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Composition and sources of mineral-forming fluids of the Orlovka orogenic gold deposit (*Southern Urals*)

S.E. Znamenskii [a,*], N.N. Ankusheva [b,c], T.A. Velivetskaya [d], S.N. Shanina [e]

[a] *Institute of Geology, Ufa Scientific Center, ul. K. Marksa 16/2, Ufa, 450072, Russia*
[b] *Institute of Mineralogy, Ural Branch of the Russian Academy of Sciences, Il'menskii Zapovednik 1, Miass, 456317, Russia*
[c] *Department of South Ural State University, ul. 8 Iyulya 10, Miass, 456304, Russia*
[d] *Far East Geological Institute, Far Eastern Branch of the Russian Academy of Sciences, pr. 100-letiya Vladivostoka 15, Vladivostok, 690022, Russia*
[e] *Institute of Geology, Komi Scientific Center, Ural Branch of the Russian Academy of Sciences, ul. Pervomaiskaya 54, Syktyvkar, 167982, Russia*

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Abstract

Fluid inclusions, REE and Y patterns, and carbon and oxygen isotope ratios in the minerals of sulfide–carbonate–quartz mineralization of the Orlovka orogenic gold deposit were studied. We have established that fluid inclusions in calcite and quartz homogenize in the same temperature range 217–170 °C and contain aqueous Mg–K–Na solutions with salinity of 3.0–6.4 wt.% NaCl equiv. According to the results of gas chromatography of inclusions in quartz, the gas phase is a mixture H_2O (79–977 ppm) + CO_2 (2.64–5.35 ppm) + CH_4 (0.002–0.018 ppm) ± N_2 (0–1.22 ppm). The REE pattern of calcite shows accumulation of LREE ($(La/Yb)_N$ = 1.28–7.18), $(La/Lu)_N$ = 1.10–6.58 (indicating a predominance of REE sorption in the fluid), and weak negative Ce and positive Eu anomalies. Negative Ce anomalies in calcite might be due to the interaction of the fluid with limestones and to the presence of a small amount of meteoric water in it. The positive Eu anomalies reflect the high-temperature environment (>200–250 °C) that existed in the fluid system before the crystallization of calcite. The $\delta^{13}C_{CO_2}$ (–2.0 to +0.9‰) values of the fluid, close to the carbon isotope composition of carbonates of the host rocks (–2.3 to +1.9‰), testify to the metamorphogenic source of carbon. The $\delta^{18}O_{H_2O}$ values of the fluid depositing quartz (3.1 to 4.5‰) and calcite (4.0 to 4.6‰; one sample has 6.6‰) suggest that metamorphic water with an impurity of meteoric water prevailed in the fluid system. We propose a model for the gold deposit formation, which takes into account the generation of a mineral-forming fluid at the progressive stage of greenschist dynamometamorphism of the host rocks and the formation of gold mineralization at the regressive stage.

Keywords: orogenic gold deposit; fluid inclusions; REE; oxygen and carbon isotopes; Southern Urals

Introduction

Genesis of orogenic mesothermal gold deposits (Groves et al., 1998) is the subject of discussions. There are many different hypotheses of the mechanisms of their formation: convective-meteoric, sedimentary-hydrothermal, hydrothermal-metamorphic, hydrothermal-magmatic, polygenetic-polychronous, etc. (Bortnikov et al., 2007; Goryachev, 2014; Groves et al., 1998; Kerrich et al., 2000).

Numerous, mostly small orogenic gold deposits are known within the Main Uralian Fault zone (Southern Urals). They occur in the Ordovician–Lower Carboniferous volcanosedimentary strata that underwent Late Paleozoic collisional deformations and greenschist facies metamorphism (Fig. 1). One of them is the Orlovka gold–sulfide–quartz deposit.

Elaboration of geological-genetic and related prediction–search models of orogenic gold deposits is a topical problem in the context of prospecting for gold (funded by the Federal Subsoil Resources Management Agency of Russia) in the Southern Urals, including the Main Uralian Fault zone. The composition and sources of ore-forming fluids are basic elements of these models.

To elucidate the physicochemical parameters and sources of mineral-forming fluids of the Orlovka deposit, we studied fluid inclusions (FI), REE and Y patterns, and oxygen and carbon isotope ratios in the gold ore minerals.

* Corresponding author.
E-mail address: Znamensky_Sergey@mail.ru (S.E. Znamenskii)

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A brief geological outline of the deposit

The Orlovka deposit lies in the Main Uralian Fault zone, 50 km north of the city of Uchaly (Fig. 1). It is localized in the zone of collisional reverse fault of SE dip formed along the contact of serpentinite melange with a terrane of Early–Middle Devonian sedimentary, volcanosedimentary, and volcanic rocks (Fig. 2) (Znamenskii et al., 2015). There are also the Asfandiyar deposit and several small ore mineralizations in this zone; their ores are similar in composition to those of the Orlovka deposit. The reverse fault consists of segments with different structures along the strike. The boundaries between these segments are transfer faults of E–W and NW strikes. All known gold deposits and ore shows are confined to the most dislocated segment of the fault zone, with an imbricated structure and intense greenschist dynamometamorphism of its rocks. The most complete section of the ore-hosting strata consists of three members (from bottom to top): limestones with intercalates of carbonaceous clayey-siliceous shales, siltstones, and sandstones; mafic volcanosedimentary rocks; and pyroxene–plagioclase porphyrites and their breccias. The thickness of the ore-hosting beds reaches 150 m.

The major gold reserves of the deposit are concentrated in the Orlovka ore zone (950 m long in strike, up to 200 m long in dip, and 4.2 m thick (on average); the average gold content is 4.4 ppm). It is confined to the fault separating tectonic slices. East of the zone, several small orebodies were stripped in the secondary ruptures of the imbricated reverse fault, including the mineralized Zhila (Vein) 2 zone of commercial value (120 m long in strike and 1.7–4.0 m thick; the gold content is 0.2–5.3 ppm). The orebodies are composed of albite–biotite(or muscovite)–quartz–chlorite–epidote–actinolite schists with younger carbonate–quartz veinlets. The carbonate is calcite. Sometimes, the veinlets contain albite and prehnite. The ore-bearing schists have textures indicating their formation under intense stress: thrust duplexes, plication, kink bands, boudinage, etc. Localization of carbonate–quartz veinlets is controlled by local extension structures: flexures of foliation surfaces, extension fractures cutting foliation, extension duplexes, etc. (Fig. 3*a*, *b*). Most of the veinlets make sharp contacts with the host schists and lack metasomatic rims (Fig. 3*c*). They are, most often, of zonal structure (Fig. 3*d*). The edges are composed of calcite, and the cores are formed by younger quartz. Apparently, the veinlets formed mainly from periphery to core. They are accompanied by disseminated sulfide (mostly pyrite) mineralization and native gold. In addition to pyrite, the veinlets contain minor chalcopyrite, galena, and arsenopyrite. From our data, the Au content in the pyrite is low (0.07–7.7 ppm). Sulfides and native gold are confined to the veinlet selvages. Beyond the ore-bearing faults, dynamometamorphic transformations are less intense. The number of carbonate–quartz veinlets and the content of sulfide minerals significantly decrease, and the content of gold is of no commercial value.

In 2006–2009, the Bashkirgeologiya Inc., with financial support by the Federal Subsoil Resources Management Agency of Russia, performed prospecting and evaluated the prognostic P_2 gold resources of the Orlovka and Asfandiyar deposits at 25 tons (with the average gold content being 4.0 ppm).

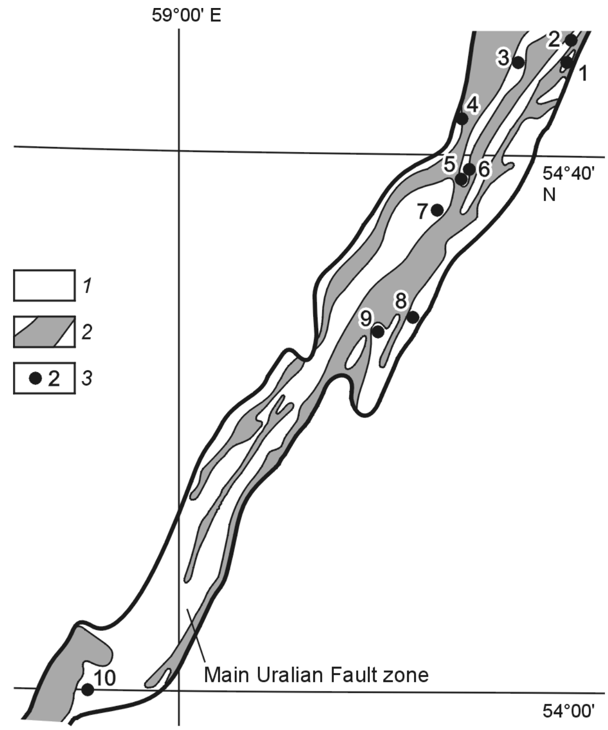

Fig. 1. Position of the Orlovka deposit in the Main Uralian Fault zone. *1*, Paleozoic complexes; *2*, serpentinites and serpentinite melange; *3*, orogenic gold deposits: 1, Orlovka, Asfandiyar; 2, Srednee Ubaly; 3, Andrei-Ivanovka; 4, Siratur; 5, Malyi Karan; 6, Aleksandrovka; 7, Veseloe; 8, Belaya Zhila; 9, Ganovka; 10, Mindyak.

Fluid inclusions

We performed microthermometric studies of FI in quartz and calcite from carbonate–quartz veinlets developed in the Orlovka ore zone and in the host schists of its hanging and lying flanks. We also carried out a gas chromatography analysis of the bulk volatiles in FI in quartz.

Microthermometric studies

The studies were performed using TMS-600 (Linkam) thermocryostage equipped with an Olympus BX-51 microscope and LinkSys V-2.39 software, ensuring measurement of the temperatures of phase transitions in the range from –196 to 600 ºC (analyst N.N. Ankusheva, Laboratory of Thermobarogeochemistry of the South Ural State University). The error of measurement was ±0.1 ºC at –20 to 80 ºC and ±1 ºC beyond this temperature range. The salt composition of the inclusion fluids was estimated from eutectic temperatures (Borisenko, 1977). Homogenization temperatures were measured at the moment when the vapor bubble disappeared from FI during the heating. The inclusions were first cooled and