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Kyanite of the Bol'shiye Keivy as a complex raw material

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Abstract. The paper discusses the potential of giant kyanite ores deposits of the Bol'shiye Keivy on the Kola Peninsula as a complex of raw materials containing great amounts of nickel sulphide and cobalt with associate gold, titanium minerals (ilmenite and ruthile), graphite, rare metals and earths. It has been shown that resources of the deposits may be doubled with staurolite. The latter is a material of fluxes for metallurgic industry alternative to fluorite. As an example, general characteristics of the New Shuururta kyanite ores deposit have been provided. The latest results in the technology of enrichment and technological processing of kyanite ores have been highlighted.

Аннотация. В статье рассмотрены перспективы гигантских месторождений кианитовых руд Больших Кейв на Кольском полуострове как источника комплексного сырья, содержащего значительные запасы сульфидов никеля и кобальта с попутным золотом, титановых минералов (ильменита и рутила), графита, редких металлов и редких земель. Показано, что запасы месторождений могут быть удвоены за счёт ставролита – альтернативного флюориту источника флюсов для металлургии. В качестве примера дана общая характеристика кианитовых руд месторождения Новая Шуурурта. Освещены последние результаты в технологии обогащения и металлургического передела кианитовых руд.

Key words: Kola Peninsula, Caves, kyanite ores, New Shuururta, mineral structure, chemical compound, technology of enrichment, alumina
Ключевые слова: Кольский полуостров, Кейвы, кианитовые руды, Новая Шуурурта, минеральный состав, химический состав, технология обогащения, глинозем

1. Introduction

Russia is one of the world leaders in the aluminium production. However, metallurgic plants have been supplied with only 45 % of the domestic alumina, the rest of it being imported. The main problem of the alumina industry is the lack of high-quality bauxites. Their resources are quite low, most of these occur at great depths. The possibility to discover deposits of high-quality bauxites on the Earth crust is extremely mean. Along with bauxites, the low-quality bauxite raw materials, i.e. nepheline ores (urthites) and nepheline concentrates from tailings of the apatite-nepheline ores floatation, have been used in Russia to produce alumina. As of 2008, the bauxite production in Russia reached 5.5 mln tons, nepheline ores production reached 3.3 mln tons. 3.3 mln tons of alumina have been produced from this raw material. Only 34 % of alumina has been extracted from all types of aluminium ores (*Information and Analytical Centre…*, 2012). The low quality of the domestic material used for the alumina production in Russia provides huge expenditures of electric energy and a need to radically change the state of art. Taking into account the high technological level of the complex processing and almost unlimited nepheline resources, in the nearest future it is to remain important raw material for the aluminium production. However, kyanite ores with high alumina content may be considered alternative to bauxites and many types of bauxite-free aluminium raw materials (Fig. 1) (*Rimkevich et al*., 2006). It is the first reason of our coming back to the problem of exploring the Keivy kyanite deposits half a century after their being put on the state balance. The second reason is the complex nature of kyanite ores on a number of components, rare elements, first of all. Despite the fact that the complex extraction of resources draws certain technological and economical difficulties, the state approach requires a sustainable use of the mineral resources. Now it is clear that the extracting rare elements while processing the Keivy kyanite deposits can be compared with a world-scale deposit processing. It is particularly topical in the current tension in the world market of rare metals due to the unpredictable trade politics of the biggest monopolist of China.

2. Utilization of the sillimanite group minerals

The sillimanite group minerals, in particular, kyanite, are valuable mineral raw materials. Like sillimanite and andalusite, kyanite is high-alumina raw material for the production of high-quality refractories used in the ceramic, glass and concrete industry, black and non-ferrous metallurgy, production of special isolators, candles, etc. Kyanite is used in the foundry industry as well. It contains 63 % of Al_2O_3 (Fig. 1), which stimulates attempts at its using in the alumina industry. Due to the extremely low silica modulus (< 2) and absence of acids, there is no efficient industrial technology of its processing so far. Laboratory research carried out by VAMI testified to the possibility of producing alumina from kyanite with the electric-thermal method, but this process involves too much energy. At the same time, a technology of producing silicon-aluminium alloys like silumine from kyanite has been elaborated. If the silumine production is based on the kyanite concentrate, its efficiency will increase as compared with the synthetic method. Currently, new methods of the silumine production from the kyanite concentrate with no alumina and electrolytic aluminium applied have been prospected. These are the zinc and filtration methods and the plasmic one, which may help to reduce aluminium up to the pure metal directly from the concentrate.

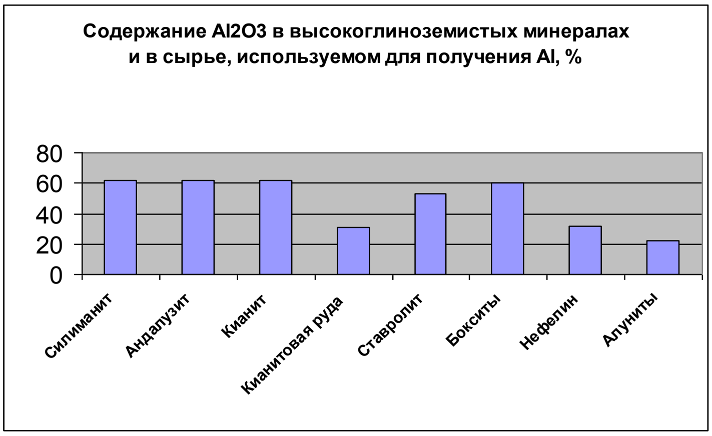


Fig. 1. The main high-alumina minerals and raw materials for the alumina production

The behavior of heated kyanite, sillimanite and andalusite and temperature of their transformation into mullite are important for their industrial use. Kyanite is best-going for the mulite production, performing the lowest temperature of the mullite formation out of the three polymorphic modifications. At the same time, its volume increases up to 18 %. The kyanite behavior during heating provides its considering a refractory. As the latter, it is widely used all around the world, the Scandinavian countries inclusive, where 90 % of kyanite is used in the refractory industry. Its minor amounts are utilized in the ceramic and glass production. In Russia it minor amounts are used during the refractory material production in various industries, i.e. the aviation, construction, metallurgic ones, etc. But it is technical alumina produced from bauxites, which is mostly used for the refractory material production.

3. Outline of the Bol'shiye Keivy resources

In the European part of the Russian Federation there are unique resources of bauxite-free ores represented by the Bol'shiye Keivy kyanite schists. Deposits of the Keivy group occur in the NE part of the Kola Peninsula (Fig. 2).

Fig. 2. Geographical location of the Keivy province of high-alumina schists

High-alumina schists are the Archaean metamorphosed sediments. The schists are folded into an aprx. 200-km-long syncline structure. The productive series thickness is up to 1 km. There are three suits and seven units within the series. 23 kyanite deposits to follow have been identified in the richest high-alumina unit: the Vorgelurta, Tavurta, Tyapsh-Manyuk, Chervurta, Bol'shoy Rov, Bezymyannaya, Kyrpurta, Yagelyurta, Shuururta, etc. (Fig. 3). Kyanite and other high-alumina minerals are present in other units as well, which may provide a considerable extention of resources. The Bol'shiye Keivy are nowadays the world-biggest province of high-alumina raw material. In the Keivy shists there are about 90 % of the prospected kyanite ores of Russia. The ore reserves up to the depth of 100 m are 999 mln tons, resources – 11 mln tons. The kyanite reserves – 338 mln tons, resources – 2 billion tons. Favorable conditions of ore bodies setting allow their open-pit mining with high technical-economical characteristics (*Bel'kov et al*., 1974).

The mineral composition of the kyanite schists is to follow: major – kyanite, quartz; secondary – muskovite, plagioclase, staurolite, zinc-bearing staurolite, graphite, dickite, pyrrhotite, pyrite, ruthile, ilmenite; accessory – chalcopyrite, pentlandite, violarite, magnetite, molubdenite, galenite, sphalerite, gold, macinawite, chalcosine, limonite, hematite, biotite, chlorite, garnet, clinozoisite, apatite, zircon, orthite, monazite, chatonite, titanite, fluorite. The chemical composition of the kyanite schists is to follow (%): SiO_2 58.47-61.58; Al_2O_3 28.83-35.76; TiO_2 0.66-2.28; Fe_2O_3 0.07-2.28; FeO 0.20-1.07; CaO 0.18-0.74; MgO 0.08-0.50; S 0.01-0.68; P_2O_5 0.12-0.26; K_2O+Na_2O 1.0-2.21.

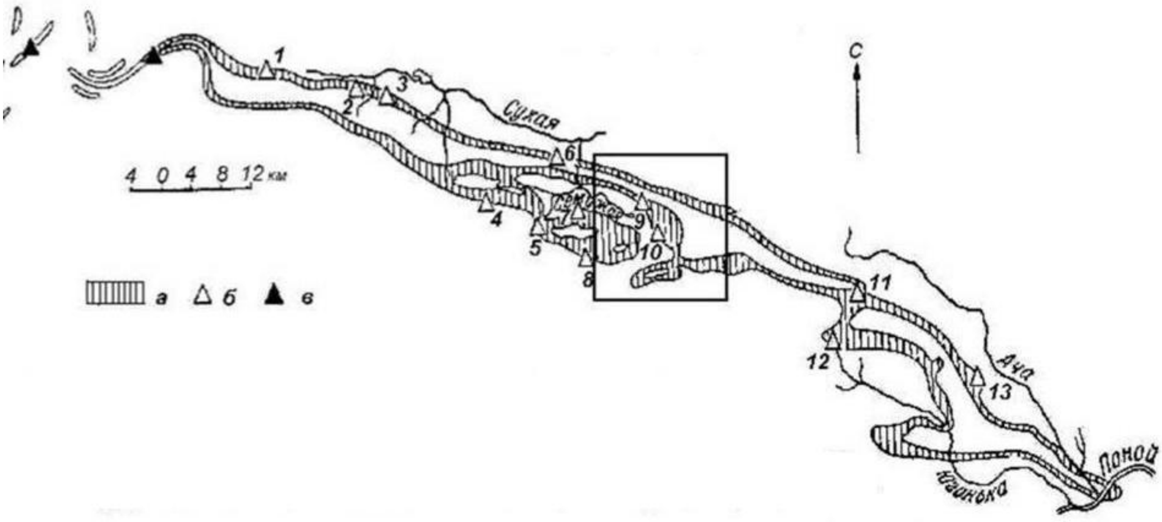
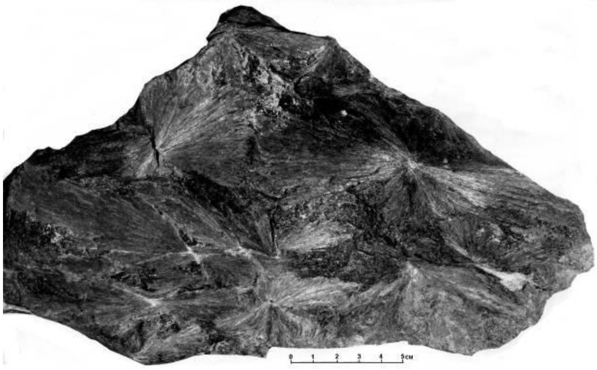


Fig. 3. The location of the major kyanite and sillimanite ores in the Big Keivy structure (*Bel'kov*, 1963).
а – staurolite-kyanite schists of unit B; б – kyanite deposits; в – sillimanite deposits in the Western Keivy; numbered deposits: 1 – Vorgelurta, 2 – Tavurta, 3 – Tyapsh-Manyuk, 4 – Chervurta, 5 – Bol'shoy Rov, 6 – Bezymyannaya, 7 – Kyrpurta, 8 – Yagelyurta, 9 – Shuururta, 10 – Eastern Shuururta (rectangle indicates the location area), 11 – Kaypurta, 12 – Nussa, 13 – Manyuk

There are no considerable changes in composition of the kyanite ores of various deposits. There is a Al_2O_3 enrichment in deposits with dominating concretion ores, which corresponds with the high concentration of kyanite there. As compared with the concretion ores, the needle ones are poorer in alumina, but contain more alkalii, and the concretion ores are rich in iron and graphite (*Bel'kov*, 1963; *Bel'kov et al.*, 1981). Notably, the iron and titanium admixtures are connected with staurolite, ilmentite and ruthile, which are excluded during the enrichment (*Alekseev*, 1976).

4. Kyanite ores textures

The peculiar feature of the Keivy kyanite deposits is a considerable change of ore textures in different deposits. It is essential for selecting the way of enrichment. *I.V. Bel'kov* (1963) and his successors distinguished three main ore types. The first one comprises the fibrous-needle ores, where kyanite occurs as radial- and sheaf-like radiated aggregates (Fig. 4). The second type is the paramorphic ores, where kyanite occurs as needle and prismatic crystal (Fig. 5). The third type is the concretion ores, where kyanite is represented by ellipsoid or spherical concretions (Fig. 6). Some deposits are represented by complex ores. Different is the role of various ore types in the deposit formation. The greatest volume is occupied by fibrous-needle ores (61.9 %), less developed are the paramorphic (35.7 %) and concretion ores (2.4 %).



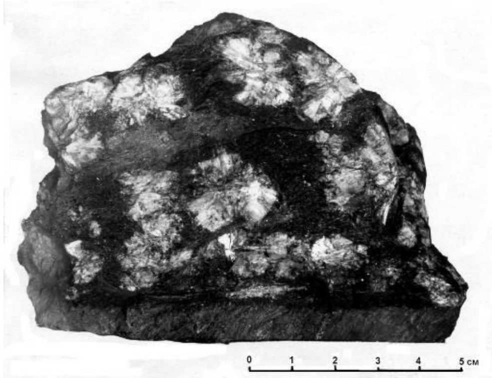


Fig. 4. Fibrous-needle ore Fig. 5. Paramorphic ore

Fig. 6. Concretion ore. Light – kyanite, dark – quartz

The enrichment of each ore type requires certain technology (*Alekseev et al*., 1966; *Alekseev*, 1974). The concretion ores are related to the coarsely disseminated ones and are industrially best-valued. They may be the raw material, where granulated aggregates of dense kyanite are extracted from. The latter are necessary to produce refractories and electric-technical silumine, since they originally contain massive rich aggregates of kyanite with lots of harmful admixtures of iron and titanium. The most efficient technology of such ores' enrichment is the gravitation-floatation one, combining the enrichment in heavy suspensions with granulated kyanite concentrated produced and the kyanite floatation from siftings and intercalated enrichment products.

The fibrous-needle, radial-radiated and paramorphic ores perform a fine kyanite dissemination in the country rock as small needle crystals, prisms and needle-radiated accumulations irregularly scattered within the rock. To uncover kyanite the rock should be ground. It is reasonable to enrich such ores via floatation. The gravitation enrichment processes cannot be applied for them, since there is no well-manifested isolated kyanite and therefore minor difference in specific weights of the valuable mineral and barren rock.

Complex ores contain coarsely and finely disseminated kyanite aggregates. Such ores may be enriched via floatation, but the most economically favorable technology may be the one with the preliminary enrichment in heavy suspensions to waste a part of the barren rock into a dump. The obtained heavy fraction with its main part of kyanite occurring as aggregates with the barren rock and minor ore classes ("siftings") may be additionally enriched via floatation, producing ready kyanite concentrates. Jointly elaborated by "Mekhanobr" and Kola Branch of the USSR Academy of Sciences and tested on the plant "Sibelektrostal", the gravitation-floatation-magnetic scheme of enrichment of the coarse concretion kyanite ore of the Shuururta deposit provides producing kyanite concentrates with 56-57 % of Al_2O_3, about 40 % of SiO_2 and 0.6 % of FeO (*Bel'kov et al*., 1974; *Alekseev*, 1976; *Alekseev et al*., 1966).

In 1971 VAMI jointly with other organizations prepared the technical-economical report "On the industrial utilization of the Keivy deposits kyanites". It had the conclusion that it was reasonable to enter production of the kyanite concentrate to produce high-alumina refractories and aluminium alloys from it. The potential of the JSC "Keivsky Mining Enriching Plant" might be about 3.2 mln tons of the ore with 1 mln tons of the kyanite concentrate output, 650 ths tons of it would serve to produce high-alumina refractories and 350 ths tons – the aluminium alloys. Major challenges of exploiting the Keivy deposits are their being far from the transport streams and consumers and having no electric energy sources. Currently, the situation has been changing for the better. First, a never freezing sea port on the Barents Sea coast, 70 km from the New Shuururta quarry, the Gremikha settlement, was vacated after the military station was liquidated (Fig. 2). Second, due to the development of the Stockman gas condensate deposit, an opportunity of constructing a new natural gas driven thermal plant occurs.

5. Geological setting of the New Shuururta deposit

The New Shuururta deposit is located in the central part of the Big Keivy in front of the Gremikha settlement on the coast of the Barents Sea. It is the biggest deposit with well-developed rich macroconcretion ores. It is one of the most promising regarding its size and state of study. A detailed technological study of the ore washability has been carried out here. The deposit is recommended for the first-priority development. The kyanite ore deposit is represented by three bedded varieties to follow (from the up down): paramorphic kyanite ores with the average thickness of 35 m; macroconcretion kyanite ores with the average thickness of 105 m; microconcretion kyanite schists with the average thickness of 25 m. The deposit trend is sublatitudal, dipping 35-40° northwards. The deposit rates: about 6 km length, up to 300 m width (Fig. 7). The ore reserves are estimated as 1 billion tons containing 41.5 % of kyanite (*Bel'kov et al*., 1974). Thus, there are favorable conditions for the deposit open mining.

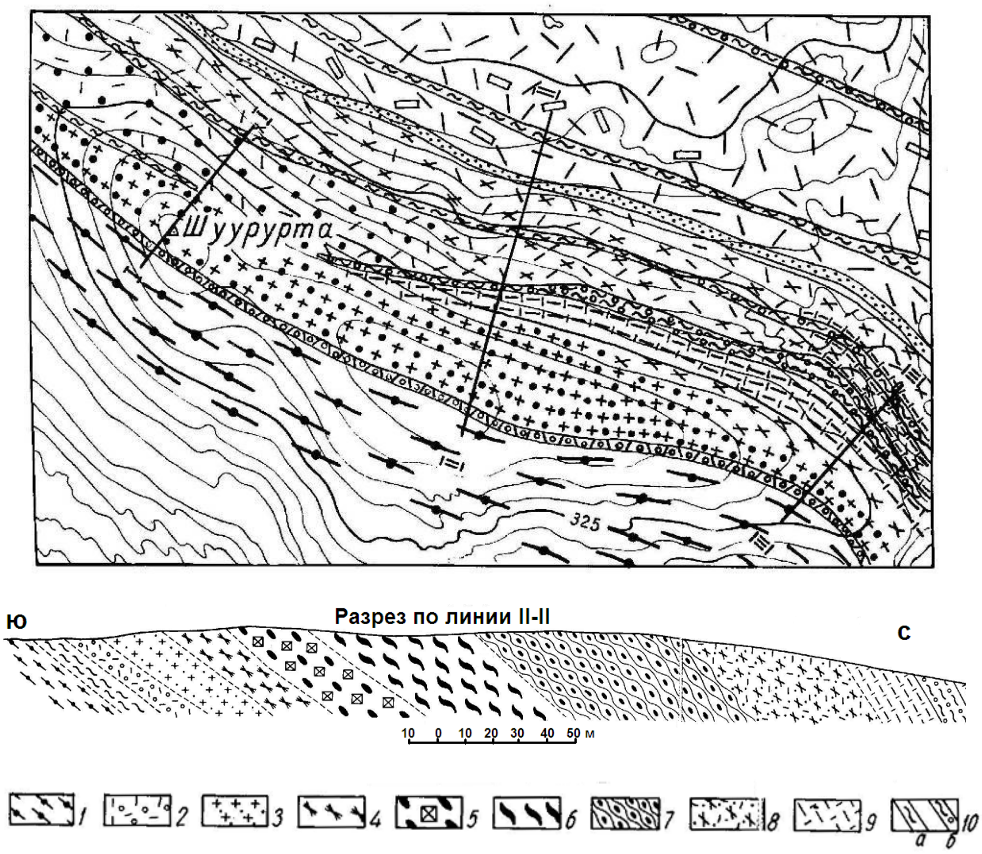


Fig. 7. Geological scheme of the New Shuururta deposit (*Bel'kov*, 1963). 1. Garnet-biotite gneisses. 2. Unit A schists. 3-7. Kyanite schists: 3. Microconcretion-paramorphic, 4. Aggregate-fibrous, 5. Concretion-paramorphic, 6. Macroconcretion, 7. Microconcretion. 8. Staurolite porphyroblastic schists. 9. Staurolite-kyanite porphyroblastic schists. 10. Amphibolites: a – feldspar, b – garnet-feldspar

6. General characteristic of the ores

The Keivy schists are geochemically peculiar with the combination of alumina with carbon, sulphur, titanium, rare and rare earth elements, gold (*Bel'kov et al*., 1974; *Bel'kov*, 1963; 1981; *Neradovsky et al*., 2008). Though the Keivy ores have the kyanite specialization, additionally defines features of their metal content are worth some extra study. The accessories to follow are of peculiar interest: titanium oxides – ruthile and ilmenite; sulfides – pyrrhotite, pentlandite and chalcopyrite; graphite (Fig. 8) and minerals of rare metals and rare earths – potential sources of extra mineral components of kyanite ores, increasing their value as complex raw materials. At the same time, major rock-forming minerals of kyanite schists, i.e. quartz and muscovite, may be defined as individual products either, which allows suggesting a possibility of almost no-waste technology of using the Big Keivy kyanite ores (Fig. 8).

Fig. 8. Composition of major elements of kyanite ores

We should mind that the concretion kyanite ores of the New Shuururta deposit comprise four components: kyanite concretions and paramorphoses, quartz substrate and veinlets (Fig. 9, Table 1). These data testify to the fact that 50 % of the ore volume contains no kyanite, and margins between the kyanite and "empty" phases are contrast.

Fig. 9. Texture of the ore from the New Shuururta deposit:
1 – concretions, 2 – paramorphoses, 3 – substrate, 4 – quartz veinlets

Table 1. Mineral composition of the kyanite ores main components

	Concretions	Paramorphoses	Quartz substrate	Quartz veinlets
Volume, %	40	10	45	5
	Contents of minerals			
Kyanite	75-97	40-85	0	0
Quartz	1-20	7-50	80-95	85-93
Muscovite	0-3	5-10	1-10	5
Ruthile	0,1-2	<1	1-5	1-10
Graphite	1-5	<1	3-10	0-1
Sulfides	<1	<1	<1	Single grains

7. Technology of enriching the kyanite ores of the New Shuururta

Technological investigations of the ores washability have been carried out on a number of characteristic deposits, but the most profound research has been paid to the New Shuururta deposit ores (*Alekseev*, 1976), since a mine has been settled here and some big technological samples have been selected. The concretion ore has been studied in labs (Fig. 6, 9), it average composition being as follows (%): Al_2O_3 32.53, TiO_2 0.98, Fe_2O_3 1.12,

K_2O 0.94, SiO_2 60.68. The alumina content in pure variabilities of the concretion kyanite is high (60.21), the content of impurities is low: Fe_2O_3 0.12, TiO_2 0.35. It corresponds with the mineralogical data on the concretions composition (Table 1).

In result, a technological scheme, which allows producing high quality kyanite concentrates (Table 2), has been elaborated. The concentrates are applied in various industries, in the aluminium one first of all (*Alekseev et al.*, 1966). The floatation line of the scheme of extracting kyanite from the New Shuururta deposit ore has been tested on a non-stop operating machine with the 40 kg/h productivity. Using this scheme, semi-industrious tests of a characteristic sample from the New Shuururta deposit with the weight of 1200 tons have been carried out on the "Sibelectrostal" plant in Krasnoyarsk. The ore composition is to follow (%): kyanite 38.53, TiO_2 1.03; Fe_2O_3 0.95; S 0.16. Table 3 represents results of the semi-industrious tests.

Table 2. Results of laboratory tests of enriching the ore of the New Shuururta deposit (%)

Concentrates	Output	Extraction Al_2O_3	Contents		
			Al_2O_3	Fe_2O_3	TiO_2
Concentrate from siftings (5+0 мм)	8.5	17.8	54.99*	1.13	2.69
Concentrate from middlings	7.1	16.0	57.63**	0.41	0.85
Concentrate from ore with the grain size of 16+5 mm	20.5	44.0	56.16***	0.25	0.45

Note: Al_2O_3 contents regarding heated matter (%): * 56.36; ** 58.91; *** 57.86.

Table 3. Integrated results of semi-industrious tests (%)

Products	Output	Contents			Extraction of kyanite alumina
		Al_2O_3 (kyanite)	Fe_2O_3	TiO_2	
Concentrates					
Heavy suspension	20.1	56.7	0.55	0.5	42.1
Floatation concentrate from siftings	5.6	50.1	2.1	5.0	10.5
Floatation concentrate from middlings	7.0	57.5	0.6	0.9	15.0
General	35.7	55.3	–	–	67.6
Tailings					
Heavy suspension	15.5	8.4	–	–	4.8
Floatation of siftings	20.2	8.3	–	–	6.4
Floatation of middlings	5.9	15.0	–	–	3.3
Magnetic fraction of siftings	1.0	28.6	–	–	1.1
Magnetic fraction of middlings	0.15	35.8	–	–	0.2
General tailings	42.75	9.8	–	–	15.8
Slimes					
From primary siftings	4.6	15.5	–	–	2.7
From floatation of siftings	16.0	14.0	–	–	8.7
From floatation of middlings	3.95	35.6	–	–	5.2
General slimes	24.55	18.1	–	–	16.6
Initial ore	100.0	26.8	–	–	100.0

As a result of tests an experimental portion of the kyanite concentrate of about 170 tons has been produced for industrial meltings for sillumine on the Dnepropetrovsk Aluminium Plant. 100 tons of the concentrate have been electrothermically melted. The melting has revealed this method of the sillumine and aluminium foundry alloys production from the kyanite concentrate being economically more benefiting in comparison with the synthetic one. The kyanite raw material provides no expenditures on the silicon production and minimizes the need of the electrolytic aluminium. Besides, the kyanite concentrate is characterized by a much higher quality than kaolin, i.e. Al_2O_3 content is 56 % as opposed to 37.5 % with the similar content of the iron and titanium oxides (*Alekseev*, 1974).

8. Investigation on the kyanite metallurgy

Traditionally, kyanite is used to produce mullite-series refractories. VAMI has carried out investigations on the initiate electromagnetic production of aluminium-silisic alloys from kyanite. In the interval of 1300-1800 °C SiO_2 reduces during the kyanite mullitization, in the interval of 1800-1900 °C free SiO_2 reduces, and formation of the aluminium-silisic alloy begins under more than 1900 °C. From 5 to 10 % of aluminium and silicon are vapoured under smelting of aluminium-silisic alloys (*Ostanin et al*., 1974).

We have studied the thermodynamics of processes in the $Al_2O_3 – SiO_2 – C$ system for products of the kyanite mullitization $3(Al_2O_3{\cdot}SiO_2) \rightarrow 3Al_2O_3{\cdot}SiO_2 + SiO_2$. Experiments have proved the system to act as two independent subsystems to follow: $SiO_2 – C$ and $Al_2O_3 – C$. Thermodynamically most probable here are the reactions leading to the silicon carbide production, i.e. $3Al_2O_3{\cdot}2SiO_2 + SiO_2 + 9C \rightarrow 3Al_2O_3 + 3SiC + 6CO$. Partially, the silicon monooxide occurs and is transferred on the sample volume ($3Al_2O_3{\cdot}2SiO_2 + 2C \rightarrow 3Al_2O_3 + 2SiO + 2CO$). Further, the silicon carbide forms on SiO meeting carbon. Performing these processes in real conditions allowed producing mullite refractories with high thermal shock resistance (50 thermal shocks, 1300 °C – water).

In the kyanite-carbon system a preliminary reducing roasting is needed due to the technological reasons. The kyanite ore of the New Shuururta deposit has been used as an alumosilicate component. The chemical composition of the kyanite ore is to follow (%): Al_2O_3 40.94, SiO_2 53.0, K_2O 1.31, CaO 1.57, TiO_2 1.16, Fe_2O_3 0.58, C 2.33. The grain-size composition of the kyanite ore is to follow (%): 32 (fr. 2.5-1 mm), 12 (1-0.4), 5 (0.4-0.315), 10 (0.315-0.16), 14 (0.16-0.063), 27 (< 0.063). To create the conditions preventing direct contact of mullite grains, SiO_2 and Al_2O_3 with carbon, which block the most possible thermodynamical reactions of carbidization and provide a free diffusion of reducing gases and gaseous products, the samples have been not pressed, but made as clay pellets with a ripper added. In these conditions the system mostly performed reactions of high-temperature dissociation of the silicon dioxide on gaseous components to follow (*Grishin et al*., 2010): (1) SiO_2(solid) = SiO(gas) + O(gas), (2) $2SiO_2$(solid) = 2SiO(gas) + O_2(gas), (3) $SiO_2 \rightarrow$ SiO(gas) + $0.5O_2$. The presence of free carbon in the system shifted the equilibrium to the gaseous products formation. The key role of SiO in the process of the alumina transportation has been justified in special experiments.

As for an open system, the blend carbon present in a sample does not contribute to reducing of the silicon oxide, which is free or fixed with mullite via a direct contact with it, but shifts the equilibrium of reactions (1-3) to the SiO formation. Owing to this accessory impact of carbon, during the kyanite mullitization alumina effectively dissociates under a high temperature and produces gaseous SiO. The latter diffuses from the sample volume, vapouring silicon, reduces and disproportionates on the covering carbon according to the reactions $SiO_г + 2C_{тв} = SiC_{тв} + CO_г$ and $2SiO_г \rightarrow SiO_2 + Si$, producing SiC, SiO_2 and Si (*Grishin et al*., 2010). In a pseudo-open system concentrate Al_2O_3 (98 %) with ratio Al_2O_3 / SiO_2 > 700 has been produced. It is a precursor for the production of corundum refractories, sillumine and metallic aluminium.

9. Perspectives of the accessory components extraction

Staurolite. The staurolite concentrate is separated under the electromagnetic separation of kyanite schists, since it is a noxious impurity (due to the high content of iron) and considered as production wastes. The average content in the ore is 5 %, the prognosis reserves in the kyanite ores exceed 100 mln tons. The staurolite reserves in Unit G up to the depth of 200 m are more than 4.5 billion tons. Staurolite may be used as an alternative source of fluxes, i.e. fluorite and bauxite (*Popova et al*., 1992). The technology of the steal smelting using the staurolite concentrate has been successfully introduced on the Makeevka Metallurgic Plant. Adding of staurolite increases the rate and level of the metal disulphuration 1.2-1.5 times, increases the steel output and decreases the self-value. The staurolite concentrate is ecologically friendly, contains neither toxic, fluorine ones first of all, and explosive compounds, not hydroscopic and has a regular grain-size composition. Using it instead of fluorite considerably improves the ecological setting of the production. Staurolite may be an independent high-alumina raw material. Once applied, it provides the Murmansk region with a perspective of the monopolist staurolite raw material supplier of metallurgic plants of the Russian North-West. Using staurolite as a new mineral dramatically increases the value of the Bol'shiye Keivy as a complex ores source.

Sulfides. The kyanite ore contains selenium pyrrhotite, pentlandite, chalcopyrite, sphalerite, molybdenite and other sulfides. The sulfide concentrate is produced using the electromagnetic separation and floatation. During the ore processing, 2.1 % of the sulfide concentrate is extracted from the total ore volume. With the floatation technique applied, pyrrhotite of 85-87 % content is extracted from the magnetic fraction, total output from the ore is 1.12 % (total extraction about 50 %). Admixtures to follow have been defined in pyrrhotite (%): Ni 0.176, Co 0.164; in the sulfide concentrate (%): Co 0.09-0.17, Ni 0.11-0.23, Se 0.0005-0.0021, Au 0.18-0.52 g/t, etc. (*Tokarev, Yashchenko*, 1968). The expected output of the sulfide product with the current extraction applied is 5 kg/t. Reserves (t): Au > 7000, Ni 34000, Co 26000, Se 260.

Titanium minerals. Kyanite ores contain from 1 to 10 % (1-2 % in average) of ilmenite and ruthile. Especially high concentrations of ruthile are observed in the muscovite-quartz veins developed in the graphite-quartz substrate (Fig. 10). Titanium minerals have almost no connection with kyanite, so they will rest in enrichment tailings in association with quartz and muscovite. Their reserves exceed 100 mln tons.

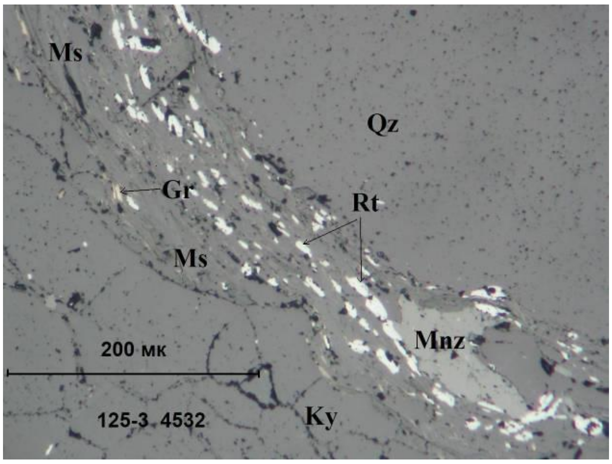


Fig. 10. Quartz veins with ruthile and monazite

Graphite. The average graphite content in the kyanite ore is about 2 %. The quartz-muscovite substrate contains 3 % of graphite, the quartz-muscovite aggregate is enriched with graphite up 5 % near concretions and quartz veins. With the floatation applied, the graphite concentrate with the content of 20-25 % has been produced. In the concentrate Au 0.025 g/t has been identified. Reserves exceed 100 mln tons.

Rare earths. Totally, the content of rare elements Sc, Zr, Hf, Th in the kyanite ore is 0.23-0.25 %, which allows estimating their reserves in the Keivy schists as 27-29 mln tons and considering these as a new promising source of rare elements. In labs we have produced a coarse concentrate with 0.37 % of rare elements. Thus, the possibility to produce the rare elements concentrate from common concretion kyanite ores has been proved. Further research is to provide determining of mineralogical phases and estimating the real output of rare elements after the complex enrichment of the kyanite ore.

Rare Earth Elements. Results of the chemical analysis has testified to the REE content in the concretion kyanite ore varying from 0.04 to 0.18 %. The forecasted reserves of kyanite ores up to the depth of 100 m are 11.7 billion tons (*Bel'kov et al*., 1974), REE reserves – from 4.7 to 21.1 mln tons. According to these data, Bol'shiye Keivy correspond with the major REE deposits (*On the approval…*, 2007; *Samsonov, Samsonov*, 2012) and exceed reserves of some exporter countries, which allows considering these as a new promising REE source.

In labs we have produced a course REE concentrate from a coarse concretion ore. The total content of REE and yttrium has proved 1.62 %. Results of analysis pay evidence to the REE concentration going irregularly. Elements of the cerium group (from La to Gd) have concentrated 11-13 times regarding the initial ore, those of the yttrium group – 1.5-8 times. The concentration of Th has risen 13 times. Roentgenometric data have showed the presence of monazite in the concentrate. Analysing the mineralogical data in synthesis, we may conclude that the major concentrate of the cerium group of REE and Th is monacite. It associates with ruthile and zircon in muscovite-quartz veins (Fig. 10). Other REE concentrators will be defined after a more detailed research. Further investigations are to provide estimating the actual output of REE after the complex enrichment.

10. Ecological safety

All the Keivy kyanite deposits outcrop, tracing dry gently dipping plateaus. The ore mining is possible with a system of quarries along series strike. Due to the great amount of the excavated rock mass, it is reasonable to first enrich ores in situ to produce the complex concentrate. The problem of its transporting, which has been recently considered about the key one in the scheme of the Keivy deposits processing, nowadays finds an unexpected solution of the Gremikha port, the former Naval Forces station. We should consider the possibility of getting separate concentrates in the Gremikha settlement and shipping them by sea to ports of Murmansk and Arkhangelsk. It is reasonable to make the final procession of concentrates on common capacities of the Ural and Siberia plants.

The following circumstances shade perspectives of the deposits processing. All along the Bol'shiye Keivy southern bottom the Kola Peninsula major vein of the Ponoy River flows. There is a possibility of polluting salmon breeding grounds through tributaries or air-by dust transportation. Besides, a number of plateau areas are reindeer pastures state-protected as a basis of the Sámi national economy. Nevertheless, the experience of neighbor Finland shows that interests of the state, companies and private owners in the sphere of the mineral mining may meet and do interests of the locals preserving traditional trades.

11. Conclusion

The observed materials testify to the Keivy kyanite deposits being a promising multicomponent raw material, first of all, for the production of refractory materials and alumina. In synthesis, kyanite and staurolite are almost an unlimited reserve of the high-alumina raw materials. The current situation with the industrial use of kyanite and staurolite is unfavorable for the Keivy development, since there are more accessible and developed sources of alumina and refractories. The key trend of further research is the elaboration of technologies of producing kyanite from staurolite, which would be able to actually compete with the currently used low-alumina raw materials.

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