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The Gerfed gold deposit: fluids and *PT*-conditions for quartz vein formation (*Yenisei Ridge, Russia*)

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Abstract

At the Gerfed gold deposit, fluid inclusions were studied by thermobarometry, gas chromatography, Raman spectroscopy, and ICP MS in quartz samples of three types: quartzites, Au-poor (<1–2 ppm) feathering veins, and Au-rich (>2.8–10 ppm) feathering veins. It has been found that these three types were produced from fluids differing in composition and thermobarogeochemical parameters. The quartzites formed from low-salinity (<7.0 wt.% NaCl equiv) homogeneous fluids of essentially aqueous–chloride composition at 120–230 °C and 0.1–0.5 kbar. The gas phase in these fluids comprises H_2O, CO_2, CH_4, and N_2, with $CO_2/(CO_2 + H_2O)$ = 0.04–0.15 and CO_2/CH_4 = 2.2–3.8. The Au-poor feathering veins formed from homogeneous and heterogeneous fluids at 150–300 °C and 0.5–2.0 kbar. The salinity of the fluids increased to 10 wt.% NaCl equiv. The gas phase in them comprises H_2O, CO_2, N_2, and CH_4. Here, $CO_2/(CO_2 + H_2O)$ = 0.09–0.17 and CO_2/CH_4 = 2.2–2.3. The Au-rich feathering veins formed from heterogeneous and more saline (6.0–23.3 wt.% NaCl equiv) CO_2–H_2O fluids at higher temperatures (150–400 °C) and pressures (1.1–2.5 kbar). In this fluid $CO_2/(CO_2 + H_2O)$ = 0.18–0.27 and CO_2/CH_4 = 4.1–20.8. All three quartz types show negative Eu anomalies and a distinct predominance of LREE over HREE. Differently directed trends of REE and Eu/Sm in the quartzites and feathering veins suggest that the fluids were produced from different sources. The fluids of the gold-bearing quartz veins are enriched in K, Li, and Rb, and those of the Au-poor feathering veins, in Sr and Na. The quartzites have low Rb and Sr and similar Na and K contents. Areas with a high and bonanza gold content in feathering-vein stockworks formed when high-temperature saline H_2O–CO_2 fluids were superposed on the Au-poor quartzites and feathering veins.

Keywords: fluid inclusions; quartz; gold; rare-earth elements

Introduction

The metamorphic rocks of the Yenisei Ridge contain hundreds of quartz veins, but the number of gold-bearing (commercial) ones is considerably smaller (Li, 1997; Li and Nelyubov, 1970; Li et al., 1985; Seredenko, 1985). A combination of gold-bearing and barren quartz veins is exemplified by the Gerfed deposit in the Yenisei Ridge. Studies of the deposit geology and the modeling of the conditions for quartz formation from vein bodies by thermobarogeochemical methods revealed the factors favoring the formation of areas with bonanza gold. The fluid characteristics obtained might be useful for the prediction of gold-bearing quartz veins in prospecting, exploration, and appraisal works.

The Gerfed deposit: a brief geological and mineralogical summary

Vasil'evskii Rudnik CJSC now conducts geological-exploration works at the Gerasimovo-Fedorovskoe (Gerfed) deposit. This deposit, originally named the Magistral'naya vein, is located in the Partizanskii ore district of the Yenisei Ridge. It was discovered in 1890, and its development was started immediately in small open-pit mines in individual areas with visible gold. The first brief description of this deposit was given by A.K. Meister (1900, 1903). Later the data on its geologic structure and gold content were supplemented by exploration geologists: S.V. Rezanov (1927–1932), P.Ya. Zhilkin (1936), V.G. Golubev (1948–1953), K.Sh. Yarkaev (1959), B.E. Shelekhov (1959–1962), V.A. Zonov (1975–1977), V.S. Vlasov (1976–1978), and G.S. Palienko (1980–1990). The data collection and the results of targeted studies

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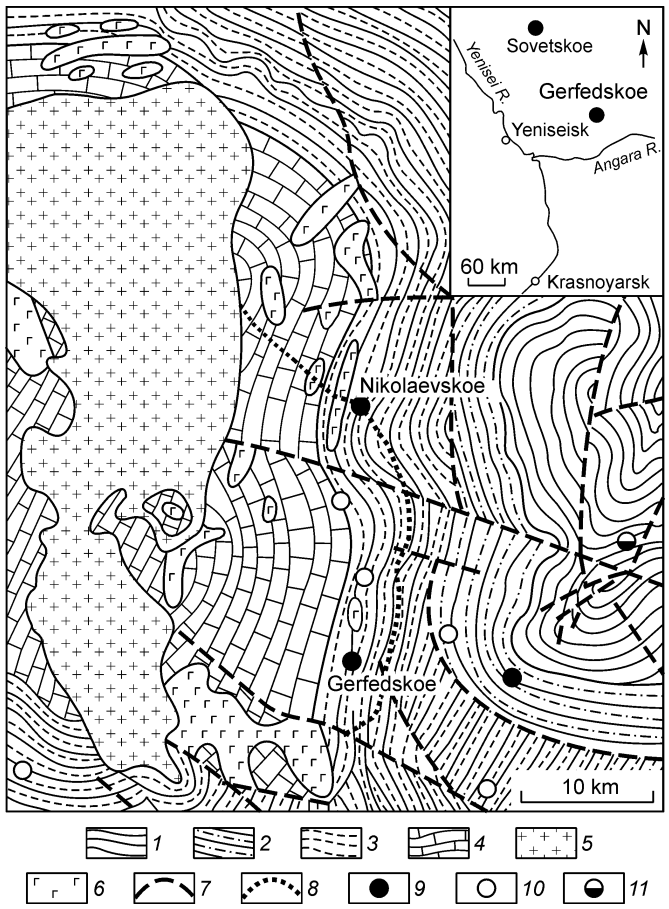

Fig. 1. Geological sketch map of deposits and ore occurrences in the Gerfed ore field (Li and Nelyubov, 1970). *1*, phyllitic schists of the Uderei Formation; *2*, phyllites and laminated siltstone schists of the Gorbilok Formation; *3*, phyllites and sandstones with porphyrite and tuffite lenses of the Korda Formation; *4*, marmorized limestones of the Penchenga Formation; *5*, granites; *6*, orthoamphibolites; *7*, ruptures; *8*, unstripped part of the granite intrusion, according to gravity data; *9*, gold deposits; *10*, gold occurrences; *11*, Au–Sb deposit.

were presented in (Krendelev and Luchko, 1970; Li et al., 1985).

The gold-bearing quartzites of the Gerfed deposit, together with the similar Nikolaevskoe deposit, the Verkhneborovoe, Ivanovskoe, and Verkhneudereiskoe ore occurrences, and the Magnitnaya, Ermakovskaya, and other veins, form the Gerfed–Nikolaevskoe ore field, which extends from north to south for more than 15 km along the large Meister fault. The ore field is located on the eastern flank of a surface doming, the core of which is the Tatarskaya granitoid pluton (Fig. 1).

The dense homogeneous quartzites of the Magistral'naya, Nikolaevskaya, Verkhneborovaya, and other veins, with relicts of psammitic and psephytic textures, are represented by the metamorphosed and silicified strata of mature chemical-weathering crust, predominantly of quartzose composition, which occupied an intermediate position between the Lower and Upper Proterozoic. The relationship between the deposits of the ore field and the Lower–Upper Proterozoic stratigraphic unconformity distinguishes it from the numerous gold-ore localities of the Yenisei Ridge in the orebody structure and the localization of mineralization (Sazonov et al., 2010a,b). The coarse banded distribution of gold in the Magistral'naya vein might suggest the initial sedimentary enrichment of the quartzites in gold.

The quartzites of the Magistral'naya vein, from the footwall side, are adjoined by roughly E–W-trending quartz veins, which sometimes form bunches. The contacts between the filling veins and the Magistral'naya vein are welded and do not intrude the quartzites. These veins are 25–200 m long and 0.2–6.5 m thick, up to 14 m in individual bulges. Some feathering veins were traced downdip to depths of 100–200 m. The following veins are distinguished: SE-striking and steeply dipping ones, adjoining the quatzites of the Magistral'naya vein at a right angle; NE-trending and gently dipping ones, adjoining the quatzites at acute angles. The quartz vein and veinlets are distributed nonuniformly; condensed areas occur in the general scattered pattern, in which the branching and closing veins form stockwork deposits. These bunches or stockwork areas are usually considerably richer in gold than the other areas, not saturated with feathering veins or veinlets.

The Penchenga Formation, which underlies the quartzites of the Magistral'naya vein and contains feathering quartz veins, is dominated by metamafic greenschists. The major minerals are quartz, albite, sericite-muscovite, chlorite, zoisite, actinolite, and calcium–iron–magnesium carbonates. Metamafic schists with biotite and stilpnomelane occur as individual interbeds. The schists contain lenticular orthoamphibolite bodies, which belong to the Indigli complex. The rocks have a relict microgabbroic and doleritic texture; they are mainly of actinolite–albite composition, admixed with relict augite, metamorphic chlorite, and metamorphic zoisite. The Korda Formation, which is located from the hanging-wall side of the Magistral'naya vein, consists of interbedded siltstones, pelites, and silty pelites, affected by greenschist metamorphism. The rocks are of similar mineral composition, vary slightly in color and the character of relict bedding, and belong to carbonaceous chlorite–sericite–quartz phyllitic schists. Near the formation bottom, the schists are enriched in sulfides (pyrrhotite, pyrite), which form pockets, stratal and intruding veinlets, lenses, and impregnation. In the areas adjoining the quartzites of the Magistral'naya vein, the host rocks underwent dynamic metamorphism, chloritization, albitization, carbonatization, and silicification, which were developed in the schists as porphyroblasts, aggregates, and veinlets of the corresponding minerals. The metasomatic rocks accompanying the quartzites of the Magistral'naya vein form subconformable tabular and lenticular bodies and are localized in the tectonic zone of the undulose, brecciated, and mylonitized rocks of the Penchenga and Korda Formations (~1 km thick).

The columnar quartzite orebody consists of 11 isolated lenticular and tabular fragments. The length of individual quartzite bodies varies from 180–200 to 420 m and is traced to a depth of over 450 m. The maximum thickness of the Magistral'naya vein is 31.5 m, and its total thickness is over 7 km. The strike of the vein is 10°–20°, and its southeastern dip is 30°–60°, the average strike being 15°. In general, the vein is conformable to the host rocks at the contact between the Penchenga and Korda Formations. Despite the simple