New data on mineral complexes of the Turgoyak limestone deposit (South Ural)

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Abstract. The main purpose of the research was to ascertain additional development potential of the oldest mining plant in the Southern Urals - the Turgoyak limestone deposit (Miass District, Chelyabinsk region, South Ural). An additional site dike survey work and mineral veins enclosed in carbonate rock strata and overlapping Low Devonian jasperoid rock was carried out. The main purpose of that exploration was a detailed study of the chemical and mineral composition of both dikes and host rock and their secondary alterations. In addition to photographic documentation and mapping, an interrelation between dikes and veins and theirs contacts was determined. Also the connection with them of newly formed sulfide and other secondary minerals was detected (recorded). Subsequently rock and mineral samples were analyzed by microscopic methods, X-ray diffraction and X-ray phase analysis, X-ray fluorescence analysis by RLP-3-01 device, a DRON-7 diffractometer, and a DELTA Premium portable spectrometer. Those investigations resulted in establishment of silicate and calcareous skarns, spatially associated with diabase dikes at the Turgoyak flux limestone deposit. In addition to the skarns, vein polymetallic bodies were recorded there. The most interesting of those are carbonate-quartz-axinitic and axinitic ones. The veins of this composition contain superimposed post-skarn sulfide mineralization, with signs of increased gold content. Given the development at the deposit of the dyke complex and the skarns forming on it, it is possible to forecast the existence of a granitoid intrusion in deep horizons that can generate industrial ore mineralization.

Keywords: skarns, dikes, axinite, gold ore mineralization, veins, X-ray phase analysis

1. Introduction

The main purpose of the research is to show additional reserves of the oldest mining enterprise in the Southern Urals related to the prospects of detecting skarn type ores. Conducted researches show the possibility of detecting a hidden skarn mineralisation, potentially gold-bearing in the area of the Turgoyak flux limestone deposit.
Miass district of the Chelyabinsk region (Figure 1) is a major centre of mechanical engineering and mining with a well-developed energy and transport infrastructure. The Turgoyak deposit is among its oldest enterprises. It has been developed by quarrying since the end of the forties of the last century, and the limestone mined here goes to the metallurgical plants of the Urals, Central and Western Russia.

From a geological viewpoint, the deposit belongs to Turgoyak strata of the Lower Devonian age [1, 2] and is part of a giant tectonic block, which is enclosed in a serpentinite melange of the Main Ural fault [3-5]. Within that block, the strata is deformed into a syncline structure, stretching 25 km in the northeast direction, with a width of 140 to 700 m. Over the sixty years of operation of the quarry, the deposit has been thoroughly studied. In the central part, it is divided by a lateral faulting into the southern and northern blocks, where limestones steeply dip to the east, as well as to the south-east with angles of 65 - 85˚ (Figure 2a). The limestone are gray and bluish-gray, lenticularly layered (Figure 2b), of high quality. Taking into account their average chemical composition (CaO — 55.19%; MgO — 0.33%; SiO₂ — 0.33%; S — 0.02%; P₂O₅ — 0.04%) [2,6] they consist of calcite (97.0%) and as a minor impurity include dolomite (1.5%), siliceous and clay minerals (1.5%).

![Figure 2](image1.png)

**Figure 2.** Limestones of the Turgoyakskoye stratum (a - rock exposure, southern flank of the deposit; b - ore limestone with a lenticular-layered structure; c - microscopic structure of limestone; at the top, large remnants of recrystallized echinoderms. Thin section, polars crossed.

The rocks are marbled, but sometimes contain relics of recrystallized echinoderm fossils (Figure 2c). The recrystallization of limestone is enhanced in the contact areas of diabase dykes and calcite veins, which cross both limestone and overlying jasperoid. The dikes either vertical or acclivous, can be traced up to 300 m and have a thickness of 0.5 - 5 m.

![Figure 3](image2.png)

**Figure 3.** Jasperoids of the stratum overlying the limestones (a - Jasperoid ore with indistinct fine horizontal stratification; b - ore with elements of gradational layering; c - the microscopic structure of jasperoid; in the center - inclusion of phosphate recrystallized to the state of apatite. Thin section, plane polarized light.

The transition from limestone to jasperoid rock is gradual, through the interlayering in the range of 2 - 3 m. The jasperoid is dirty green in color with gray, brown and yellowish hues. Macroscopically, it
is solid monolithic rock with hardly visible horizontal and lenticular stratification (Figure 3a). In some cases, clastic structures with an unclear gradation constitution are observed (Figure 3b). In thin sections, they are composed of weakly crystallized chaledony-like quartz with fine fragments of carbonate, mica flakes, rare quartz sand grains, and also disseminated pyrite. In addition, there are grains and inclusions of phosphate, recrystallized to the state of microcrystalline apatite (2.5% \( \text{P}_2\text{O}_5 \)) (Figure 3c).

2. Materials and methods
As part the RUDN University students’ geological practice, an additional site exploration of the southern flank of the Turgoyak cast mine was carried out. The exploration was accompanied by detailed photographic documentation of the rock material and sampling for various types of analyses. The analyses were carried out at RUDN University and RGGRU University’s labs. In addition to optical microscopy phase, structural, and fluorescent X-ray methods were used to determine the mineral and material composition of the samples using an RLP-3-01 device, a DRON-7 diffractometer, and a DELTA Premium portable spectrometer.

3. Results and discussion
The field and cameral analytical studies made it possible to establish the development of skarn rock at the Turgoyak deposit (Figure 4) and closely related compound rock veins with axinite mineralization.

Skarns are represented by silicate and carbonate varieties. The first are formed upon diabase dykes, often replacing them entirely. The latter make up slim (0.2–1.5 m) margins around the first ones and appear only in cases when diabase dikes intersect limestone (Figure 4a). Macroscopically diabase and skarn look very similar to each other. The presence of the latter is obvious only because of the typical dirty green color hues (Figure 4b). In thin sections, skarns are composed of slightly crystallized mineral aggregates, the identification of which causes considerable difficulties (Figure 4c). Calcite (by twinkling and abnormal interference colors under the microscope), amphibole (by cleavage with an angle of 57°), garnet (by isotropism), epidote (by bright multicolored “lights”) and quartz are identified with certainty. X-ray phase analysis supplements information about minerals (Figure 5).

According to its results, skarns consist of epidote (2.90; 2.81; 2.53; 2.40 Å), calcite (3.85; 3.03; 1.91; 1.87 Å), quartz (3.34; 2.28; 1.98 Å), amphibole (8.44; 3.13 Å), chlorite (14.2; 7.08; 2.01 Å), vesuvian (2.59; 2.45 Å), wollastonite (2.16; 1.82 Å) and garnet. Potassium spar (4.25; 4.02 Å) and scapolite (marialite) are also found in silicate skarns (3.20; 2.68; 2.12 Å). Identified chemical components are: Fe - 3.27%; Mn -0.43%; Ca — 6.19%; K - 2.24%; Ti - 0.28%; further in ppm: V - 30; Ga - 11; Cr - 450; Ni - 145; Sr - 59; Zr — 6; Zn - 52; W - 8; Ta - 100. Veins bodies, along with the well-known calcite veins, are also represented by polymineral buildups. In addition to the usual minerals (calcite and quartz), axinite is involved in their formation (Figure 6).
The latter either fills the central parts of the veins or composes independent bodies up to 1 m width (Figure 7).

Axinit has a vitreous lustre, light brown in color with shades of pink; under the microscope it forms aggregates of translucent tabular wedge-shaped crystals up to 1.5 cm in size. The hardness of the axinite on the Mohs scale is 6.5 - 7. In ultraviolet rays, it emits a faint glow. In thin sections, axinite varies from colorless to brownish shades and has a high relief and positive refractive index (Figure 8a). It has low double refraction, with gray interference colors. When the analyzer is on, there is a noticeable dispersion of the optical axes (the mineral does not go completely dark) (Figure 8b).

According to XRD analysis, the separated fraction relates to magnesioaxinite (Ca$_2$MgAl$_2$BSi$_4$O$_{15}$OH) with cell parameters: $a = 7.138$ Å; $b = 9.161$ Å; $c = 8.943$ Å; $\alpha = 91.9$; $\beta = 98.1$; $\gamma = 77.5$ (Figure 9).
Figure 9. X-ray diffraction (XRD) patterns of fraction rich in axinite.

The increased sulfur content is noteworthy, which is most likely due to sulphide minerals’ ingress in the sample. The latter accompany axinite veins, and associate with their selvages (Figure 10).

Sulfides are represented mainly by the veinlets of pyrite and, partly, by chalcopyrite. It is important to emphasize that, in addition to selvages, the presence of pyrite is also noted in the near-contact zones in limestone, not in veinlet form, but in the form of pockets and solitary crystals up to 1 cm in size (Figure 11). The formation of axinite veins occurred after the skarn formation. The veins associate with fissures in skarns (Figure 12). Taking into account field observations and microscopy data, it is possible to outline a few stages in skarn-vein formations. At the first stages, the skarnification, most likely, had an alkaline nature of metasomatism. This is indicated by the development of alkaline amphibole halos in the host skarn rock (Figure 13).

The latter in thin sections, in addition to cleavage at an angle of 57°, is distinguished by low (gray) interference colors, the dispersion of optical axes, and the development of twins. According to X-ray phase analysis, it relates to amphibole close to crossite of Na₂(Mg, Fe⁺²)₃(Al, Fe⁺³)₂Si₈O₂₂(OH)₂ [7] (Figure 14 and 15).
Signs of the alkaline nature of the process is the presence of skarn minerals of the scapolite group – marialite (Na₄Al₃Si₉O₂₄Cl) and potassium feldspars (K[AlSi₃O₈]). Subsequently, the geochemical environment probably changed to a less alkaline one, which caused amphibole corrosion and mass development of fine-grained mineral aggregate of calcite (CaCO₃) and calcium aluminosilicates (epidote Ca₂Al[Fe³⁺, Al]₂[Si₂O₇]₂[SiO₄]O[OH]; wollastonite Ca₃(SiO₄); vesuvian (Ca, Na)₉(Al, Mg, Fe)₁₃(SiO₄)₁₀(Si₂O₇)₄(OH,F,O)₁₀ and garnet Ca₃Al₂[SiO₄]₃) in diabases.

As a result, skarnified rocks almost without original volcanics features appear on the flanks of the diabase dikes. Finally, at the final stage of skarn formation, low alkalinity conditions appear, favorable for the mass development of quartz, for recrystallization of epidote (Figure 16) and for calcite veins' formation.

It can be assumed that this stage proceeded on the background of high tectonic activity of the region, accompanied by fragmentation and rock fracturing. In thin sections, such a scenario of events is indicated by a common presence of twin gliding with distinct deformation structures in calcite (Figure 17).

The final stage of mineral formation is associated with calcite-quartz-axinite veins' formation and the chalcopyrite-pyrite and pyrite precipitates accompanying them. This rock assemblage requires special attention, since according to the data obtained by the RLP-3-01 device (x-ray fluorescent spectrometer), its gold content is recorded at up to several dozens of ppm (Figure 18).

The consanguinity of skarns and granitoid intrusions is widely known and proven by many researchers [8-17]. Therefore, taking into account the above, it can be assumed that at the Turgoyak deposit at deep level under the limestone bank there is a granitoid massif which is associated with skarns formation. If this is true, then as we approach the intrusion, we should expect an increase in the activity of the skarnification processes and the growth of their ore potential. Moreover, this concerns not only gold, but also other skarn ore mineralization: Cu, Zn, Pb, W, B and others [8-13,15-16]. Of particular interest is boron. As is known, it can accumulate in limestone skarns, forming industrial
agglomerations of datolite minerals (CaB$_4$SiO$_4$ OH) and danburite (Ca$_3$B$_2$Si$_2$O$_8$) [8-10,18]. Often in such cases they are accompanied by axinite [9,10,18].

At the Turgoyak deposit, the presence of this mineral is established in the form of veins, spatially associated with identified skarns. Thus, as can be seen from the above, there is every reason to expect at the deep horizons of the deposit a concentration of not only gold, but also boron industrial mineralization. To confirm this conclusion, it is necessary to carry out a full range of prospecting and exploration operations with the use of drilling technologies.

4. Conclusion

Taking into account the research results, it can be assumed that at deep level under the limestone bank at the Turgoyak deposit there is a granitoid massif which is associated with skarns formation. Therefore, an increase in the activity of the skarnification processes and the growth of their ore potential should be expected, and this concerns the skarn ore mineralization, such as Au, Cu, Zn, Pb, W, B and others.

5. References

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