.9}\text{Hf}_{0.0}\text{Nb}_{0.2}\text{Ta}_{0.0}\text{Al}_{0.2}\text{Si}_{25.7}\text{Cl}_{1.2}\text{H}_{2.0}$ [Σ anions = 76.75]
 $\text{Na}(1)_{5.92}[\text{Na}(4)_{4.92}\text{K}_{0.31}\text{Ca}_{0.27}\text{Ca}_{0.44}\text{Sr}_{0.06}]\text{Zr}_{2.00}\text{Na}(5)_{2.20}[\text{Ca}_{5.15}\text{Fe}_{0.23}\text{Mn}_{0.24}\text{REE}_{0.22}\text{Y}_{0.14}]\text{Zr}_{2.00}\text{Fe}_{0.22}\text{Fe}_{0.46} \times$
 $\times [\text{Zr}_{2.93}\text{Nb}_{0.02}\text{Hf}_{0.02}]\text{Zr}_{3.00}[\text{Si}_{1.85}\text{Nb}_{0.15}]\text{Zr}_{2.00} \dots$ Johnsen, Grice, 1999
- 14 Eudialyte-R $\bar{3}m$
No 10
Gardar complex
E. Greenland
 $\text{Na}_{15.7}\text{K}_{0.4}\text{Ca}_{6.6}\text{Sr}_{0.7}\text{REE}_{0.0}\text{Y}_{0.1}\text{Fe}_{1.8}\text{Mn}_{0.4}\text{Zr}_{2.8}\text{Hf}_{0.0}\text{Ti}_{0.2}\text{Nb}_{0.1}\text{Al}_{0.1}\text{Si}_{25.8}\text{Cl}_{1.1}\text{H}_{1.4}$ [Σ anions = 76.91]
 $\text{Na}(1)_{5.77}[\text{Na}(4)_{4.29}\text{K}_{0.35}\text{Ca}_{0.71}\text{Sr}_{0.65}]\text{Zr}_{2.00}\text{Na}(5)_{2.05}[\text{Ca}_{5.89}\text{REE}_{0.03}\text{Y}_{0.08}]\text{Zr}_{2.00}\{\text{Fe}_{1.90}\text{Mn}_{0.20}\}\text{Zr}_{2.10}\text{Mn}_{0.47} \times$
 $\times [\text{Zr}_{2.76}\text{Ti}_{0.22}]\text{Zr}_{3.00}[\text{Si}_{1.84}\text{Nb}_{0.16}]\text{Zr}_{2.00} \dots$ Johnsen, Grice, 1999
- 15 Eudialyte-R $\bar{3}m$
No 12
Gardar complex
E. Greenland
 $\text{Na}_{15.7}\text{K}_{0.3}\text{Ca}_{6.7}\text{Sr}_{0.8}\text{REE}_{0.0}\text{Y}_{0.0}\text{Fe}_{1.6}\text{Mn}_{0.7}\text{Zr}_{2.8}\text{Hf}_{0.0}\text{Ti}_{0.2}\text{Nb}_{0.3}\text{Al}_{0.1}\text{Si}_{25.8}\text{Cl}_{1.0}\text{H}_{2.4} \dots$ [Σ anions = 77.96]
 $\text{Na}(1)_{5.75}[\text{Na}(4)_{4.26}\text{K}_{0.26}\text{Ca}_{0.72}\text{Sr}_{0.76}]\text{Zr}_{2.00}\text{Na}(5)_{2.07}[\text{Ca}_{5.91}\text{REE}_{0.03}\text{Y}_{0.08}]\text{Zr}_{2.00}\{\text{Fe}_{1.77}\text{Mn}_{0.35}\}\text{Zr}_{2.12}\text{Mn}_{0.39} \times$
 $\times [\text{Zr}_{2.80}\text{Ti}_{0.20}]\text{Zr}_{3.00}[\text{Si}_{1.73}\text{Nb}_{0.27}]\text{Zr}_{2.00} \dots$ Johnsen, Grice, 1999
- 16 Eudialyte-R $\bar{3}m$
No 7
Kipawa
Quebec, Canada
 $\text{Na}_{13.5}\text{K}_{0.7}\text{Ca}_{7.7}\text{REE}_{0.2}\text{Y}_{0.6}\text{Fe}_{0.7}\text{Mn}_{0.7}\text{Zr}_{2.9}\text{Hf}_{0.1}\text{Ti}_{0.0}\text{Nb}_{0.1}\text{Al}_{0.1}\text{Si}_{26.1}\text{Cl}_{1.0}\text{H}_{2.4} \dots$ [Σ anions = 77.49]
 $\text{Na}(1)_{5.89}[\text{Na}(4)_{2.87}\text{K}_{0.21}\text{Ca}_{2.92}]\text{Zr}_{2.00}\text{Na}(5)_{2.04}[\text{Ca}_{5.06}\text{REE}_{0.23}\text{Y}_{0.69}]\text{Zr}_{2.00}\{\text{Fe}_{1.52}\text{Mn}_{0.30}\}\text{Zr}_{2.12}\text{Mn}_{0.40} \times$
 $\times [\text{Zr}_{2.90}\text{Ti}_{0.06}\text{Hf}_{0.04}]\text{Zr}_{3.00}[\text{Si}_{1.71}\text{Nb}_{0.29}]\text{Zr}_{2.00} \dots$ Johnsen, Grice, 1999
- 17 Eudialyte-R $\bar{3}m$
No 1
Mont Saint-Hilaire
Quebec, Canada
 $\text{Na}_{15.3}\text{K}_{0.3}\text{Ca}_{5.6}\text{Sr}_{0.1}\text{REE}_{0.0}\text{Y}_{0.1}\text{Fe}_{1.8}\text{Mn}_{1.4}\text{Mg}_{0.9}\text{Zr}_{3.0}\text{Hf}_{0.0}\text{Ti}_{0.1}\text{Nb}_{0.4}\text{Ta}_{0.0}\text{Al}_{0.1}\text{Si}_{25.8}\text{Cl}_{0.7}\text{H}_{2.5} \dots$ [Σ anions = 77.48]
 $\text{Na}(1)_{5.92}[\text{Na}(4)_{4.26}\text{K}_{0.29}\text{Ca}_{0.24}\text{Sr}_{0.12}\text{REE}_{0.09}]\text{Zr}_{2.00}\text{Na}(5)_{2.08}[\text{Ca}_{5.32}\text{Mn}_{0.40}\text{REE}_{0.23}\text{Y}_{0.05}]\text{Zr}_{2.00}\{\text{Fe}_{1.77}\text{Mn}_{0.13}\}\text{Zr}_{2.00}\text{Mn}_{0.82} \times$
 $\times [\text{Zr}_{2.97}\text{Ti}_{0.03}]\text{Zr}_{3.00}[\text{Si}_{1.67}\text{Nb}_{0.33}]\text{Zr}_{2.00} \dots$ Johnsen, Grice, 1999
- 18 Eudialyte-R $\bar{3}m$
No 8
Kipawa
Quebec, Canada
 $\text{Na}_{14.8}\text{K}_{0.4}\text{Ca}_{6.5}\text{Sr}_{0.1}\text{REE}_{0.0}\text{Y}_{0.0}\text{Fe}_{0.5}\text{Mn}_{0.5}\text{Mg}_{0.1}\text{Zr}_{3.0}\text{Hf}_{0.0}\text{Ti}_{0.2}\text{Nb}_{0.1}\text{Al}_{0.1}\text{Si}_{25.6}\text{Cl}_{1.0}\text{Fe}_{0.9}\text{H}_{2.0} \dots$ [Σ anions = 77.35]
 $\text{Na}(1)_{5.84}[\text{Na}(4)_{3.77}\text{K}_{0.39}\text{Ca}_{1.70}\text{Sr}_{0.06}\text{REE}_{0.07}]\text{Zr}_{2.00}\text{Na}(5)_{2.17}[\text{Ca}_{4.74}\text{REE}_{0.47}\text{Y}_{0.79}]\text{Zr}_{2.00}\{\text{Fe}_{1.32}\text{Mn}_{0.55}\}\text{Zr}_{2.18} \times$
 $\times [\text{Fe}_{0.25}\text{Mg}_{0.09}]\text{Zr}_{2.00}\{\text{Zr}_{1.63}\text{Ti}_{0.21}\text{Nb}_{0.16}\}\text{Zr}_{2.00} \dots$ Johnsen, Grice, 1999
- 19 Eudialyte-R $\bar{3}m$
No 11
Gardar complex
E. Greenland
 $\text{Na}_{14.6}\text{K}_{0.3}\text{Ca}_{6.8}\text{Sr}_{1.3}\text{Ba}_{0.1}\text{REE}_{0.1}\text{Y}_{0.1}\text{Fe}_{0.1}\text{Mn}_{1.4}\text{Zr}_{2.6}\text{Ti}_{0.3}\text{Nb}_{0.6}\text{Si}_{25.1}\text{Cl}_{0.9}\text{H}_{1.4} \dots$ [Σ anions = 77.00]
 $\{\text{Na}(1)_{2.17}\text{Ca}_{0.83}\}\text{Zr}_{2.00}\{\text{Na}(2)_{2.27}[\text{Na}(3)_{1.83}\text{REE}_{0.13}\text{K}_{0.30}\text{Sr}_{0.06}\text{Ba}_{0.07}]\text{Zr}_{2.01}[\text{Na}(4)_{2.38}\text{Sr}_{0.62}]\text{Zr}_{2.00}\text{Na}(5)_{2.06} \times$
 $\times [\text{Ca}_{5.93}\text{Y}_{0.07}]\text{Zr}_{2.00}\text{Fe}_{0.58}[\text{Fe}_{0.40}\text{Mn}_{1.40}]\text{Zr}_{2.12}[\text{Zr}_{2.99}\text{Nb}_{0.07}\text{Ti}_{0.34}]\text{Zr}_{3.00}[\text{Si}(7)_{1.37}\text{Nb}_{0.63}]\text{Zr}_{2.00} \dots$ Johnsen, Grice, 1999
- 20 Eudialyte-R $\bar{3}m$
No 13
Amdrupfjord
Kangerdluarsuq
E. Greenland
It was approved by the CNMNC as new mineral
Kentbrooksite
 $\text{Na}_{15.6}\text{K}_{0.3}\text{Ca}_{3.3}\text{Sr}_{0.2}\text{REE}_{1.1}\text{Y}_{0.4}\text{Fe}_{0.7}\text{Mn}_{1.8}\text{Mg}_{0.1}\text{Zr}_{3.0}\text{Hf}_{0.1}\text{Ti}_{0.2}\text{Nb}_{0.6}\text{Al}_{0.1}\text{Si}_{25.1}\text{Cl}_{0.3}\text{F}_{1.5}\text{H}_{1.2} \dots$ [Σ anions = 78.10]
 $\{\text{Na}(1)_{2.90}\text{REE}_{0.10}\}\text{Zr}_{3.00}\text{Na}(2)_{2.37}[\text{Na}(3)_{2.82}\text{REE}_{0.18}]\text{Zr}_{3.00}[\text{Na}(4)_{1.86}\text{REE}_{0.66}\text{K}_{0.30}\text{Sr}_{0.16}]\text{Zr}_{3.00}\text{Na}(5)_{3.02} \times$
 $\times [\text{Ca}_{3.37}\text{Mn}_{1.79}\text{REE}_{0.41}\text{Y}_{0.43}]\text{Zr}_{2.00}\text{Fe}_{0.29}[\text{Fe}_{0.45}\text{Mn}_{1.90}\text{Al}_{0.14}]\text{Zr}_{2.58} \times$
 $\times [\text{Zr}_{2.82}\text{Hf}_{0.05}\text{Ti}_{0.13}]\text{Zr}_{3.00}\text{Si}(7)_{1.85}\text{Si}(7a)_{0.26}[\text{Nb}_{0.55}\text{Zr}_{0.13}\text{Ti}_{0.06}]\text{Zr}_{2.06} \dots$
 $\text{Na}_{15.3}\text{K}_{0.3}\text{Ca}_{3.3}\text{Sr}_{0.2}\text{La}_{0.5}\text{Ce}_{0.5}\text{Nd}_{0.1}\text{Y}_{0.4}\text{Fe}_{2.7}^{3+}\text{Mn}_{1.3}^{2+}\text{Mg}_{0.1}\text{Zr}_{2.9}\text{Hf}_{0.1}\text{Ti}_{0.2}\text{Nb}_{0.6}\text{Al}_{0.1}\text{Si}_{24.6}\text{Cl}_{0.3}\text{F}_{1.5}\text{H}_{1.6}$
 $[\text{Zr}+\text{Nb}+\text{Ti} = 3.77]$
 $\{\text{Na}(1)_{4.99}\text{REE}_{0.44}\text{Y}_{0.42}\text{K}_{0.30}\text{Sr}_{0.15}\}\text{Zr}_{2.24}[\text{Ca}_{3.27}\text{Mn}_{1.78}\text{REE}_{0.62}\text{Na}_{0.33}]\text{Zr}_{2.00}[\text{Mn}_{1.90}\text{Fe}_{0.72}\text{Al}_{0.13}\text{Mg}_{0.05}]\text{Zr}_{2.89} \times$
 $\times [\text{Zr}_{2.80}\text{Hf}_{0.06}\text{Ti}_{0.13}]\text{Zr}_{3.00}\text{Si}(0)_{2.00}[\text{Nb}_{0.35}\text{Zr}_{0.12}\text{Ti}_{0.10}]\text{Zr}_{2.70}[\text{Si}(0)_{2.70}]\text{Zr}_{2.02}[\text{F}_{1.51}\text{Cl}_{0.27}\text{OH}_{2.27}]\text{Zr}_{2.00} 2.3 \text{ H}_2\text{O}$
[Σ anions = 78.30]
 $\{\text{Na}(1), \text{Na}(2), \text{Na}(3), \text{Na}(5)\}_{212.46}[\text{Na}(4)=\text{Na}_{1.69}\text{REE}_{0.44}\text{Y}_{0.42}\text{K}_{0.30}\text{Sr}_{0.15}]\text{Zr}_{3.00}[M(1)=\text{Ca}_{3.27}\text{Mn}_{1.78}\text{REE}_{0.62}\text{Na}_{0.33}]\text{Zr}_{2.00} \times$
 $\times \{M(2)=\text{Mn}_{1.90}\text{Fe}_{0.52}\text{Al}_{0.13}\text{Mg}_{0.05}\}_{23.00}\{M(2a)=\text{Fe}_{0.27}\text{Cl}_{2.73}\text{Zr}_{3.00}\}\text{Zr}=\text{Zr}_{2.81}\text{Hf}_{0.06}\text{Ti}_{0.13}\}\text{Zr}_{3.00} \times$
 $\times \{M(3)=\text{Nb}_{0.55}\text{Ti}_{0.10}\text{Zr}_{0.12}\text{Cl}_{0.23}\}_{21.00}\{M(4)=\text{Si}_{0.84}\text{Cl}_{0.61}\}_{21.00}\{M(4a)=\text{Si}_{0.26}\text{Cl}_{0.74}\}_{21.00}\{\text{Si}_{24}\text{O}_{72}\}\text{O}_2[\text{F}_{1.51}\text{Cl}_{0.27}\text{OH}_{1.17}]$
 $(\text{Na}, \text{REE})_{1.9}(\text{Ca}, \text{REE})_{0.6}\text{Mn}_{1.3}\text{Nb}_{0.5}\text{Si}_{25}\text{O}_{74}\text{F}_2 \cdot 2\text{H}_2\text{O}$ Johnsen *et al.*, 1998; Grice, 1999
- 21 Eudialyte-R $\bar{3}m$
No 4
Mont Saint-Hilaire
Quebec, Canada
 $\text{Na}_{15.3}\text{K}_{0.2}\text{Ca}_{1.6}\text{Sr}_{0.1}\text{REE}_{0.0}\text{Y}_{0.1}\text{Fe}_{1.1}\text{Mn}_{1.4}\text{Zr}_{2.7}\text{Ti}_{0.1}\text{Nb}_{0.7}\text{Ta}_{0.0}\text{Al}_{0.0}\text{Si}_{25.4}\text{Cl}_{0.4}\text{H}_{1.1} \dots$ [Σ anions = 76.63]
 $\text{Na}(1)_{2.95}\text{Na}(2)_{2.75}[\text{Na}(3)_{2.91}\text{REE}_{0.09}]\text{Zr}_{3.00}[\text{Na}(4)_{2.33}\text{REE}_{0.34}\text{K}_{0.23}\text{Sr}_{0.12}]\text{Zr}_{3.00}\text{Na}(5)_{3.24}[\text{Ca}_{3.70}\text{REE}_{0.29}\text{Mn}_{1.88}\text{Y}_{0.12}]\text{Zr}_{2.00} \times$
 $\times \text{Fe}_{0.90}\{\text{Fe}_{0.55}\text{Mn}_{1.56}\}\text{Zr}_{2.11}[\text{Zr}_{2.76}\text{Ti}_{0.13}\text{Nb}_{0.11}]\text{Zr}_{3.00}[\text{Si}(7)_{1.33}\text{Nb}_{0.67}]\text{Zr}_{2.00} \dots$ Johnsen, Grice, 1999
- 22 Eudialyte-R $\bar{3}m$
No 2
Mont Saint-Hilaire
Quebec, Canada
 $\text{Na}_{14.5}\text{K}_{0.3}\text{Ca}_{4.6}\text{Sr}_{0.1}\text{REE}_{0.0}\text{Y}_{0.2}\text{Fe}_{2.3}\text{Mn}_{1.5}\text{Zr}_{3.0}\text{Hf}_{0.0}\text{Ti}_{0.1}\text{Nb}_{0.6}\text{Ta}_{0.1}\text{Al}_{0.1}\text{Si}_{25.1}\text{Cl}_{0.8}\text{H}_{2.5} \dots$ [Σ anions = 77.67]
 $\text{Na}(1)_{2.77}\text{Na}(2)_{2.93}[\text{Na}(3)_{2.87}\text{REE}_{0.13}]\text{Zr}_{3.00}[\text{Na}(4)_{1.66}\text{REE}_{0.67}\text{K}_{0.30}\text{Ca}_{0.24}\text{Sr}_{0.13}]\text{Zr}_{3.00}\text{Na}(5)_{2.76} \times$
 $\times [\text{Ca}_{4.46}\text{Mn}_{1.23}\text{REE}_{0.14}\text{Y}_{0.17}]\text{Zr}_{2.00}\text{Fe}_{0.32}[\text{Fe}_{0.52}\text{Mn}_{0.69}]\text{Zr}_{2.11}[\text{Zr}_{1.70}\text{Si}(7)_{0.67}\text{Si}(7a)_{0.31}]\text{Nb}_{0.62}\text{Ti}_{0.06}\text{Ta}_{0.04}\text{Zr}_{0.72}[\text{Si}_{0.12}] \dots$ 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:
Khomyakovit
 $\text{Na}_{12.5}\text{K}_{0.4}\text{Ca}_{6.6}\text{Sr}_{2.2}\text{REE}_{0.1}\text{Fe}_{0.1}\text{Mn}_{0.8}\text{Mg}_{0.0}\text{Zr}_{2.9}\text{Hf}_{0.0}\text{Ti}_{0.1}\text{Nb}_{0.3}\text{W}_{0.6}\text{Al}_{0.1}\text{Si}_{24.8}\text{Cl}_{0.6}\text{F}_{1.3} \dots$ [Σ anions = 78.70]
 $\text{Na}(1)_{2.88}\text{Na}(2)_{3.28}[\text{Na}(3)_{2.03}\text{K}_{0.37}\text{Ca}_{0.40}\text{Sr}_{0.19}\text{REE}_{0.08}]\text{Zr}_{3.00}[\text{Na}(4)_{0.40}\text{Sr}_{2.60}]\text{Zr}_{2.00}\text{Na}(5)_{2.99}[\text{Ca}_{0.68}]\text{Fe}_{0.55} \times$
 $\times \text{Fe}_{0.55}\{\text{Fe}_{1.55}\text{Mn}_{0.80}\}\text{Zr}_{2.35}[\text{Zr}_{2.96}\text{Si}(7)_{0.62}\text{Si}(7a)_{0.42}]\text{W}_{0.52}\text{Nb}_{0.31}\}\text{Zr}_{2.03} \dots$
 $\{\text{Na}(1)_{2.26}\text{Ca}_{0.33}\text{K}_{0.38}\text{Sr}_{0.13}\text{REE}_{0.08}\}_{213.05}[\text{Sr}_{2.78}\text{Na}_{0.23}]\text{Zr}_{3.00}[\text{Ca}_{0.68}\text{Fe}_{0.55}\text{Mn}_{0.78}\text{Mg}_{0.03}]\text{Zr}_{2.84}\text{Hf}_{0.03}\text{Ti}_{0.05}]\text{Zr}_{3.02} \times$
 $\times [\text{W}_{0.50}\text{Nb}_{0.34}]\text{Zr}_{2.90}[\text{Si}_{24.78}\text{H}_{2.06}]\text{Zr}_{2.74}\text{O}_3(\text{O}, \text{OH}, \text{H}_2\text{O})_{23.70}(\text{OH}, \text{H}_2\text{O})_{23.00} \dots$ [Σ anions = 78.70]
 $\text{Na}_{12}\text{Sr}_{0.3}\text{Ca}_{6.6}\text{Fe}_{0.1}\text{Zr}_{3.0}\text{W}_{0.5}(\text{OH}, \text{H}_2\text{O})_{23}(\text{O}, \text{OH}, \text{H}_2\text{O})_{23}(\text{OH})_{23}$ Johnsen *et al.*, 1999
- 24 Eudialyte-R $\bar{3}m$
No 3
Mont Saint-Hilaire
Quebec, Canada
 $\text{Na}_{14.9}\text{K}_{0.2}\text{Ca}_{4.7}\text{Sr}_{0.1}\text{REE}_{1.3}\text{Y}_{0.2}\text{Fe}_{1.5}\text{Mn}_{2.2}\text{Zr}_{2.9}\text{Hf}_{0.0}\text{Nb}_{0.8}\text{Ta}_{0.0}\text{Al}_{0.1}\text{Si}_{25.1}\text{Cl}_{1.1}\text{H}_{1.7} \dots$ [Σ anions = 77.90]
 $\text{Na}(1)_{2.76}\text{Na}(2)_{2.99}[\text{Na}(3)_{2.92}\text{REE}_{0.08}]\text{Zr}_{3.00}[\text{Na}(4)_{1.50}\text{REE}_{1.20}\text{K}_{0.24}\text{Sr}_{0.06}]\text{Zr}_{3.00}\text{Na}(5)_{2.91} \times$
 $\times [\text{Ca}_{4.84}\text{Mn}_{0.88}\text{REE}_{0.10}\text{Y}_{0.18}]\text{Zr}_{2.00}\text{Fe}_{0.68}[\text{Fe}_{0.77}\text{Mn}_{1.43}]\text{Zr}_{2.22}[\text{Zr}_{2.99}\text{Si}(7)_{0.80}\text{Si}(7a)_{0.09}]\text{Nb}_{0.78}\text{Ta}_{0.07}]\text{Zr}_{2.00} \dots$ Johnsen, Grice, 1999
- 25 Eudialyte-R $\bar{3}$
No 5
Mont Saint-Hilaire
Quebec, Canada
 $\text{Na}_{15.0}\text{K}_{0.2}\text{Ca}_{1.8}\text{Sr}_{0.0}\text{REE}_{2.1}\text{Y}_{0.2}\text{Fe}_{1.4}\text{Mn}_{3.7}\text{Zr}_{2.2}\text{Hf}_{0.0}\text{Nb}_{0.9}\text{Ta}_{0.0}\text{Al}_{0.1}\text{Si}_{24.8}\text{Cl}_{0.7}\text{H}_{2.4} \dots$ [Σ anions = 78.09]
 $\text{Na}(1)_{2.80}\text{Na}(2)_{3.02}[\text{Na}(3)_{2.82}\text{REE}_{0.18}]\text{Zr}_{3.00}[\text{Na}(4)_{1.44}\text{REE}_{1.35}\text{K}_{0.19}]\text{Zr}_{2.98}\text{Na}(5)_{2.87} \times$
 $\times [\text{Mn}_{2.75}\text{Y}_{0.25}]\text{Zr}_{3.00}[\text{Ca}_{1.77}\text{REE}_{0.57}\text{Na}_{0.66}]\text{Zr}_{3.00}\text{Fe}_{0.28}[\text{Fe}_{1.13}\text{Mn}_{0.95}\text{Zr}_{0.24}]\text{Zr}_{2.32}[\text{Zr}_{2.93}\text{Nb}_{0.05}]\text{Zr}_{2.98}\text{Si}(7)_{0.80}\text{Si}(7a)_{0.20}\text{Nb}_{0.87}$
 $\{\text{Na}(1)=\text{Na}_{2.80}\}\{\text{Na}(2)=\text{Na}_{3.02}\}\{\text{Na}(3)=\text{Na}_{2.82}\text{REE}_{0.18}\}\text{Zr}_{3.00}\{\text{Na}(4)=\text{Na}_{1.44}\text{REE}_{1.35}\text{K}_{0.19}\}\text{Zr}_{3.00}\{\text{Na}(5)=\text{Na}_{2.87}\} \times$
 $\times [\text{M}(1a)=\text{Mn}_{2.75}\text{Y}_{0.25}]\text{Zr}_{3.00}[\text{M}(1b)=\text{Ca}_{1.77}\text{REE}_{0.57}\text{Na}_{0.66}]\text{Zr}_{3.00}\{M(2,4)=\text{Fe}_{0.28}\}\{M(2,5)=\text{Fe}_{1.13}\text{Mn}_{0.95}\text{Zr}_{0.24}\}\text{Zr}_{2.32} \times$
 $\times [\text{Zr}=\text{Zr}_{2.91}\text{Nb}_{0.05}]\text{Zr}_{2.98}\{M(3)=\text{Nb}_{0.87}\}\{\text{Si}(7)=\text{Si}_{0.80}\}\{\text{Si}(7a)=\text{Si}_{0.20}\} \dots$
 $\{\text{Na}_{14.37}\text{REE}_{1.25}\text{K}_{0.20}\text{Ca}_{1.80}\}\text{Zr}_{2.13}[\text{Ca}_{1.77}\text{REE}_{0.59}\text{Na}_{0.66}]\text{Zr}_{3.00}[\text{Mn}_{2.75}\text{Y}_{0.24}]\text{Zr}_{3.00}\{\text{Fe}_{1.43}\text{Mn}_{0.95}\text{Zr}_{0.24}\}\text{Zr}_{2.32} \times$
 $\times [\text{Zr}_{2.99}\text{Nb}_{0.05}\text{Hf}_{0.05}]\text{Zr}_{3.00}[\text{Nb}_{0.85}\text{Ta}_{0.02}]\text{Zr}_{2.87}[\text{Si}_{24.77}\text{Al}_{0.12}]\text{Zr}_{2.89}\text{O}_3(\text{O}, \text{OH}, \text{H}_2\text{O})_{23.00}\text{OH}_{1.27}\text{Cl}_{0.73} \text{ (Σ anions = 78.09)}$
 $\text{Na}_{12}\text{Sr}_{0.3}\text{Ca}_{6.6}\text{Fe}_{0.1}\text{Zr}_{3.0}\text{W}_{0.5}(\text{OH}, \text{H}_2\text{O})_{23}(\text{O}, \text{OH}, \text{H}_2\text{O})_{23}(\text{OH})_{23}$ Johnsen *et al.*, 1999
- 26 Eudialyte-R $\bar{3}m$
No 16
Khibiny
Kola Peninsula
 $\text{Na}_{14.5}\text{K}_{0.3}\text{Ca}_{5.1}\text{Sr}_{0.7}\text{Ba}_{0.0}\text{REE}_{1.1}\text{Y}_{0.2}\text{Fe}_{1.1}\text{Mn}_{2.5}\text{Zr}_{2.9}\text{Hf}_{0.0}\text{Ti}_{0.0}\text{Nb}_{0.9}\text{Ta}_{0.0}\text{Si}_{24.5}\text{Cl}_{0.5}\text{H}_{2.7} \dots$ [Σ anions = 78.53]
 $\text{Na}(1)_{2.94}\text{Na}(2)_{2.79}\text{Na}(3)_{3.15}[\text{Na}(4)_{0.96}\text{REE}_{0.74}\text{K}_{0.33}\text{Sr}_{0.72}\text{Y}_{0.25}]\text{Zr}_{3.00}\text{Na}(5)_{2.99}[\text{Ca}_{4.95}\text{Mn}_{0.67}\text{REE}_{0.38}]\text{Zr}_{2.00} \times$
 $\times \text{Fe}_{0.26}[\text{Fe}_{0.79}\text{Mn}_{1.83}]\text{Zr}_{2.62}[\text{Zr}_{2.96}\text{Si}(7)_{0.82}\text{Si}(7a)_{0.11}\text{Nb}_{0.95}] \dots$ Johnsen, Grice, 1999
- 27 Eudialyte-R $\bar{3}m$
No 17
Burlapa massif
N. Baikal region
 $\text{Na}_{12.9}\text{K}_{0.3}\text{Ca}_{3.4}\text{Sr}_{0.0}\text{Ba}_{0.0}\text{REE}_{1.2}\text{Y}_{0.3}\text{Fe}_{1.3}\text{Mn}_{2.2}\text{Mg}_{0.1}\text{Zr}_{3.1}\text{Hf}_{0.6}\text{Ti}_{0.4}\text{Nb}_{0.5}\text{Al}_{0.0}\text{Si}_{24.9}\text{Cl}_{0.9}\text{F}_{1.3} \dots$ [Σ anions = 78.09]
 $\{\text{Na}(1)_{2.90}\text{REE}_{0.05}\}\text{Zr}_{2.95}\text{Na}(2)_{2.51}[\text{Na}(3)_{2.84}\text{REE}_{0.16}]\text{Zr}_{3.00}[\text{Na}(4)_{1.60}\text{K}_{0.28}\text{REE}_{0.43}\text{Sr}_{0.56}\text{Ba}_{0.04}]\text{Zr}_{3.00}\text{Na}(5)_{2.91} \times$
 $\times [\text{Ca}_{3.50}\text{Mn}_{1.51}\text{REE}_{0.49}\text{Y}_{0.50}]\text{Zr}_{2.00}\text{Fe}_{0.31}[\text{Fe}_{0.37}\text{Mn}_{0.66}\text{Al}_{0.42}\text{Ti}_{0.24}]\text{Zr}_{2.69}[\text{Zr}_{2.89}\text{Ti}_{0.11}]\text{Zr}_{3.00}[\text{Si}_{0.93}\text{Nb}_{0.45}\text{Al}_{0.42}\text{Zr}_{0.20}]\text{Zr}_{2.00} \dots$
 $\text{Na}_{13.3}\text{K}_{0.2}\text{Ca}_{4.4}\text{Sr}_{1.1}\text{Fe}_{2.0}\text{Mn}_{1.4}\text{REE}_{0.2}\text{Zr}_{3.1}\text{Hf}_{0.0}\text{Ti}_{0.2}\text{Nb}_{0.7}\text{Si}_{25.4}\text{O}_{76.8}\text{Cl}_{0.9}$ [Σ cations = 53]
 $\text{Na}_{12}\{\text{Sr}_{1.80}\text{Na}_{0.96}\text{K}_{0.24}\}\text{Zr}_{3.00}[\text{Fe}_{1.99}\text{Mn}_{0.67}\text{Ti}_{0.20}\text{Zr}_{0.10}\text{Hf}_{0.04}]\text{Zr}_{3.00}[\text{Ca}_{4.85}\text{Mn}_{0.85}\text{REE}_{0.30}]\text{Zr}_{2.00}[\text{Zr}_{3.00}\text{Si}(0)_{2.70}]\text{Si}[\text{Si}_{0.3}\text{Nb}_{0.7}]\text{Zr}_{2.00} \times$
 $\times [\text{Si}_{0.9}]\text{Zr}_{2.00}[\text{Si}_{0.9}\text{O}_{24}(\text{OH}, \text{O})_3\text{OH}_{3.92}\text{Cl}_{1.1} 1 \text{ H}_2\text{O}]$ Johnsen *et al.*, 2000
- 28 Fe, Sr-analogue of kentbrooksite
R $\bar{3}m$
Alluaiv Mt.
 $\text{Na}_{15.0}\text{K}_{0.3}\text{Ca}_{5.5}\text{Sr}_{0.0}\text{REE}_{0.4}\text{Y}_{0.1}\text{Fe}_{3.2}\text{Mn}_{0.2}\text{Zr}_{2.9}\text{Hf}_{0.0}\text{Nb}_{0.2}\text{Ta}_{0.0}\text{Al}_{0.2}\text{Si}_{25.7}\text{Cl}_{1.2}\text{H}_{2.0}$ [Σ anions = 76.75]
 $\text{Na}(1)_{5.92}[\text{Na}(4)_{4.92}\text{K}_{0.31}\text{Ca}_{0.27}\text{Ca}_{0.44}\text{Sr}_{0.06}]\text{Zr}_{2.00}\text{Na}(5)_{2.20}[\text{Ca}_{5.15}\text{Fe}_{0.23}\text{Mn}_{0.24}\text{REE}_{0.22}\text{Y}_{0.14}]\text{Zr}_{2.00}\text{Fe}_{0.22}\text{Fe}_{0.46} \times$
 $\times [\text{Zr}_{2.93}\text{Nb}_{0.02}\text{Hf}_{0.02}]\text{Zr}_{3.00}[\text{Si}_{1.85}\text{Nb}_{0.15}]\text{Zr}_{2.00} \dots$ Johnsen, Grice, 1999

- 29 *Ferrokentbrooksite*
R3m
Mont Saint-Hilaire
Quebec, Canada
 $\{Na_{13.05}REE_{0.99}K_{0.32}Ca_{0.23}Sr_{0.15}\}_{\Sigma 14.74}\{Ca_{4.59}Mn_{1.24}Y_{0.17}\}_{\Sigma 6.00}\{Fe_{2.39}Mn_{0.61}\}_{\Sigma 3.00}\{Zr_{3.06}Ti_{0.44}Hf_{0.03}\}_{\Sigma 3.07} \times$
 $\times \{Nb_{0.64}Si_{0.23}Zr_{0.07}Ta_{0.02}\}_{\Sigma 0.96}\{Si_{24.93}Al_{0.07}\}_{\Sigma 25.00}O_{73}(O, OH, H_2O)_{\Sigma 22.47}\{Cl_{0.89}F_{0.70}OH_{0.40}\}_{\Sigma 2.00} (\Sigma \text{ anions} = 77.47)$
 $Na_{15}Ca_6(Fe, Mn)_3Zr_3NbSi_{25}O_{73}(O, OH, H_2O)_3(Cl, F, OH)_2$ Johnsen *et al.*, 2003₂
- 30 *Mangankhomyakovite*
R3m
Mont Saint-Hilaire
Quebec, Canada
 $\{Na_{11.51}Ca_{0.25}K_{0.30}Sr_{0.04}REE_{0.07}\}_{\Sigma 12.17}Sr_3\{Ca_6\}\{Mn_{0.04}Fe_{1.23}\}_{\Sigma 23.27}\{Zr_{2.91}Hf_{0.03}Ti_{0.01}\}_{\Sigma 2.95}\{W_{0.66}Nb_{0.41}Ta_{0.01}\}_{\Sigma 1.08} \times$
 $\times \{Si_{24.60}Al_{0.01}\}_{\Sigma 24.61}O_{73}(O, OH, H_2O)_{\Sigma 23.76}\{OH_{1.19}Cl_{0.81}\}_{\Sigma 2.00} \dots (\Sigma \text{ anions} = 78.70)$
 $Na_{15}Sr_3Ca_3Mn_3Zr_3W(Si_{25}O_{73})(O, OH, H_2O)_3(OH)_2$ Johnsen *et al.*, 1999₂
- 31 *Carbokentbrooksite*
R3m
Dara-i-Pioz,
Tajikistan
 $Na_{10.8}K_{0.4}Ca_{6.2}Sr_{0.5}Fe_{0.1}Mn_{0.2}La_{0.4}Ce_{0.6}Pr_{0.1}Nd_{0.2}Y_{0.1}Zr_{3.0}Ti_{0.2}Nb_{0.9}Si_{25.0}O_{77.6}Cl_{0.3}(CO_3)_{0.6} \cdot 4.3H_2O [Si = 25]$
 $\{N_1=Na_{2.41}\}\{N_2=Na_{2.31}Ca_{0.45}K_{0.18}\}_{\Sigma 2.94}\{N_3=Na_{2.37}Ca_{0.45}K_{0.18}\}_{\Sigma 2.67}\{N_4=La_{0.36}Ce_{0.60}Pr_{0.03}Nd_{0.15}Na_{1.39}Sr_{0.45}\}_{\Sigma 3.00} \times$
 $\times \{N_5=Na_{2.34}\}\{M_1=Ca_{5.34}Mn_{0.54}Y_{0.12}\}_{\Sigma 6.00}\{M_2=Mn_{1.08}Fe_{1.02}\}_{\Sigma 2.10}\{Z=Zr_{2.96}Ti_{0.04}\}_{\Sigma 3.00}\{M_3=Nb_{0.88}Ti_{0.13}\}_{\Sigma 1.01} \times$
 $\times \{M_4=Si\}\{Si_3O_9\}_2\{Si_6O_{27}\}_2\{O, OH, H_2O\}_3\{X_1=C_{0.38}Cl_{0.27}\}\{X_2=O\}$
 $(Na, \square)_{12}(Ca, Ce)_3Ca_6Mn_3Zr_3Nb(Si_{25}O_{73})(OH)_3(CO_3) \cdot H_2O$ Khomyakov *et al.*, 2003
- 32 *Zirsilite-Ce*
R3m
Dara-i-Pioz,
Tajikistan
 $Na_{10.1}K_{0.3}Ca_{6.2}Sr_{0.4}Fe_{0.9}Mn_{0.6}La_{0.5}Ce_{0.8}Pr_{0.1}Nd_{0.2}Y_{0.1}Zr_{2.8}Ti_{0.2}Nb_{0.9}Si_{25.0}O_{75.9}Cl_{0.3}(CO_3)_{0.4} \cdot 5.5H_2O [Si = 25]$
 $\{N_1=Na_{2.68}\}\{N_2=Na_{2.27}Ca_{0.42}K_{0.17}\}_{\Sigma 2.89}\{N_3=Na_{2.12}Ca_{0.40}K_{0.13}\}_{\Sigma 2.67}\{N_4=La_{0.47}Ce_{0.76}Pr_{0.06}Nd_{0.16}Na_{1.12}Sr_{0.43}\}_{\Sigma 3.00} \times$
 $\times \{N_5=Na_{1.94}\}\{M_1=Ca_{5.36}Mn_{0.50}Y_{0.34}\}_{\Sigma 6.00}\{M_2=Si\}_{\Sigma 3.00}\{Z=Zr_{2.80}Ti_{0.18}\}_{\Sigma 2.98}\{M_3=Nb_{0.93}\}\{M_4=Si\} \times$
 $\times \{Si_3O_9\}_2\{Si_6O_{27}\}_2\{O, OH, H_2O\}_3\{X_1=C_{0.43}Cl_{0.30}\}\{X_2=O\}$
 $(Na, \square)_{12}(Ca, Na)_3Ca_6Mn_3Zr_3Nb(Si_{25}O_{73})(OH)_3(CO_3) \cdot H_2O$ Khomyakov *et al.*, 2003
- 33 *Taseqite*
Ilmaussaq
S. Greenland
 $\{Na_{8.8}Sr_{4.8}K_{2.0}Ce_{0.2}\}_{\Sigma 13.78}\{Ca_{5.17}Mn_{0.59}Y_{0.09}\}_{\Sigma 5.85}\{Fe_{1.93}Mn_{0.92}\}_{\Sigma 2.85}\{Ti_{0.66}Nb_{0.11}Hf_{0.05}\}_{\Sigma 3.00} \times$
 $\times \{Nb_{1.06}Ta_{0.04}Sn_{0.03}\}_{\Sigma 1.13}\{Si_{24}O_{73}\}\{O_{1.65}(OH)_{0.75}(H_2O)_{0.74}\}_{\Sigma 3.14}\{Cl_{1.91}(OH)_{0.09}\}_{\Sigma 2.00} (\Sigma \text{ anions} = 78.14)$
 $Na_{12}Sr_3Ca_6Fe_6Zr_3NbSi_{25}O_{73}(O, OH, H_2O)_3Cl_2$ Petersen *et al.*, 2004
- 34 *Feklichevite*
R3m
Kovdor massif
Kola Peninsula
 $Na_{11.1}Ca_{0.8}Sr_{0.1}Fe^{2+}_{0.9}Fe^{3+}_{1.2}Mn_{0.2}La_{0.0}Ce_{0.0}Zr_{2.9}Hf_{0.1}Ti_{0.1}Nb_{0.6}Si_{25.3}O_{74.1}(OH)_{2.4}Cl_{0.5}F_{0.2} \cdot 1.7H_2O$
 $[Si + Zr + Hf + Ti + Nb + Mn = 29]$
 $Na_{10.80}\{Ca_{2.35}Na_{0.33}Sr_{0.08}Ce_{0.03}La_{0.02}\}_{\Sigma 2.81}\{Ca_6\}\{Fe^{3+}_{1.21}Fe^{2+}_{0.87}\}_{\Sigma 2.08}\{Zr_{2.85}Hf_{0.09}Ti_{0.05}\}_{\Sigma 2.99}Nb_{0.55} \times$
 $\times \{Si_{25.25}Mn_{0.21}\}_{\Sigma 25.46}O_{73}\{(OH)_{1.12}O_{0.26}(H_2O)_{1.67}\}_{\Sigma 3.05}\{(OH)_{1.25}Cl_{0.3}F_{0.19}\}_{\Sigma 2.00}$
 $\{Na(1)=Na_{1.80}\}\{Na(2)=Na_3\}\{Na(3)=Na_3\}\{Na(4)=Ca_{2.35}Na_{0.33}Sr_{0.08}REE_{0.05}\}_{\Sigma 2.81}\{Na(5)=Na_3\} \times$
 $\times \{Ca_6\}\{M(2,4)=Fe_{0.92}\}\{M(2,6)=Fe_{1.16}\}\{Zr=Zr_{2.85}Hf_{0.09}Ti_{0.05}\}\{M(3)=Nb_{0.55}\}\{M(3a)=Si_{0.45}\} \times$
 $\times \{Si(7)=Si_{0.75}\}\{Si(7a)=Mn_{0.21}Si_{0.03}\}_{\Sigma 0.26} \dots$
 $Na_{11}Ca_9(Fe^{3+}, Fe^{2+})_2Zr_3Nb(Si_{25}O_{73})(OH, H_2O, Cl, O)_5$
 $\{Na_{9.87}Ca_{0.05}K_{0.24}Ce_{0.06}La_{0.03}\}_{\Sigma 14.25}\{Ca_6\}\{Fe^{3+}_{1.69}Fe^{2+}_{0.50}Mn_{0.29}\}_{\Sigma 2.48}\{Zr_{2.97}\}\{Nb_{0.60}Si_{0.66}Al_{0.08}\}_{\Sigma 1.34}\{Si_{24}O_{72}\} \times$
 $\times (OH)_{2.37}(CO_3)_{1.05}Cl_{0.21} \cdot 1.0H_2O [Si = 24.66]$
 $(Na, Ca)_{10}Ca_9(Fe^{3+}, Fe^{2+})_2Zr_3Nb(Si_{25}O_{72})(OH)_3(CO_3)(H_2O)$ Rastsvetaeva *et al.*, 1999₁; Pekov *et al.*, 2001
- 35 *Golyshkevite*
R3m
Kovdor massif
Kola Peninsula
 $\{Na_{9.87}Ca_{0.05}K_{0.24}Ce_{0.06}La_{0.03}\}_{\Sigma 14.25}\{Ca_6\}\{Fe^{3+}_{1.69}Fe^{2+}_{0.50}Mn_{0.29}\}_{\Sigma 2.48}\{Zr_{2.97}\}\{Nb_{0.60}Si_{0.66}Al_{0.08}\}_{\Sigma 1.34}\{Si_{24}O_{72}\} \times$
 $\times (OH)_{2.37}(CO_3)_{1.05}Cl_{0.21} \cdot 1.0H_2O [Si = 24.66]$
 $(Na, Ca)_{10}Ca_9(Fe^{3+}, Fe^{2+})_2Zr_3Nb(Si_{25}O_{72})(OH)_3(CO_3)(H_2O)$ Chukanov *et al.*, 2005; Rozenberg *et al.*, 2005
- 36 *Mogovidite*
R3m
Kovdor massif
Kola Peninsula
 $\{Na_{9.02}Ca_{0.43}K_{0.30}\}_{\Sigma 9.75}\{Ca_{5.92}Ce_{0.05}La_{0.03}\}_{\Sigma 6.00}\{Fe^{3+}_{1.46}Fe^{2+}_{0.58}Mn_{0.30}\}_{\Sigma 2.34}\{Zr_{3.02}Ti_{0.09}\}\{Nb_{0.40}Si_{0.71}\}_{\Sigma 1.11}\{Si_{24}O_{72}\} \times$
 $\times (OH)_{2.86}(CO_3)_{1.03}Cl_{0.46} \cdot 0.74H_2O [Si = 24.71]$
 $Na_9(Ca, Na)_6Ca_6(Fe^{3+}, Fe^{2+})_2Zr_3Si_{25}O_{72}(CO_3)(OH, H_2O)_4$ Chukanov *et al.*, 2005
- 37 *High-tantalum eudialyte-R3m*
Poços de Caldas
Brazil
 $Na_{11.9}K_{0.7}Ca_{5.5}Sr_{0.3}Ba_{0.1}Fe_{1.3}Mn_{1.3}REE_{0.1}Zr_{3.3}Hf_{0.1}Ti_{0.2}Nb_{0.05}Ta_{0.8}W_{0.15}Si_{24.7}Al_{0.3}O_{73.4}Cl_{1.0}$
 $\{Na_{1.9}K_{0.6}Mn_{0.3}Ba_{0.1}Ce_{0.1}\}\{Na_{2.7}Sr_{0.3}\}\{Na_3\}\{Ca_{5.28}Mn_{0.72}\}\{Fe^{3+}_{1.35}Fe^{2+}_{1.14}Ta_{0.51}\}\{Zr_{2.85}Hf_{0.15}\} \times$
 $\times \{Si_{27.78}^{VI}Nb_{0.13}^{VI}W_{0.09}\}\{Si_{0.5}Al_{0.3}Ti_{0.2}\}\{Si_{24}O_{72}\}\{O, (OH)_{3.54}\}\{Cl_{1.2}H_2O\}$
 $\{Na(1)=^{VIII}Na_3\}\{Na(2a)=^{IX}Na_{1.8}\}\{Na(2b)=^{VIII}Na_{1.2}\}\{Na(3a)=^VNa_{0.6}\}\{Na(3b)=^{IV}Na_{1.38}\} \times$
 $\times \{Na(4)=^{IV}(Na_{1.9}K_{0.6}Mn_{0.3}Ba_{0.1}Ce_{0.1})\}_{\Sigma 3}\{Na(5)=^{XI}(Na_{2.7}Sr_{0.3})\}\{^{VI}(Ca_{5.28}Mn_{0.72})\}\{^{IV}Ta_{0.51}\}\{^{VI}Fe_{1.35}\} \times$
 $\times \{Zr=^{VI}(Zr_{2.85}Hf_{0.15})\}\{M(3)=^{VI}(Nb_{0.13}W_{0.09})\}\{M(3)=^{IV}(Si_{0.5}Al_{0.3})\}\{Si(7a)=^{IV}Si_{0.35}Si(7b)=^{IV}Si_{0.43}\}\{^{VI}Ti_{0.2}\} \times$
 $\times \{Si_{24}O_{72}\}\{(OH, O)_3\}_{\Sigma 3.54}Cl_{0.8} \cdot 1.2H_2O$ Rastsvetaeva *et al.*, 2003
- 38 *Hyperzirconium eudialyte-R3m*
 $\{Na_{15.87}K_{0.30}Sr_{0.33}\}\{Ca_{2.7}Mn_{1.4}Fe_{1.0}Na_{0.85}Ce_{0.35}Sr_{0.12}\}_{\Sigma 6}\{Zr_{1.2}Fe_{0.3}Na_{0.87}(OH)_{1.5}\}\{Zr_3\} \times$
 $\times \{Si_{0.5}Al_{0.5}\}\{Si_{0.5}(Ti_{0.3}Nb_{0.2})\}\{Si_3O_9\}_2\{Si_6O_{27}\}_2\{O, OH\}_{1.5}(OH)_{2.5}Cl_{0.5} \cdot H_2O$ Rastsvetaeva, Khomyakov, 2000₂
- 39 *Alluaivite*
R 3m, 2c
Alluaiv Mt.
Lovozero
 $Na_{17.5}K_{0.2}Ca_{4.5}Sr_{0.3}Ba_{0.1}Mn_{1.5}La_{0.0}Ce_{0.1}Zr_{0.05}Ti_{2.2}Nb_{0.9}Si_{25.8}O_{73.7}Cl_{0.7} \cdot 5.5H_2O [\Sigma \text{ cations} = 53]$
 $\{Na_{17.47}K_{0.12}Sr_{0.28}Ba_{0.11}La_{0.03}Ce_{0.14}\}_{\Sigma 18.15}\{Ca_{4.46}Mn_{1.47}Fe_{1.03}\}_{\Sigma 6.93}\{Ti_{2.18}Nb_{0.85}Zr_{0.05}\}_{\Sigma 3.08}\{Si_{25.82}O_{73.26}\}_{\Sigma 66} \cdot 2H_2O$
 $\{Na_{19}, Sr_{0.3}REE_{0.1}\}_{\Sigma 19.5}\{Ca_{4.5}Mn_{1.5}\}_{\Sigma 6}\{Ti_{2.2}Nb_{0.7}\}_{\Sigma 3}\{Si_3O_9\}_2\{Si_{10}O_{28}\}_2\{Cl_{0.8}(H_2O)_{1.6}K_{0.1}\}_{\Sigma 24.45}$
 $Na_{19}(Ca, Mn)_6(Ti, Nb)_3Si_{26}O_{74}Cl_2 \cdot 2H_2O$
 $Na_{38}(Ca, Mn)_{12}(Ti, Nb)_6Si_{52}O_{148}Cl_2 \cdot 4H_2O$ Khomyakov *et al.*, 1990₁; Khomyakov *et al.*, 2007
- 40 *Ti-eudialyte*
R3m, 2c
Alluaiv Mt.
Lovozero
 $Na_{34.4}Ca_{8.5}Sr_{0.8}Ce_{1.1}Mn_{2.1}Fe_{0.9}Zr_{3.6}Ti_{2.4}Si_{50.7}Al_{0.4}O_{144}Cl_{0.9}(OH)_{5.7} \cdot 1.5H_2O (Nb_{0.8} \text{ omitted})$
Modular structure (two blocks):
 $\{Na_{14.4}Sr_{0.4}\}_{\Sigma 15}\{Na_{1.3}(Ti, Fe)_{0.7}\}_{\Sigma 2}\{Ca_{4.8}Mn_{1.2}\}_{\Sigma 6}\{Zr_{2.3}Ti_{0.7}\}\{Si_{1.6}Al_{0.4}\}_{\Sigma 2}\{Si_3O_9\}_2\{Si_6O_{27}\}_2\{Cl_{0.2}(OH)_{1.7}\} +$
 $+ \{Na_{14.5}Ce_{0.5}\}_{\Sigma 15}\{Na_{2.1}Sr_{0.4}Fe_{0.5}Ce_{0.2}\}_{\Sigma 3}\{Ca_{3.7}Na_{1.9}Ce_{0.4}\}\{Ti_{1.7}Zr_{1.3}\}\{Si_{1.1}Mn_{0.9}\}_{\Sigma 2}\{Si_3O_9\}_2\{Si_6O_{27}\}_2\{Cl_{0.7}(OH)_{1.7} \cdot 1.5H_2O$
In General:
 $\{Na(1)Na(2)Na(3)Na(4)Na(5a)Na(5b)Na(6)Na(7)Na(8a)Na(8b)Na(9a)Na(9b)\}\{M(5)=Na_{0.67}Ce_{0.23}\} \times$
 $\times \{M(6)=Na_{2.6}Sr_{0.4}\}\{M(7)=Na_{1.83}Ce_{0.27}\}\{M(8)=Na_{0.94}Ce_{0.23}\}\{M(9)=Na_{1.46}Sr_{0.37}\}\{M(3)=Ca_{4.77}Mn_{1.23}\}_{\Sigma 6} \times$
 $\times \{M(4)=Ca_{3.7}Na_{1.87}Ce_{0.12}\}_{\Sigma 6}\{Ti, Fe\}_{\Sigma 2}\{Na(10)=Na_{1.33}(OH)_{1.0}\}\{M(1)=Zr_{2.33}Ti_{0.67}\}\{M(2)=Ti_{1.7}Zr_{1.3}\} \times$
 $\times \{Ti(1a)=Si_{0.2}\}\{Ti(1b)=Si_{0.8}\}\{Ti(2a)=Si_{0.16}\}\{TM=Si_{0.4}Al_{0.4}\}\{Ti(3a)=Mn_{0.9}\}\{Ti(3b)=Si_{0.1}\}\{Ti(4a)=Si_{0.8}\}\{Ti(4b)=Si_{0.2}\} \times$
 $\times \{Si(1)_3O_9\}\{Si(2)_3O_9\}\{Si(3)_6Si(7)_3O_{27}\}\{Si(4)_6Si(8)_3O_{27}\}\{Si(5)_3O_9\}\{Si(6)_3O_9\} \times$
 $\times \{Si(9)_6Si(11)_3O_{27}\}\{Si(12)_6Si(10)_3O_{27}\}Cl(1-2)OH(1-9)H_2O(1-4)$
 $(Na_{34.2}K_{0.1}Ca_{8.6}Sr_{0.8}Ba_{0.1}REE_{1.4}Mn_{2.2}Fe^{2+}_{0.9}Zr_{2.6}Ti_{3.3}Nb_{0.8}Si_{51.0}Al_{0.23}O_{144}(OH)_{6.5}Cl_{1.0} \cdot 1.3H_2O [\Sigma \text{ cations} = 106]$
 $\{N(1)=Na_{3.0}\}\{N(1)^*=Na_{2.75}Ce_{0.27}\}\{N(2)=Na_{3.0}\}\{N(2)^*=Na_{2.68}Ce_{0.23}\}\{N(3)=Na_{3.0}\}\{N(3)^*=Na_{2.6}Sr_{0.4}\} \times$
 $\times \{N(4)=Na_{3.0}\}\{N(4)^*=Na_{3.0}\}\{N(5)=Na_{2.97}\}\{N(5)^*=Na_{3.0}\}\{M(1)=Ca_{3.7}Na_{1.87}Ce_{0.12}\}_{\Sigma 6}\{M(1)^*=Ca_{4.77}Mn_{1.23}\}_{\Sigma 6} \times$
 $\times \{M(2)=Fe_{0.23}\}\{N(6)=Na_{1.46}Sr_{0.37}\}_{\Sigma 6}\{N(7)=Na_{0.67}Ce_{0.23}\}_{\Sigma 6}\{M(2)^*+N(7)^*=Na_{1.33}Ti_{1.0}Fe_{0.67}\}_{\Sigma 6} \times$
 $\times \{M(3)=Si_{0.67}Al_{0.33}\}_{\Sigma 6}\{M(3)^*=Mn_{0.9}Si_{0.1}\}_{\Sigma 6}\{M(4)=Si_{1.0}\}\{M(4)^*=Si_{0.8}\} \times$
 $\times \{Z=Zr_{2.0}Ti_{0.7}Nb_{0.3}\}_{\Sigma 3}\{Z^*=Ti_{1.7}Zr_{1.0}Nb_{0.3}\}_{\Sigma 3} \dots$
 $\{^{VI-IX}(Na_{15.0})\}\{^{VI-XI}(Na_{14.1}Ce_{0.5}Sr_{0.4})\}\{^{VII}(Ca_{3.73}Na_{1.87}Ce_{0.4})\}\{^{VIII}(Ca_{4.77}Mn_{1.23})\}\{^{IV-VIII}(Na_{21.13}Sr_{0.37}Fe_{0.27}Ce_{0.23})\} \times$
 $\times \{^{IV-VII}(Na_{1.33}Ti_{1.0}Fe_{0.67})\}\{^{VI}(Zr_{2.0}Ti_{0.7}Nb_{0.3})\}\{^{VII}(Ti_{1.7}Zr_{1.0}Nb_{0.3})\}\{^{IV}(Si_{0.67}Al_{0.33})\} \times$
 $\times \{^{IV}Mn_{0.9}^{IV}Si_{0.1}\}\{^{IV}Si\}\{Si_{48}O_{144}\}(OH)_{6.2}(H_2O)_{1.3}Cl_{0.9}$
 $Na_{30}(Ca, Na, Ce, Sr)_{12}(Na, Mn, Fe, Ti)_6Zr_3Ti_3MnSi_{51}O_{144}(OH, H_2O, Cl)_9$ Khomyakov *et al.*, 2007

It was approved by the CNMNC as new mineral: *Dualite*

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 detalization (inside of square brackets – [] – carcass elements are printed; inside of braces – { } – “extracarass” 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.

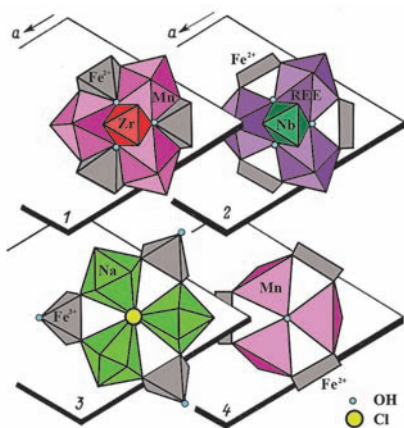


Fig. 3. Statistically possible well-ordered distribution of "additional" cations in M_1 , M_2 and M_3 polyhedra in the structurally maximum ordered eucolite (by the example of barsanovite). 1 – rigid cluster consists of: Zr^{4+} -octahedron, Fe^{3+} -apex polyhedron and Na 8-apex polyhedron occupied 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 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, $Si_{1.86}Nb_{0.12}$ 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: $[Si(7,7a), M(3,3a,3b)] = Si_{1.3}Nb_{0.63}$ 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, $Si(7) = 0.85$, $Si(7a) = 0.26$, $M(3) = Nb_{0.55}Zr_{0.13}Ti_{0.06}$ 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).

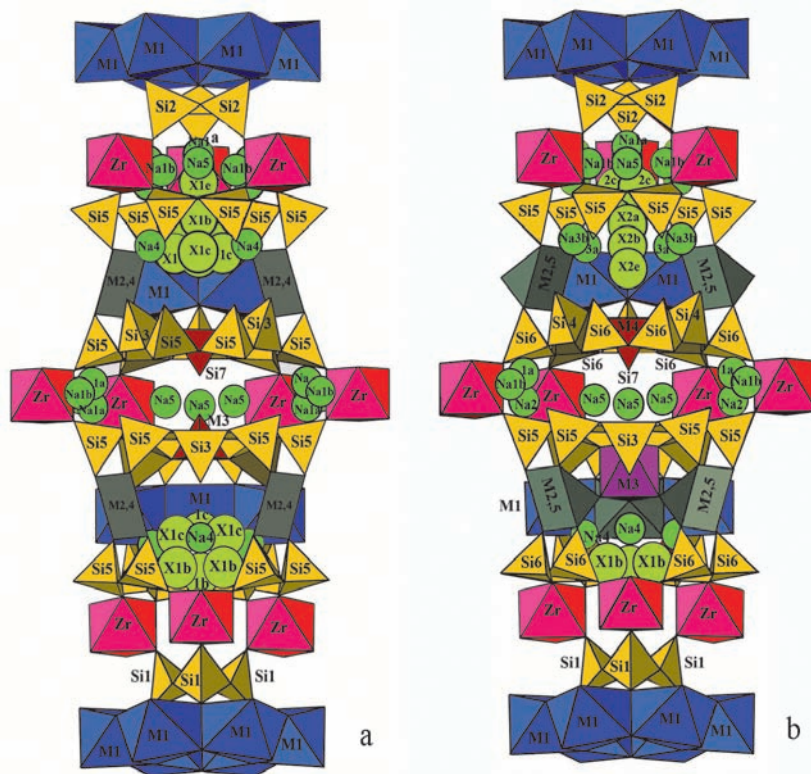


Fig. 4. Crystal structures of centrosymmetrical $R\bar{3}m$ (a) and acentrical $R3m$ (b) eudialytes. After O. Johnsen and, J.D. Grice (1999).

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 . Eucolites 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 – *kentbrooksite* (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 *kentbrooksite*. These authors did not bother to refer either to the data on the similar eucolite 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-eucolite 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 eucolite studies, and the term *eucolite*, with no reference to the previous papers and its criticism, they decidedly replaced the *eudialyte-eucolite* isomorphous series by *eudialyte-kentbrooksite* one, pretending they do not understand it is one and the same and that they commit “scientific forgery” (Johnsen, Gault, 1997; Johnsen, Grice, 1999; Johnsen *et al.*, 2003.).

Of course, the appearance of *kentbrooksite* 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 *eucolite*. Perhaps they did not know that the first analysis of eucolite 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 *kentbrooksite* 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 kentbrooksit, and the authors persistently "push" their "new" minerals — khomyakovite, manganokhomyakovite, oneillite (Johnson *et al.*, 1999, 1999₂) into eudialyte-kentbrooksit 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 kentbrooksit 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 kentbrooksit" (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.*, 2003₁; 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 kentbrooksit (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 ferrokentbrooksit appeared abroad (Johnsen *et al.*, 2003₂) (table 1, No 29), which by chemical composition and properties is similar to the "Fe,Cl-analogue of kentbrooksit" 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 kentbrooksit" (table 1, No 28), containing Nb_{0.7}Si_{0.3} in M(3). The niobium content in these specimens is higher than in kentbrooksit. If that is so kentbrooksit 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 *kentbrooksit* 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 predecessors₂; 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; Boki, 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: *ferriferous 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 agpaitic 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.*, 2003; Khomyakov, 2004; Khomyakov *et al.*, 2006), iron in a proper eudialyte Na₁₃Ca₆Fe₃Zr₃Si₃(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.*, 2003₂), *Fe,Cl-analogue of kentbrooksites* (Ekimenkova *et al.*, 2000₄), *Fe,Sr-analogue of kentbrooksites* (Ekimenkova *et al.*, 2000₃), *K-kentbrooksites* (Rastsvetaeva, Khomyakov, 2005), *georgbarsanovites* (Khomyakov *et al.*, 2007), *carbokentbrooksites* (Khomyakov *et al.*, 2003). The same "sheep" is *zirsilite*-Ce¹² (Khomyakov *et al.*, 2003) which differs from carbokentbrooksites only with switched positions of N₄ 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 N₄ position. *Khomyakovite*¹³ and *manganokhomyakovite* (Johnsen *et al.*, 1999₁) "grazing" on the same field, but the "birth-marks" on their skin are made of tungsten and not 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.*, 2003₁). 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), *golyshchevite*¹⁴ (Chukanov *et al.*, 2005; Rozenberg *et al.*, 2005₁) 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" N₃ and N₄, 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% ZrO₂, 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 (CO₃)-group, although "lawmakers" (Johnsen *et al.*, 2003₁) 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: Na₁₅Ca₆Mn₃Zr₇W(Si₂₅O₇₃)(O,OH,H₂O)₃(Cl,F)₂.

¹⁴ — It was proved by means of Nuclear Gamma Resonance — NGR (Mossbauer effect) that Fe³⁺ in the "iron" position in golyshchevite and mogodivite is predominant over Fe²⁺ and occupies octahedron which corresponds to the similar conclusion for eucolites (Pol'shin *et al.*, 1991). Besides these minerals are (CO₃) — dominant in X₁ 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 on 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

$$[N(1)_3N(1^*)_3N(2)_3N(2^*)_3N(3)_3N(3^*)_3N(4)_3N(4^*)_3 \times N(5)_3N(5^*)_3][N(6)_3][N(7)_3][M(2)_3M(2^*)_3] \times [M(3)M(3^*)][M(4)M(4^*)][M(1)_6M(1^*)_6][Z_3Z^*_3] \times$$

$$[Si_3O_9]_2[Si_3O_9]^*{}_2[Si_9O_{27}]_2[Si_9O_{27}]^*{}_2[O,OH,H_2O]_4 \times [O,OH,H_2O]^*{}_4X_2X^*{}_2$$
, 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 it 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

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).

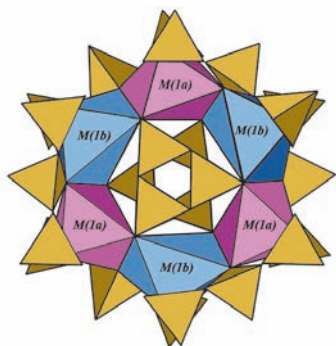


Fig. 5. In the 6-member ring in oneillite crystal structure octahedra M(1a) are smaller [M-O distance 2.227 Å] and occupied with Mn. Octahedra M(1b) are bigger (2.431 Å) and occupied with Ca and REE. After O. Johnsen & J.D. Grice (1999)

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 ($M(1a) = \text{Fe}_{2.2}\text{Ca}_{0.5}\text{Mn}_{0.3}$, $M(1b) = \text{Ca}_{2.7}\text{REE}_{0.3}$ – Ekimenkova *et al.*, 2000₁), and also sodium and other elements ($M(1a) = \text{Mn}_{2.1}\text{Ca}_{0.72}\text{Ce}_{0.18}$, $M(1b) = \text{Na}_{1.35}\text{Ca}_{1.05}\text{Ce}_{0.48}\text{Sr}_{0.15}$ – 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 $\text{Ca}_{2.7}$ and $\text{REE}_{0.3}$, and the other half – $\text{Fe}_{2.2}$ with $\text{Ca}_{0.5}$ and $\text{Mn}_{0.3}$; (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 – $\text{Ca}_{2.1}$ and $\text{REE}_{0.90}$; and (3) “eudialyte with ordered sodium and manganese” (Rastsvetaeva, Khomyakov, 2000₁) (table 1, No 43), where $M(1a) = \text{Mn}_{2.1}\text{Ca}_{0.72}\text{Ce}_{0.18}$ и $M(1b) = \text{Na}_{1.35}\text{Ca}_{1.05}\text{Ce}_{0.45}\text{Sr}_{0.15}$.

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-decationized 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-

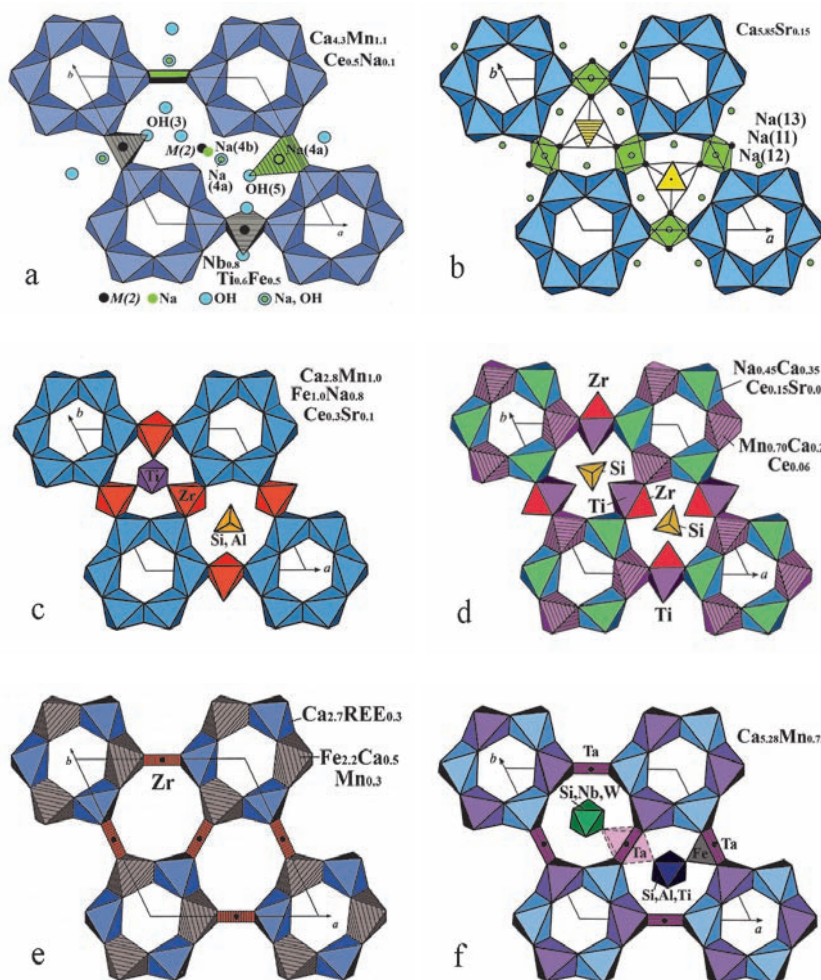


Fig. 6. Occupation of the "iron" position with impurities of different composition and valency. After A.P. Khomyakov (1998), (2001₃), (2002₂), (2000₁), I.A. Ekimenkova et al. (2000₃) and R.K. Rastsvetaeva et al. (2003) respectively. A – various occupancy in the low-ferriferous eudialyte: flat square Fe^{2+} (position $^{[4]}\text{Fe}^{2+}$) occupied with sodium (Na4b), 5-apex polyhedra M(2) (half-octahedra) with additional OH(3)-group, occupied with Fe^{3+} or Mn ($^{[3]}\text{Fe}^{3+}$, $^{[5]}\text{Mn}$), 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" $^{[4]}\text{Fe}$ (cpfu 1.55) and two types of 5-apex polyhedra: M(2a) = $\text{Zr}_{0.63}\text{Na}_{0.57}$ 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" ($^{[4]}\text{Ta}_{0.51}$) (octahedral coordination is also possible) and iron – in 5-apex polyhedra ($^{[5]}\text{Fe}_{1.35}$) 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 MVCVS 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 *eucolite*. Replacement of the comprehensive term eucolite with special terms — *kentbrooksite*, *georgbarsanovite* and the introduction of *eudialyte-kentbrooksite*, *eudialyte-barsanovite* or *eudialyte-georgbarsanovite* series instead of *eudialyte-eucolite* are disrespectful to predecessors contributions to the eudialyte problem study. The eudialyte-eucolite 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 eucolite* and apply "rational" systematization: «CaMnNbF-eucolite», «CaFeNbCl-eucolite» 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-eucolite 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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