ORE CONTROL OF KHIZOVAARA STRUCTURE DEPOSITS

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ABSTRACT
Ore-controlling factors determine the patterns of formation and localization of mineralization within ore regions and deposits. The need for this study arises from the importance of integrated assessment of mineral resources and improvement of metasomatic formation techniques. This is especially important for geological materials which are mined for their direct commercial value (industrial materials). This article is devoted to the study of the ore control of complex industrial minerals. The Khizovaara structure belongs to the Tikshozero greenstone belt. Within the structure, a multistage metamorphism and metasomatism processes are manifested. The totality of lithological, structural and petrologic ore control factors determines the existence within the structure of several deposits. These are deposits of industrial minerals, such as garnet, quartz, muscovite, kyanite, staurolite. In almost all cases, the ores are complex. The following objects were studied: Southern Lens (kyanite + quartz) deposit, Northern lens (kyanite + quartz) deposit, East Khizovaara (muscovite + quartz) deposit, Vysota-181 (garnet + staurolite + kyanite + muscovite + quartz) deposit, ore occurrence Fuxit (decorative rocks). For the ores of each site, the processes of regional metamorphism of the amphibolite facies of kyanite-biotite and muscovite-chlorite-kyanite subfacies are important. Metamorphism, tectonic regime and geological connection with rocks has been studied as a ore control factor, based on this, data on the quantitative distribution of industrial minerals of metamorphic genesis have been obtained. Acidic and alkaline metasomatites of each site are considered. On the basis of these data, metasomatic processes that lead to the formation of complex ores are revealed. The process of superposition of metasomatosis products of the late stage on the products of early stage metasomatosis was studied. This process leads to the formation of complex ores of three or four minerals. The result of the work is a general scheme of metamorphic and metasomatic ores control for all studied objects.

Keywords: khizovaara structure, garnet, kyanite, muscovite, metasomatism, tectonic control.
INTRODUCTION

This work is the result of years of research. The interim result of the study was presented at the profile conference [1]. The results of the conference and discussion formed the basis for two articles, the first of which is devoted to factors controlling the muscovite ores within the Northern flank of the structure [2]. The second article proves the unity of rock composition and metamorphism parameters in the Northern and Southern flanks of the structure [3]. Greenstone belts in North Karelia, e.g. the Tiksheozero belt, are promising for industrial mineral (quartz, garnet, kyanite, staurolite, muscovite, pyrite and talc) ore prospecting [4]. Ore formation is associated with multi-stage metamorphic (amphibolite- and granulite-facies metamorphism) and metasomatic processes. The Khizovaara structure was found to host kyanite (Khizovaara deposit), muscovite (East Khizovaara deposit), garnet ore (Vysota-181 deposit) and ornamental rock (Fuksitovy prospect) deposits [5, 6, 7, 8]. All the ores are complex (several industrial minerals can be produced and separated in one flow chart). Complex muscovite, kyanite and garnet ores are confined to zones subjected to intense amphibolite-facies metamorphism and felsic- and mafic-facies metasomatism. The goal of the paper is to describe structural, metamorphic and metasomatic processes as controlling factors for deposits in the Khizovaara Ore Field. Questions of mineralogy of the southern flank of the Khizovaara structure, to which the deposit of complex garnet ore “Vysota -181” is confined, are of scientific and practical interest.

Mapping and analytical methods

Metasomatic zoning and associated complex ores were analyzed using methods for mineralo-technological mapping based on identification of metamorphic types of a protolith, the petrographic composition of metasomatic zones and industrial tests for minor industrial samples [5]. It is a convenient method for large-scale survey used for assessing the distribution pattern of industrial minerals. The paper focuses on classification of ore-controlling factors and ore types. Therefore, thin sections from oriented samples were analyzed petrographically to reveal microstructural features; mineralogical and X-ray fluorescence analyses (with identification of petrogenic elements) were done to study the chemical and mineral trends of rock alteration controlled by the degree of metasomatic reworking. The composition and chemical zoning of minerals were studied on a VEGA II LSH (Tescan) scanning electron microscope with an INCA Energy 350 (Oxford instruments) energy dispersion microanalyzer.

Geological structure of the Khizovaara Ore Field

The Khizovaara Ore Field was first described as an ore zone of kyanite deposits, based on integrated geological prospecting supervised by N.A. Volotovskaya. Survey has revealed the Khizovaara structure composed of schist and amphibolites of Archean age. Structurally, the Khizovaara structure was described as a syncline fold hinge with small-scale folds and faults (Fig. 1). Three promising kyanite ore lenses – northern, southern and eastern- were delineated by geological survey. The lenses consist dominantly of kyanite gneiss and quartz-kyanitic metasomatic rocks that display a complex petrographic composition. More recently, the same research team headed by Volotovskaya conducted an additional study of suite rocks [9]. As a result, the metamorphic complexes...
were subdivided as follows (the same systematics as the authors proposed):
- Muscovite, bimica-garnet and muscovite-garnet schist
- Biotite, biotite-garnet and biotite-amphibole gneisses
- Feldspar and garnet amphibolites

As a result of the multi-stage study of the structure, lenses in kyanite deposits were delineated, new localities in the Khizovaara Ore Field were revealed, described and appraised, and metamorphism and metasomatism were studied in detail. Most authors are unanimous as to the complexly folded structure of the Khizovaara Ore Field and two well-defined stages of metamorphism that have formed modern ore-hosting complexes. In accordance with the modern concepts of the structure, there are felsic metasomatic zones on the structure margins to which kyanite, muscovite, staurolite, quartz and garnet occurrences and deposits are confined.

The primary protolith is not always obvious because of deep metamorphic re-working, but it has been clearly shown that mafic and intermediate metavolcanics, as well as highly metamorphosed sedimentary-volcanic and sedimentary rocks, have contributed to the structure and its individual zones [10]. The structure margins consist of felsic and intermediate intrusions, and the main ore occurrence is associated with metamorphic-metasomatic complexes and metasomatic rocks confined to the structure margins (metamorphic rocks after sedimentary-volcanic and terrigenous rocks).

Metamorphism and metasomatism in the Khizovaara structure

Metamorphism and metasomatism in the Khizovaara Ore Field have been studied for a long time. At the present time two stages of metamorphism: Lopian (2.6-2.8 Ga) [11] and Svecofennian (1.7-1.9 Ga) [12, 13], are recognized. Studying a later Svecofennian stage is essential for assessment of ore-controlling factors at Vysova-181 deposit. In various years various authors estimated the parameters of the Svecofennian stage of metamorphism at P~6-7 kBar and T~620-670° [12,13,14].

Figure 1. Khizovaara ore field scheme. Ore deposits: 1. South and North lens (kyanite). 2. East lens (kyanite). 3. Fuxit occurrence (Decorative rock). 4. Eastern Khizovaara deposit (muscovite). 5. Vysova-181 deposit (garnet).
which is consistent with a kyanite-biotite-staurolite subfacies of an amphibolites facies [15]. Of special interest is the study of metasomatism associated with regional metamorphism. The authors of a monograph on metasomatic processes associated with regional metamorphism [16] discussed various options of acid leaching for various rock types in the Khizovaara structure. The mechanism of formation of kyanite quartzite and quartz-muscovite and quartz-muscovite-kyanite schists in rear zones has been unveiled and described. These rock complexes are ore-bearing for deposits in the northern Khizovaara structure. Ore-hosting rocks at Vysota-181 deposit have been derived in a similar fashion, but they contain higher garnet concentrations in all metasomatic zones. Garnet-bearing metasomatic rocks of the deposit are understood as felsic (biotite-staurolite-garnet-quartz and garnet-muscovite-kyanite-quartz, kyanite-quartz, kyanite, muscovite-quartz metasomatic rocks) and mafic (garnet-staurolite-biotite-amphibole, garnet-biotite-plagioclase, garnet, staurolite-kyanite-feldspar and garnet-quartz metasomatic rocks) facies [7, 17].

**Detailed areas: Khizovaara deposit (South, North and East lenses)**

The best-known deposit in the Khizovaara Ore Field, which was partly mined in the past for kyanite concentrate production (Fig. 2, 3). The southern and Northern lenses of the deposit will be discussed below. They are best-studied and are close to each other. Rocks of the deposit occur as a series of subparallel lens-shaped kyanite-bearing bodies confined to the weathering crust of tholeiite-series andesites, high-alumina metamorphic rock (biotite gneiss and bimica schist) horizons of the Tikshezero series [4]. The lenses are oriented SW-NE and dip at 50-60°. Kyanite mineralization is represented by two types of kyanite. The effect of metasomatism as an ore-controlling factor under stepwise metamorphic alteration conditions could be much greater than it was assumed earlier, as suggested by the structural alteration of amphibole-biotite, kyanite-biotite and micaceous rocks with kyanite quartzite (secondary quartzite). This alternation could be due to either rock folding or a metasomatic column event. Both factors are probably essential. In this case, the most intense metasomatic alterations are confined to tectonically weakened zones and rock contacts. Mineralization is confined to kyanite-quartz, quartz-muscovite-kyanite and graphite-kyanite-quartz metasomatic rocks.
Eastern Khizovaara deposit

The deposit is confined to rocks of the Tiksheozero series (biotite schist) at the contact with amphibolites [8]. Prospecting and appraisal has revealed the weakly-cutting position of high-grade muscovite-bearing bodies, supporting the multiple pattern of muscovite mineralization. The useful sequence consists of white to light-grey quartz-muscovite metasomatic rocks with secondary kyanite quartzite interbeds and lenses that contain 1.3-8.5% muscovite. Muscovite is silvery-white, occasionally greenish, imbricate, 5-7mm in size, fine-scaly and acicular. Muscovite concentration decreases from the centre to the periphery of the deposit [8].

The content of muscovite in metasomatites developed by biotite gneisses is much higher than in apomafibolite metasomatites. This is due initially to the high content of mica in the protolith. With the gradual removal of the iron-magnesia component, the biotite-staurolite paragenesis is replaced by muscovite-kyanite and muscovite-quartz (Fig. 4, 5). As a result of active processes of milonitization (crushing and grinding of the rock in zones of tectonic breaks), shale metasomatites are formed in the rear zones, composed mainly of small flaked muscovite. Thus, the high content of muscovite is characteristic of the rear and intermediate zones of metasomatism. It is to such zones that the main ore deposit of the deposit is confined, the bulk of which is composed of the Muscovite + quartz mineral paragenesis.

Due to the fact that the content of iron is a limited indicator for individual areas of use of muscovite, the behavior of the Fe-Mg components in metasomatic changes in muscovite ores has been analyzed. The chemical composition of monofractions reflects an increased content of FeO + Fe₂O₃ in muscovite of advanced metasomatic zones and a decrease in iron content in muscovite of the rear zones. This phenomenon fits well with the theoretical acid leaching scheme, in which Fe and Mg are the most mobile components. In practice, in the rear zone, significant variations are observed not only in the mineral composition of metasomatites, but also in the chemical composition of minerals. No consistent changes in useful mineral concentration with depth were observed. This corroborates the connection of the intense schistosity of biotite gneisses at the contact with amphibolites and the most vigorous metasomatism (contacts with amphibolites are subvertical).
Vysota-181 deposit

There are three groups of metamorphic rocks at Vysota-181 deposit: garnet and other amphibolites, amphibole-bearing biotite gneisses and garnet-biotite gneisses. It should be noted that the presence of garnet in amphibole-bearing rocks is associated with metasomatic processes, as indicated by either the absence or presence of small garnet concentrations in amphibolites occurring outside the main deposit structure. Garnet-biotite gneisses and associated metasomatic rocks, widespread in the centre of the structure, are most essential. Associated with them is the complex mineralization of the central lens of the deposit. All the rocks display signs of tectonic deformations that took place simultaneously with metamorphism of tectonic deformations; in this case, amphibolites are highly stable. The structure of these rocks clearly exhibits signs of ductile and brittle deformations. Felsic metasomatic rocks are widespread. They are the most common ore-bearing rocks. Mafic metasomatic rocks are scarce and are most commonly characterized by the presence of staurolite (Fig. 6, 7). Garnet is quite common in both metamorphic and metasomatic rocks. The most intense tectonic deformations occur along strike at 80°. There are signs of cataclastic deformations of large garnet porphyroblasts and the simultaneous appearance of garnet crystalloblasts of a different generation. Structural alterations are mainly represented by mylonitization with gradual (one zone after another) replacement of biotite by muscovite. Obviously, the intensity of metasomatic processes is commonly controlled by the activity of tectonic deformations. In schistosity zones one can always observe muscovite-quartz-facies metasomatism, which gives rise to muscovite-rich (up to 30%) zones.

To compare the mineralized rocks and metasomatites, the composition of samples taken from the Khizovaara structure was analyzed. The composition of the rock deposits according to sources and the author’s work is shown in the AFM diagram (Na2O + K2O-Fe2O3 + FeO-MgO; (Fig. 8).

The results of the study show that the compositions of the surrounding mineralization of the “Vysota-181” deposit correlate with the compositions of metabasites and meta-andesites described for the Khizovaara structure. At the same time,
there are two trends in metasomatic changes in the composition of the rocks: debasification of the rocks of the northern flank, associated with the removal of Fe$_2$O$_3$, FeO, MgO, and an increase in iron content in the rocks of the southern flank.

**Petrological factors**

- Regional amphibolites-facies metamorphism

It is important to point out that the formation of the existing ore complexes is associated with a later stage (~1.8 Ga), which is regarded as a metamorphic ore-controlling factor. The results of multi-equiponderous barometry using a TWQ software complex show a pressure of $>6.0$ kBar and a temperature of 590° С and 630° С for garnet amphibolites and garnet-biotite gneisses, respectively (mean values).

Examples of industrial minerals produced by Svecofennian metamorphism are garnet from garnet-biotite gneiss and garnet amphibolite at Vysota-181 deposit [4], part of kyanite ore in the Southern and Northern lenses and staurolite mineralization in the local zones of the Khizovaara deposit. A metamorphic factor is clearly characteristic of all the rocks of the deposit but is not the most essential for existing ore bodies.

- The retrograde metamorphic

A retrograde metamorphic stage (diaphtheresis), identified by many authors [14, 17, 18] leads to the formation of dominantly muscovite, muscovite-quartz and muscovite-kyanite-quartz associations in alumina-rich rocks. Tiksheozero micaeous rocks are most favourable for muscovite mineralization.

- Multi-stage felsic kyanite-quartz-facies metasomatism.

It is ubiquitous and is a major ore-forming factor. Metasomatism is indicated by: metasomatic zoning, typical lenticular and veined morphology, the presence of protolith rock relics, porphyroblasts of garnet and quartz after kyanite, granoblastic rock structures, pseudomorphs (dominantly kyanite after staurolite and quartz after kyanite), mineral zoning and anchimonomineral rocks confined to rear zones. Felsic kyanite-quartz-facies metasomatism is a control factor for most kyanite ores in the Southern and Northern lenses, for light almandine garnets of Vysota-181 deposit and for metasomatic lenses and veinlets of kyanite-quartz composition as part of the ore body of the Eastern Khizovaara deposit.

- Multi-stage staurolite-garnet-facies metasomatism.

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**Figure 8. Compositions of the rocks of the Khizovaara ore field.** 1-8: [3]. 1 – komatiites, 2 – basalts, 3 – andesites; 4-6: 4 – amphibolites of the Khizovaara field, 5 – amphibole-biotite gneisses of the Khizovaara field; 6 – kyanite-containing metasomatites of the deposit “Khizovaara”; 7-8. 7 – amphibole-biotite gneisses of the East Khizovaara field, 8 – muscovite-containing metasomatites of the East Khizovaara field; 9 – amphibolites of the “Vysota-181” deposit, 10 – amphibole-biotite gneisses of the “Vysota-181” deposit, 11 – garnet-biotite gneisses of the “Vysota-181” deposit, 12 – garnet-bearing metasomatites of the “Vysota-181” deposit.
Kinematic indicators show that this stage of metasomatism is a more recent process than acid leaching. Associated with mafic metasomatism, related to Fe-and Mg-saturation of rocks, is the occurrence of pyrope-almandine garnet at Vysota-181 deposit and metasomatic staurolite at all localities of the Khizovaara structure.

- Multi-stage muscovite-quartz-facies felsic metasomatism.

A lower-temperature stage of metasomatism associated petrologically with diaphthoresis. The formation of Ms mineralization have long been attributed to muscovite-quartz-facies metasomatism [4,18], but it was not until 2001 that the reserves of the Eastern Khizovaara deposit were evaluated during prospecting and appraisal. The main body of the deposit occurs as the alternation of muscovite-quartz, kyanite-quartz and muscovite metasomatic rocks. The formation of muscovite mineralization often takes place after the protolith of micaeous rocks (amphibole-biotite and biotite gneisses).

- Fe-Mg metasomatism associated with acid leaching.

This process is described in detail for metasomatic rocks from the Khizovaara structure and Vysota-181 prospect [18]. Interestingly, during this process anchimineral granitites are derived as veined and lenticular bodies often confined to contacts between protolith rocks. For Vysota-181 deposit, this fact could be explained by the debasification of deep-seated Fe- and Mg-rich metamorphic rocks. This process is due to the high Mg mobility and the relative inertness of Fe, as has already been described for the Khizovaara structure [18].

Structural factors

The structural ore-controlling factors at the deposit include the deformation mode of ore localization. It is advisable to consider the deformation regimes as early, synchronous and late, since the shear strains synchronous with the Svecofenn stage of metamorphism synchronous and later are clearly separated based on structural analysis.

The host rocks are an indicator of the geodynamic environment of the formation of ores and their consideration in the context of studying structural control is logical for the formational analysis of large structures. For the control factors considered in the work, the study of this issue is not fundamental.

In relation to the field, it is logical to consider synchronous and late deformation modes as structural ore-controlling factors. Thus, in the work, only those structural factors that directly determine the movement of solutions, the localization of ore bodies, and structural kinematic parageneses are considered. Structural factors relate to the ore distribution (synchronous) and ore colossal (synchronous ore and late ore), responsible for the boundaries of the ore mineralization, the body and the thickness of the ore bodies.

As an ore controlling factor, synchronous deformation is significant for the formation of all natural ore varieties in metasomatises. Spamming of rocks on the background of deformation environments creates zones that are well permeable to solutions, thus controlling the metasomatic zonality (mineral distribution factor). For the zone of shear deformations, the formation of structural parageneses is characteristic, which are the totality of all structural forms formed in a single general
stress field. Structural parageneses can be repeated at different scales within a single tectonic zone and have a number of features: 1) Structural paragenesis of a lower order (as compared with the main compression zone and the following transgression from it) can have excellent shear directions. 2) The synchronicity of tectonic processes with metamorphism and metasomatism determines the appearance of various structural-material parageneses, the reasons for the formation of which can be described only with the help of ordinary structural-kinematic drawings. Not participating in the formation of mineralized rocks, brittle (late) deformations are responsible for the localization of ore bodies. Most often manifested horstically graben structural paragenesis, with elevations up to 10 m., which are characteristic of compression settings. In addition, plane-parallel crack systems often contain hydrothermal quartz cores.

Obviously, metasomatic processes take place along narrow shear zones during synmetamorphic deformations of biotite gneisses, which are more susceptible to allochemical changes, accompanied by changes in the initial chemical composition of rocks due to the introduction or removal of the substance. Depending on the goals and objectives in the geological mapping of metasomatic rocks can be used different principles. When evaluating the mapping of a scale of 1:10000-1:50,000, the maximum information about the ore body is provided by studying the formation type, petrographic and petrochemical composition of metasomatites. In case of separation of technological types and ore grades, it is necessary to take into account the peculiarities of the metasomatic and chemical zonality of such rocks. The attraction for this facies analysis allows to distinguish metasomatic bodies and zones that unite the facies of certain thermobarometric conditions and are characterized by a set of mineral parageneses. This approach is convenient for the selection of technological types and grades of ores and can be used for all variants of metasomatic change of rocks.

**Lithologic stratigraphic factors**

The geological connection of ore bodies with metamorphic rocks formed by the protolith of volcanogenic and volcano-genic-sedimentary rocks is the most important geological attribute relating to the lithologic-stratigraphic factors controlling ores. These factors can be characterized as ore-distributing, since the placement of the ores of garnet, kyanite, staurolite, muscovite and quartz is associated with the petrochemical specialization of protolith rocks and their natural permeability for hydrothermal-metasomatic solutions. Data on host rock ores are used in the primary mapping and geometrization of ore deposits, identifying patterns of mineralization. For deposits, due to active metasomatic processes, the character of host rocks does not always correlate with specific types of ores.

- geological connection with the sequences of amphibole gneisses (host rocks for all deposits of the ore field).

Amphibole gneisses in the work are a number of rocks with a predominant content of Amph, Bt, and Pl (n > 70) and a gneissic structure. Data strata are distributed in the southern and northern flanks of the structure, subvertically standing out on the day surface. In the primary composition of amphibole-biotite gneisses, garnet is weakly developed (~ 1%), thus the spatial relationship with amphibole-biotite gneisses is the ore controlling factor for
garnet metasomatic generation, kyanite and muscovite. The permeability of rocks for hydrothermal-metasomatic solutions is high, therefore complex ores containing four and five mineral ore parageneses are formed on the substrate of amphibolite-biotite gneisses (muscovite is not an equilibrium mineral and manifested as a result of superimposed low-temperature processes)

– geological connection with the thickness of garnet amphibolites (host rocks).

No-granat amphibolites are widely developed within the Khizovar structure. They are usually described as deeply metamorphosed basalts and subvolcanic rocks. Within the structure, garnet-containing amphibolites are distinguished, the content of garnet at amphibolite contacts with other rocks and in tectonically weakened metasomatized zones is especially high, which may indicate the appearance of garnet as a sign of metasomatic transformations against the background of allochemical Svekofenn metamorphism. Metasomatites with amphibolites as an initial substrate are rare and small in terms of their area.

Spatial association with amphibolites is the ore controlling factor for garnet metamorphic and metasomatic generation, staurolite, kyanite and muscovite, as well as quartz from anhimonomineral secondary quartzite and hydrothermal veins. The stratum of garnet-biotite gneisses is the optimal zone for metasomatic mineralization due to the high permeability due to the lithological structure and tectonic processes.

Analysis of the data in Table 1 shows some essential features: formation of ores in the process of metamorphism largely depends on the chemical composition of ores and partly. Metasomatism forms the ore of certain minerals depending on the chemical specializations. Ky ores with the highest concentrations of these minerals are produced by acid leaching after initially high-alumina rocks. The same process after intermediate gneisses often forms Grt-Ky and St-Ky mineralization (produced by the superposition of mafic metasomatic rocks on felsic metasomatic products). Ms ores are generated by diaphthoresis and simultaneous muscovite-quartz-facies metasomatism mainly after the protolith of Bt, Amph-Bt and bimica gneisses. Grt mineralization is characteristic of metamorphic rocks such as Grt amphibolites, Grt-Bt gneisses and metasomatic rocks after them. Such Grt formation takes place in Fe-Mg metasomatic zones (faulting). The ore types described practically never occur in pure form. As a result, complex ores are formed.

The stages of ore formation are summarized in Table 2. Information on the age of processes is based on literary sources, with
The factors that control the ore  

| The factors that control the ore | Ores |
|---------------------------------|------|
| Lithologic stratigraphic factors |      |
| Geological connection with the Amph gneisses. | + + + + |
| Geological connection with the Grt gneisses. | ++ – – – |
| Geological connection with the Grt-Bt gneisses. | ++ + + ++ |
| Structural factors |      |
| Synchronous deformation modes | ++ ++ ++ ++ |
| Late deformation modes | + + + + |
| Petrological factors |      |
| Svecofennian metamorphism of amphibolite facies with parameters T~650 p~5-6 kbar. | ++ – – – |
| Acidic metasomatism of kyanite-quartz facies. | + – ++ + |
| Acidic metasomatism of muscovite-quartz facies. | – – + ++ |
| Metasomatism of staurolite-garnet facies | ++ ++ – – |
| Fe-Mg metasomatism associated with acid leaching. | ++ – – – |

Table 1. Applicability of control factors to the description and geometrization of ore types.

The general agreement of almost all authors on the polychronicity of metasomatic processes [11, 13, 14].

CONCLUSION

The main factors controlling ores in the deposits of the Khizovaara structure, are petrological and lithological. The main petrological factors is multi-stage acid kyanite-quartz, mafic staurolite-garnet-facies metasomatism responsible for the formation of Ky, Ky-Qtz (Khizovaara deposit), Ms-Qtz, Ms-Ky-Qtz (Eastern Khizovaara deposit) and Grt-St-Ky-Ms-Qtz and Grt-Ms-Qtz (Vysota-181 deposit) metasomatic rocks that make up over 70% of the ore volume. For many ores in the rear zones of metasomatism restriction to one or another type of protolith loses is not significant because of their uniform composition (e.g. rear ancammonomineral granatites, kyanite-quartz and muscovite-quartz ores). Such bodies are commonly confined to contacts between metamorphic complexes and tectonic unconformities. Thus, the lithological factor at a final metasomatism stage loses its significance for mineralization. The structural factor is extremely important for micaceous rocks that are not resistant to tectonic processes and milonitization. It is established that the ore mineralization of the southern flank of the Khizovaara structure is represented by complex garnet mineralization, petrologically associated with the intense metamorphism of the Svekofennian period, combined with metasomatic processes, and spatially confined to rocks of the sedimentary-volcanogenic stratotectonic association. The deposit is characterized by ore mineralization inherent in the objects of the northern flank of the Khizovaara structure (kyanite and muscovite secondary quartzites, the appearance of decorative rocks of garnet-muscovite-kyanite-quartz composition). The garnet mineralization is unique, characteristic of both metamorphic and metasomatic rocks. The reason is the rock formation that occurs as a result of poly-

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chronic synmetamorphic metasomatic processes. Within the entire Khizovaara ore field, mineralization is confined to sedimentary-volcanogenic and terrigenous deeply metamorphosed rocks, with a gneissic or slate-like texture. The formation of ores occurs as a result of regional metamorphism of the amphibolite facies and synchronous metasomatism, which is most clearly manifested in the zones of intense schismatis on contacts of gneisses with metabasites.

Table 2. Geological time

| Age, M   | Stage                                                                                       | Ores                        |
|----------|---------------------------------------------------------------------------------------------|-----------------------------|
|          | Formation of terrigenous sedimentary rocks of medium composition (main lens)                | –                           |
| 2873+/-36 [14] | Formation of volcanogenic rocks of andesite and dacite composition and gabbro sills (northern part of the structure) | –                           |
| 2776+/-15 [14] | Metamorphism of the Iopian age, formation of amphibolites, amphibole-biotite gneisses, garnet-biotite gneisses. | Grt, Ky + Grt, Ky           |
| 2778+/-21 [11] |                                                                                           |                             |
|          | Formation of basalts (central part of the structure)                                       |                             |
| 1822+/-38 [14] | Metamorphism of the Svecofennian stage, synchronous processes of metasomatic rock change occur against its background | Grt                         |
| 1800+/-7  [13] | 1. Metasomatism of St-Grt facies                                                          | Grt, St                     |
|          | 2. Acid metasomatism Ky-Qtz facies                                                         | Ky, Qtz, Grt                |
|          | 3. The discharge processes of Fe-Mg metasomatism of the main facies                        | Grt                         |
|          | Metamorphism of the late Svekofen stage with the synchronous process of acid metasomatism | Ms, Ky                      |
|          |                                                                                           | Ms, Qtz                     |

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