ISSN 1028-334X, Doklady Earth Sciences, 2016, Vol. 466, Part 2, pp. 161–164. © Pleiades Publishing, Ltd., 2016.
Original Russian Text © A.V. Volkov, K.Yu. Murashov, A.A. Sidorov, 2016, published in Doklady Akademii Nauk, 2016, Vol. 466, No. 5, pp. 574–577.

GEOCHEMISTRY

Geochemical Peculiarities of Ores from the Largest Natalka Gold Deposit in Northeastern Russia

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Received June 5, 2015

Abstract—This study of the behavior of trace and rare earth elements in ores from the Natalka gold deposit allows us to draw several conclusions. It is suggested that ore formation is related to the regional metamorphism of the host terrigenous carbonaceous rocks, which could be the major source for trace and rare earth elements. Minor enrichment of the Natalka ores in W is evidence of the contribution of magmatic fluid, which could be superimposed on early quartz veins, in ore formation. Our results support the metamorphic–magmatic model of formation of economic gold–quartz deposits of the Yana–Kolyma Belt. The similarity of metasomatites of the Natalka deposit with disseminated gold–sulfide refractory ores from the Nezhdaninskoe and Bakyrchik deposits points to the possible presence of such ores in the Natalka deposit. Our data are important for forecasting regional metallogenic reconstructions, search, and evaluation of gold deposits.

DOI: 10.1134/S1028334X16020161

The formation of large economic gold deposits requires geochemical enrichment in the global mean content by a coefficient of >1000. At average contents in ores (1–10 g/t), however, gold and many other associated metals are still trace elements, the composition and distribution of which in ores are extremely important for understanding the genesis of the deposits, and could be used as criteria of their forecast and evaluation. For ores of the black shale–hosted gold deposits, data on the composition and distribution of most trace and rare earth elements are extremely limited. The geological structure, composition, and formation conditions of the Natalka deposit, as well as REE behavior during wall–rock alteration, have been discussed in detail [1]. The geochemical peculiarities of the host terrigenous rocks were also studied previously [2].

This study of the geochemical peculiarities of ores from the Natalka deposit is based on new ICP MS and RFA data, which were obtained in the Analytical Laboratory of the Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Russian Academy of Sciences (analysts A.I. Yakushev and Ya.V. Bychkova). Figure 1 shows the photographs of the studied samples of major ore types of the deposit.

The results of analysis of trace elements in the ores from the Natalka deposits are shown in Fig. 2, where they are normalized relative to the mean values for the upper crust [3]. As follows from Fig. 2, the gold–quartz veins of the deposit are enriched in chalcophile elements (Au, Ag, As, Sb) and insignificantly enriched in Pb and W in comparison with the mean values of those elements in the upper crust [3] and host Permian rocks [2]. The coefficients of enrichment vary from several to thousands of times, which indicates the geochemical similarity of trace elements and their synchronous participation in ore formation. On the basis of the data of [2], the host Permian rocks were insignificantly enriched in Au, Ag, Ni, Co, Zn, Cr, Li, and Sc relative to the upper crust [3] and could be their source for the ore-forming fluid. The enrichment of the Natalka ores in W (Fig. 2) may indicate the contribution of magmatic fluids, which could be superimposed on the early quartz veins, to the formation of ores [4].

It is known that Cl-rich hydrothermal fluids concentrate effectively the LREEs but they are depleted in HREEs: the Hf/Sm, Nb/La, and Th/La ratios, as a rule, are <1. At this, the F-rich fluids synchronously accumulate the LREEs and HREEs and the Hf/Sm, Nb/La, and Th/La ratios are >1 [5]. According to the analytical data, the ores from the Natalka deposit are evidently enriched in LREEs, but are depleted in HREEs (Fig. 3) with Hf/Sm, Nb/La, and Th/La ratios of <1. Thus, it may be concluded that the ore-forming fluids of the deposit belonged to the NaCl–H_2O hydrothermal system enriched in Cl relative to F. The results of study of fluid inclusions in quartz of ores of the Natalka deposit [1] are consistent with this conclusion.

The U/Th value in ores reflects the redox peculiarities of the host media [6] and is ≤0.75, 0.75–1.25, and >1.25 under oxidized, oxygen-free, and reduced conditions, respectively. The U/Th values in ores of the Natalka deposit is significantly lower than 0.75 (0.35,

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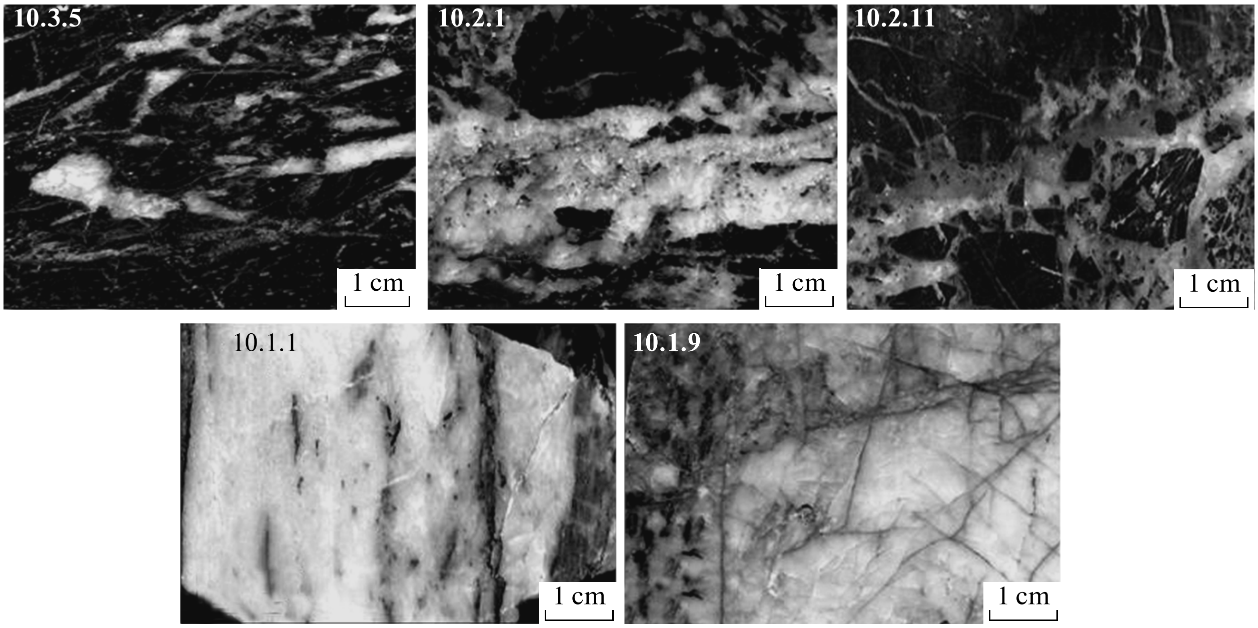

Fig. 1. Ore types of the Natalka deposit. 10.3.5, veinlets of auriferous quartz in siltstone (mine 3, horizon 100 m); 10.2.1, gold–quartz veinelts in siltstone (mine 1, horizon 1200 m); 10.2.11, clasts of siltstone in a veinlet of metamorphic quartz (mine 3, horizon 1100 m); 10.1.1, quartz bands in carbonaceous siltstone (mine 1, horizon 1200 m); 10.1.9, massive quartz with small clasts of siltstone (mine 2, horizon 1150 m).

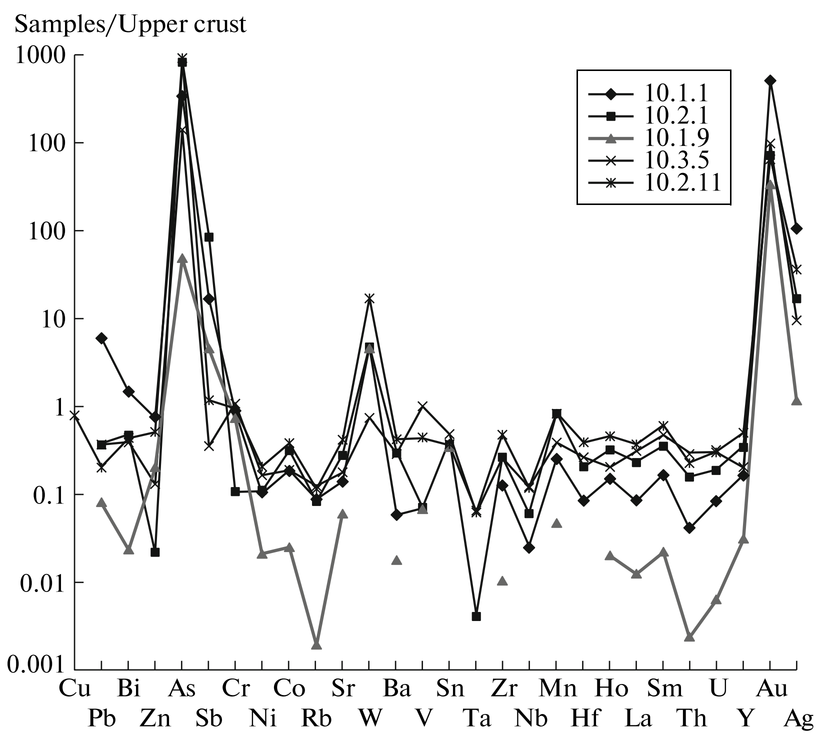

Fig. 2. Trace elements in major ore types of the Natalka deposit. Here and in Fig. 3, 10.1.1 and others, sample numbers in Fig. 1.

on average) and is slightly higher than those in the host Permian rocks [2] indicating the acid conditions of ore formation. The Co/Ni ratio in ores of the Natalka deposit is very close to 1.0, which is typical of metamorphic hydrothermal fluids [4].

The possibility of effective use of the Y/Ho ratio in assessment of the origin of ore-forming fluids is shown in [4, 7]. In the Natalka ores, its value is 29.35, on average, and is in a range that indicates the relation of ore formation to metamorphism [4, 7].

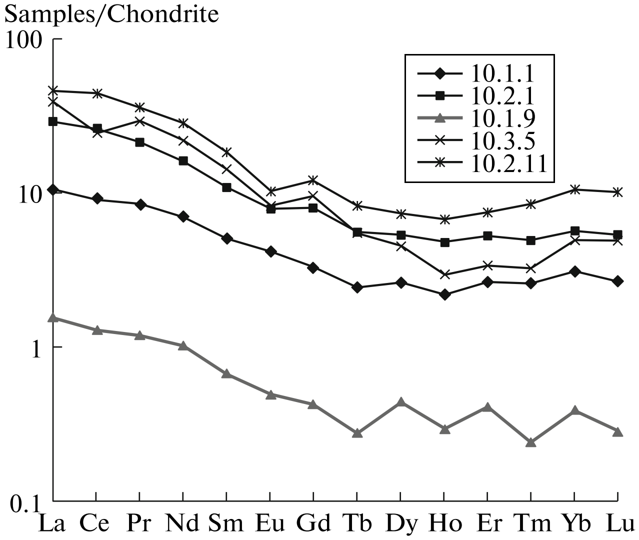

Fig. 3. REEs in major ore types of the Natalka deposit.

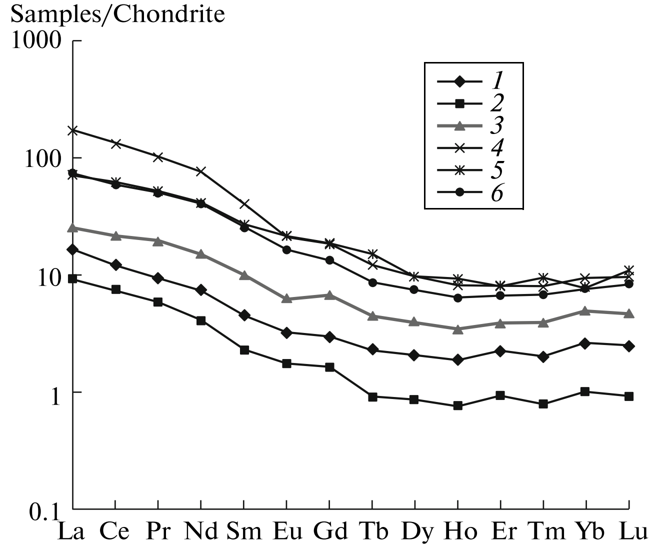

Fig. 4. REE patterns of mean values in the ores and metasomatites of some gold–quartz and gold–sulfide disseminated deposits in terrigenous rocks. (*1*) Poor gold–quartz ores, Rodionovskoe deposit; (*2*) rich gold–quartz ores, Mal'dyak deposit; (*3*) gold–quartz ores, Natalka deposit; (*4*) ore-bearing beresites, Nezhdaninskoe deposit [10] (gold–sulfide disseminated ores); (*5*) gold–sulfide disseminated ores, Bakyrchik deposit [9]; (*6*) ore-bearing metasomatites, Natalka deposit [1].

The composition and chondrite-normalized REE patterns of the deposit are shown in Fig. 3a. The REE sum in ores is lower by several times relative to the Upper Permian rocks of the region [2], chondrites, and the upper crust [3]. The chondrite-normalized REE patterns of the ores are characterized by slightly inclined LREE-rich and HREE-poor spectra (Fig. 3a). The total REE content in ores is 33.54×10^{-6}, on average. The enrichment of the REE pattern in LREEs ($La_N/Yb_N = 5.14$, $\Sigma LREE/\Sigma HREE = 6.83$) is accompanied by a flat HREE pattern ($Gd_N/Yb_N = 1.35$). The inclined and flat areas of the REE pattern in the ores (Fig. 3) are similar to those for the Upper Permian host rocks [2], which allows us to suggest the inherited REE evolution in the ores.

The Eu and Ce anomalies are considered to be markers of the redox conditions [1, 8]. Small negative δCe (0.94) and δEu (0.75) anomalies in the ores from the deposit indicate the acid conditions of ore formation [8].

Comparison of the average REE values of the ores from five deposits shows the same character of the distribution pattern and various enrichment of ores in these elements (Fig. 4). The REE pattern of metasomatites of the Natalka deposit [1] is very similar to those of disseminated gold–sulfide refractory ores from the Bakyrchik [9] and Nezhdaninskoe [10] deposits. At the same time, the metasomatites of the Natalka deposit and disseminated ores from the Bakyrchik and Nezhdaninskoe deposits are evidently distinct in the degree of REE enrichment from the gold–quartz ores from the Mal'dyak and Rodionovskoe deposits (Fig. 4).

The geochemical peculiarities of the behavior of trace and rare earth elements in the stockwork ores from the Natalka deposit allow us to draw several conclusions. The ore formation is related to the regional metamorphism of the host terrigenous carbonaceous rocks, which could be the major source of trace and rare earth elements. The negative Eu anomalies and the low ΣREE contents in the ores from the Natalka deposit are typical of metasomatic fluids [7, 11]. Minor enrichment of the ores in W is evidence of the contribution of magmatic fluid, which could be superimposed on the early quartz veins, to ore formation [4]. These results correlate with the metamorphic–magmatic model of the formation of the gold–quartz deposits of the Yana–Kolyma Belt [12]. Geochemical similarity of metasomatites of the Natalka deposit with disseminated gold–sulfide refractory ores from the Bakyrchik and Nezhdaninskoe deposits supports the presence of these ores in the Natalka deposit [13]. Our data are important for forecasting the regional metallogenic interpretations, searching for, and evaluating gold deposits.

ACKNOWLEDGMENTS

This work was supported by the Russian Science Foundation (project no. 14-17-00170).

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Translated by I. Melekestseva