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GEOCHEMISTRY

First Estimate of the Age of Gold Ores of the Darasun Deposit (Eastern Transbaikal Region) by the Sm–Nd Method

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Determination of the age of ores is a challenge for several reasons. Isotope datings of ores are absent for many deposits, such as the Darasun gold deposit, which has been exploited since the nineteenth century. It is worth mentioning that the Darasun Mine was the second (after the Balei Mine) largest gold mining plant of the Chita district in the Soviet time. The gold was primarily mined in the Darasun deposit. The study of this deposit became a pressing issue because of the resumption of its exploitation in 2004.

The Darasun deposit incorporates more than 200 sulfide–quartz ore veins formed in three stages: (1) the quartz–sulfide stage (quartz–tourmaline, quartz–pyrite, and pyrite–arsenopyrite assemblages with gold and ankerite); (2) the sulfide–sulfosalt stage (sphalerite–galena and chalcopyrite–fahlore assemblages with bismuth tellurides and gold); and (3) the sulfoantimonite stage (sulfoantimonite and quartz–carbonate assemblages) [1]. In addition, the medium-scale Talatui deposit and the small Teremkin deposit are also developed in the study region. All these deposits are confined to igneous rocks (Fig. 1). The oldest (Early Paleozoic) metamorphosed gabbroids are intruded by Middle Paleozoic and Early Mesozoic granodiorites, diorites, granites, granosyenites, and syenites. The majority of researchers [2–8 and others] believe that gold mineralization of the study region is associated with high-alkali subvolcanic intrusions of the Middle–Upper Jurassic Amudzhikan Complex related to the collision of the Siberian and Mongol–Sinian continents at the Early–Middle Jurassic boundary [9], because both ore and subvolcanic bodies are confined to the same structures. The K–Ar and Rb–Sr data indicate that magmatic and hydrothermal processes took place in the Darasun deposit region 175–91 Ma ago [2, 3, 5–8]. However, these data are based on the analysis of bulk samples of igneous and metasomatic rocks.

Direct datings of ore veins in the Darasun deposit were absent until recently. Estimation of the age of gold ores of this deposit is not a trivial issue, because visible contacts (correlation) of ores with sedimentary rocks are absent here. Minerals suitable for the K–Ar and Rb–Sr datings are also lacking.

Therefore, we used the Sm–Nd isotope method at this deposit for the first time. We investigated mono-mineral samples of tourmaline, calcite, and arsenopyrite related to the early stage of ore vein formation in the Darasun deposit (table). In terms of the chemical composition, all tourmaline samples belonged to intermediate members of the schorl–dravite–povondraite–uvite series. Tourmaline and arsenopyrite were dissolved in the hydrofluoric acid in Teflon chambers at 180°C for 5 days. The sample weight varied from 700 mg (arsenopyrite) to 400 mg (tourmaline) and 50 mg (carbonate).

The Sr and Nd isotopic compositions, as well as Rb, Sr, Sm, and Nd concentrations in minerals, were determined by isotope dilution in a TRITON^{TM} solid-phase thermoionization multi-collector mass spectrometer at the Isotope Research Center of the Karpinskii All-Russia Research Institute of Geology (St. Petersburg). Chemical elements were extracted by the routine procedure of chromatographic fractionation [11]. Uncertainties of determination were 0.3% for ^{147}Sm/^{144}Nd and

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Fig. 1. Geological map of the Darasun ore group (based on materials of the Darasun geological-exploration expedition). (*1*) Alluvial sediments; (*2, 3*) Middle–Upper Jurassic Amudzhikan Complex: (*2*) volcanic rocks, (*3*) subvolcanic and dike porphyry rocks (diorite porphyries, granodiorite porphyries, granite porphyries, and others); (*4*) Triassic Amanan Complex (biotite–hornblende granites and granodiorites); (*5, 6*) Upper Paleozoic–Lower Mesozoic Olekma Complex: (*5*) biotite and leucocratic granites, (*6*) syenites, granosyenites, and quartz syenites; (*7*) Middle Paleozoic Krestov Complex (diorites, quartz diorites, and granodiorites); (*8*) Lower Paleozoic Kruchina Complex of metamorphosed gabbroic rocks (granitized gabbro, amphibolites, gabbro diorites, and troctolites); (*9*) tectonic fractures; (*10*) ore bodies; (*11*) deposits: (1) Darasun, (2) Teremkin, (3) Talatui. (*a*) Ring-shaped anomaly; (*b*) Darasun intrusion framework.

$^{87}Sr/^{86}Sr$ ratios, 0.5% for Rb, Sr, Sm, and Nd concentrations, and better than 0.005% for the Sr and Nd isotopic compositions. Based on the replicate measurements of the La Jolla, BCR-1, BCR-2, and SRM-987 standards, reproducibility of the analysis of Sm and Nd was ±0.005%.

In minerals from ore veins of the Darasun deposit, the Sm and Nd contents are 1.701–0.040 and 7.803–0.191 ppm, respectively (table 1). The Sm/Nd ratio shows significant variations accompanied by regular changes in the Nd isotopic composition. This makes it possible to use the isochron model for the dating of mineralization. The $^{147}Sm/^{144}Nd$–$^{143}Nd/^{144}Nd$ linear trend (based on four data points) can be considered an isochron relationship corresponding to 100 ± 18 Ma (MSWD = 0.077) and the primary Nd isotopic composition of $(^{143}Nd/^{144}Nd)_0 = 0.512478 \pm 0.000019$ (Fig. 2). However, the Rb and Sr isotope data did not yield an

Contents (ppm) and isotopic compositions of Sm, Nd, Rb, and Sr in minerals from the Darasun gold deposit

Sample no.	Mineral	[Sm]	[Nd]	^{147}Sm/^{144}Nd	^{143}Sm/^{144}Nd	εNd	[Rb]	[Sr]	^{87}Rb/^{86}Sr	^{87}Sr/^{86}Sr	(^{87}Sr/^{86}Sr)$_t$
1185dr/86	Tourmaline	0.68	3.04	0.1345	0.512567	–0.4	2.56	1501	0.00494	0.70698	0.70697
1176dr/86	Tourmaline	1.07	7.80	0.0827	0.512532	–0.2	1.06	710.9	0.00430	0.70671	0.70670
170dr/85	Calcite	1.70	4.10	0.2509	0.512642	–0.8	1.15	220.6	0.01512	0.70664	0.70661
30dr/85	Arsenopyrite	0.04	0.19	0.1253	0.512560	–0.3	1.43	1.092	3.79139	0.71368	0.70668

Note: Samples 1185dr/86 and 1176dr/86, Mine 14, horizon 210 m, Yuzhnyi crosscut, Nagornyi vein sector. Sample 1185dr/86 was taken from a vein of the following composition: coarse-crystalline pyrite (30%) in the central part of the vein, fine-grained compact tourmaline (30%), quartz (25–30%), pink carbonate (10%) along the vein selvage, and montmorillonite coating (beresitized granodiorite is the host rock). Sample 1176dr/86 was taken from a 15-cm-thick vein of the following composition: fine-grained tourmaline (60%) in the central part of the vein, quartz (20%), pyrite patches (15%) in tourmaline and quartz, chalcopyrite, and relicts of the host rock (5%). Sample 170dr/85: Mine 14, horizon 160 m, Yuzhnyi crosscut, Nagornyi vein sector. The sample was taken from a banded vein (dark quartz–pyrite–tourmaline vein grading into light quartz–pyrite vein with tourmaline and carbonate near the selvages). Sample 30dr/85: Mine 14, horizon 160 m, crosscut into the Razvedochnaya vein. The sample was taken from a 5-cm-thick banded veinlet composed of pinky cream carbonate (with single sphalerite grains) at the center successively replaced by coarse- and fine-grained arsenopyrite aggregates (locally associated with pyrite and chalcopyrite) at the edge. Beresitized granodiorite porphyry is the host rock.

analogous temporal relationship due to low Rb contents and insignificant variations of the Rb/Sr ratio in the studied minerals (table).

Values of the initial isotope relations (ε(Nd) = –0.3 ± 0.3 and (^{87}Sr/^{86}Sr)$_t$ = 0.7067 ± 0.0002) testify to the crustal origin of the source of mineralization, although one cannot rule out the participation of an undepleted (chondritic) material of mantle reservoir [10].

The age estimate (~100 ± 18 Ma) obtained for gold ore veins of the Darasun deposit indicates that gold ores are younger than was previously considered. Despite a significant error value, the results obtained suggest that the ore-forming process in the Darasun deposit is unrelated to the collision stage. Instead, this process is related to the formation of Early Cretaceous volcanoplutonic complexes of the Mongol–Okhotsk zone (Fig. 3), which accompanied the genesis of rifts [9, 12, and others]. This statement is fairly consistent with the conclusion about the similarity of the Darasun deposit with porphyry-type deposits [5], because these deposits are also associated with plutonovolcanic andesite complexes [13]. At the same time, it is known that porphyry gold deposits associated with alkaline magmatism are often conjugated with epithermal deposits [14 and others]. In this connection, the Early Cretaceous age (114–120 Ma, K–Ar method) of epithermal Au-bearing quartz–adular veins in the Balei deposit attracts our attention (Fig. 3). The Darasun and Balei deposits probably represent different depth facies (porphyry and epithermal facies, respectively) of the early Cretaceous gold mineralization. Since the Darasun and Balei deposits are proxies of two major types of gold mineralization in the Transbaikal region, the genetic model proposed in the present paper can change prospecting criteria for gold mineralization in this region. However, further mineralogical–geochemical and isotope investigations are needed for checking this point of view.

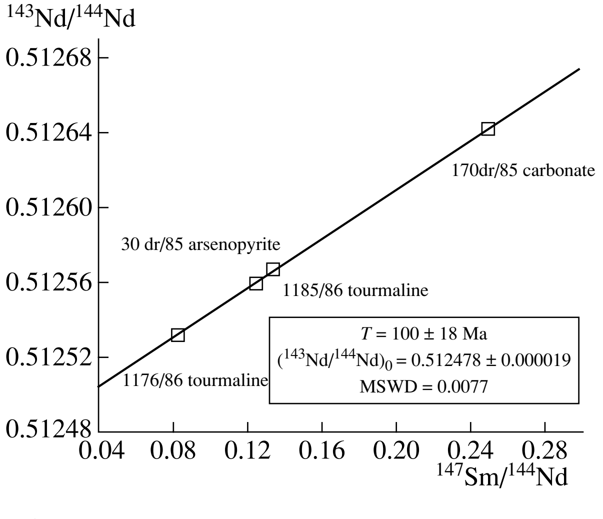

Fig. 2. Sm–Nd isochron for minerals from ore veins of the Darasun deposit.

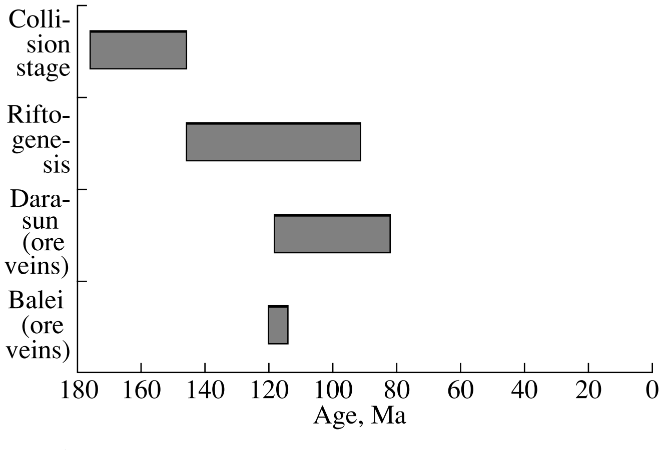

Fig. 3. Datings of igneous rocks, ores, and metasomatites from the Darasun deposit and its vicinities ([2–8] and new data).

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