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GEOLOGY

Geodynamic Setting of Gold Ore Deposits of the Neoproterozoic Bodaibo Trough

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The aim of this work is to show that the formation of the unique Sukhoi Log deposit and other smaller gold ore deposits of the Bodaibo area was related to a series of geological and geodynamic events. Each of these events was determined by certain settings spanning giant territories in the southern framing of the Siberian Craton. All these independent events were separated by a time span of hundreds of millions of years. They did not affect the type, timing, and position of the subsequent geological processes. At the same time, each stage of the geological evolution of the Bodaibo trough, which hosts the large Bodaibo group of the gold ore deposits of the Sukhoi Log type (hereafter, the Bodaibo group deposits), had a certain influence on processes of gold mineralization in the study region; this influence is reflected in the accumulation of Au-prone metalliferous sediments at the first stage. Subsequent structural and metamorphic transformations of rocks in the trough fostered the redistribution of Au in the sediments. At the final stage, ore deposits were formed under the influence of magmatism in a within-plate setting.

According to [1, 2], the Bodaibo group deposits formed over a long period (~500 Ma) spanning from the Middle Riphean to Late Paleozoic. Let us consider each stage in the evolution of the Bodaibo trough and assess its significance in the formation of the unique Sukhoi Log deposit.

The Bodaibo trough is mainly composed of the carbonaceous carbonate–terrigenous rocks. Based on findings of stromatolites and microphytoliths, the rocks correlate with the Middle–Late Riphean sequences in the Baikal and Lena lithostructural zones. These rocks formed at the passive margin (currently represented by the Patom arc) of the Siberian continent [3] in the relatively deep troughs in a continental-margin riftogenic setting [4]. This stage of the formation of rift structures is recorded in the Riphean sequences, which correlate with the Medvezhevsk Formation on the basis of the abundance of mafic and presumably ultramafic rocks [5]. The riftogenic setting existed for ~200 Ma (900–700 Ma BP) [5] and promoted the separation of the continental margin into series of troughs and uplifts [7, 8]. The ore-productive sequences accumulated since the Middle Riphean to 700 Ma BP simultaneously with the formation of grabens. These sequences are made up of carbonaceous terrigenous–carbonate rocks typical of the passive continental margin. They are grouped into Buzhuikhta, Ugakhan, Khomolkha, Aunakit, and other formations. The Khomolkha and Aunakit formations are enriched in Au, PGE, and other siderophile and chalcophile elements. The Au content in the rocks is often three to five times (locally, up to ten times) higher than the clarke abundance even well beyond the ore deposits and fields. For example, concentrates of insoluble carbonaceous matter extracted from the Khomolkha Formation contain 1–2 g/t Au, while bitumoids (soluble carbon compounds) contain up to 10*n* g/t Au [9]. Note that precisely these two formations serve as ore-enclosing rocks at the majority of ore deposits and occurrences of the Bodaibo area.

Sedimentation in the Bodaibo trough continued after the cessation of rifting as well. Therefore, the black shales in the Bodaibo sequence are overlapped by the Vendian polymictic sandstones. In general, the first stage of the formation of the Bodaibo group deposits is related to the formation of the passive continental margin of the Siberian continent at the boundary with the Paleoasian Ocean. Continental rifting of this stage was further replaced by the accumulation of thick sedimentary sequences with a large amount of Au- and PGE-rich carbonaceous rocks on the platform margin.

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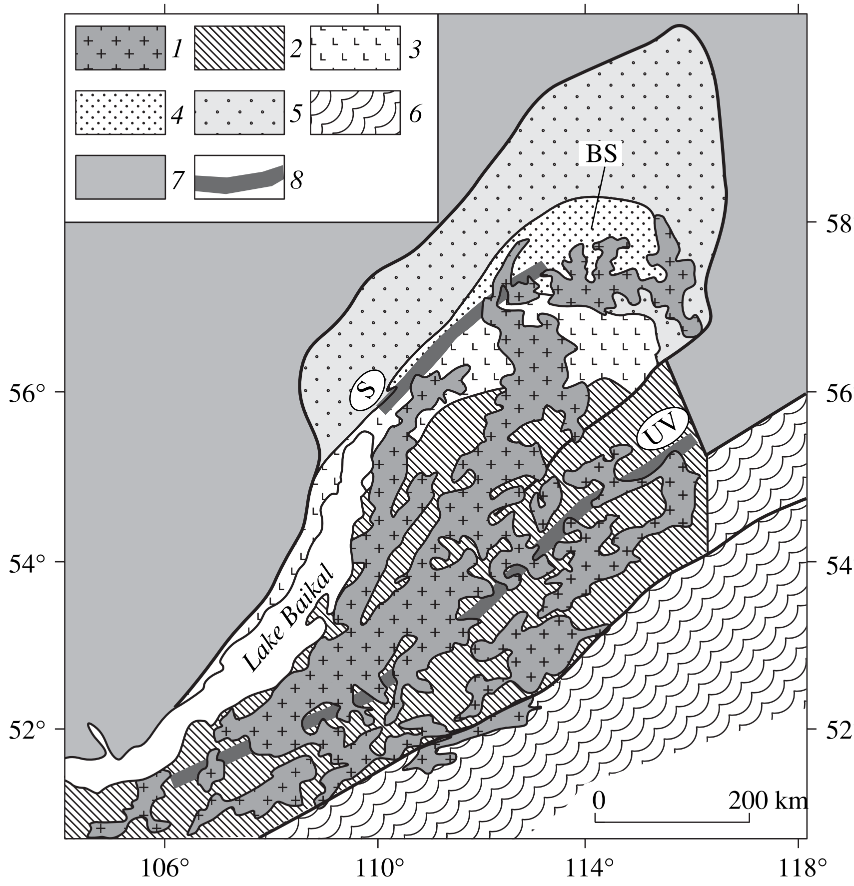

Fig. 1. Location scheme of the Bodaibo synclinorium (BS) among geological structures of the southern framing of the Siberian Craton. (*1*) Granites of the Angara–Vitim batholith; (*2*) Precambrian Barguzin terrane; (*3*) Baikal–Muya zone; (*4*) Riphean metalliferous sediments, including the Bodaibo trough; (*5*) Baikal–Patom area of the Precambrian continental-margin sedimentation; (*6*) Caledonides of the Central Asian foldbelt; (*7*) Siberian Craton; (*8*) riftogenic (bimodal and alkaline) magmatism zone within the Angara–Vitim batholith: (S) Synnyr, (UV) Uda–Vitim.

The next stage of the Bodaibo trough evolution involved folding, napping, and metamorphic reworking of the metalliferous sediments. As a result, the Bodaibo trough was transformed into a large synform separated by overthrusts into smaller synforms and antiforms. According to the geochronological data [8, 10], the Late Riphean–Vendian sequences underwent catagenesis (up to metagenesis) 500–600 Ma BP. Termination of these processes in the Early Cambrian is detected by the low grade of metamorphic transformations of the common Lower Paleozoic sedimentary cover in both marginal parts and folded framing of the platform [3]. However, some researchers [10] believe that higher-grade metamorphism and folding occurred later in Early Paleozoic, but definitely prior to the Devonian. During this stage, Au presumably migrated to the lower *PT* gradient zone within the carbonaceous sequences [1, 11].

The sedimentary sequence of the Bodaibo trough underwent folding and metamorphism simultaneously with the formation of convergent plate boundaries within the Paleoasian Ocean [3, 12]. Processes of convergence, which began in Late Vendian (~570 Ma BP) and fostered the formation of island arcs and metamorphic belts along the boundaries of the Precambrian terranes and microcontinents, ceased after the Caledonian collision ~500 Ma BP. Evidently, these processes spanned also areas of the Siberian Craton adjacent to the Paleoasian Ocean. In particular, they provoked thermal reworking of the Patom–Bodaibo fragment of the platform margin. This is recorded by resetting of isotope systems and metamorphic age of the sedimentary sequences determined [8, 10] for the adjacent Olokit graben and Bol'shoi Patom areas.

Thus, the second stage of the formation of the Sukhoi Log deposit is indirectly related to the closure of the Paleoasian Ocean and collisional settings at the Siberian continental margin. This stage promoted the partial redistribution of Au in the rocks of the Bodaibo trough and the subsequent formation of ore deposits [11, 13].

Devonian endogenous activity could have also played a certain role in the formation of the Bodaibo group deposits. For example, geophysical investiga-

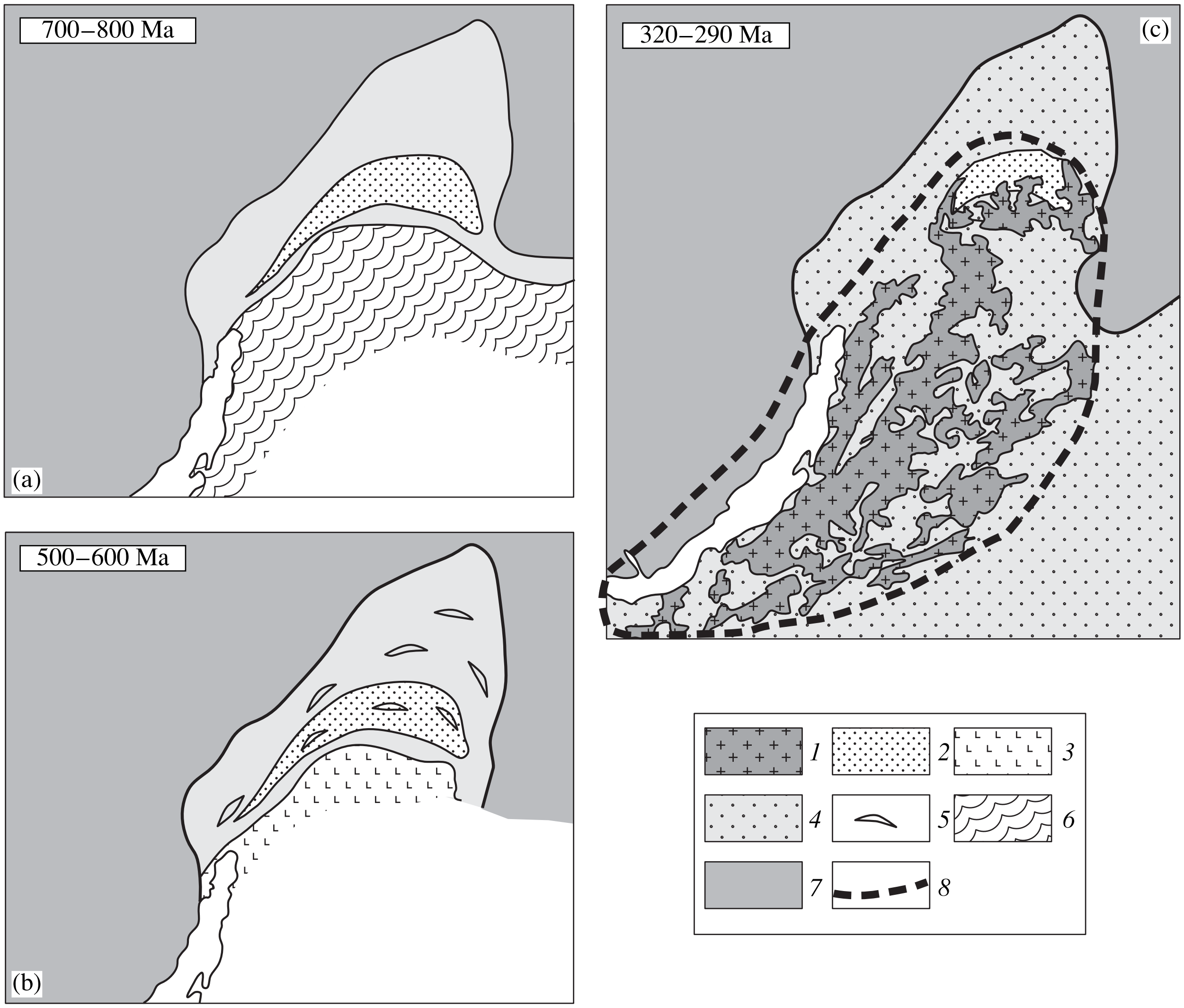

Fig. 2. Scheme of the Late Riphean–Paleozoic geological evolution of the southern margin of the Siberian Craton and its folded framing. Stages: (a) 700–900 Ma BP: formation of platformal cover, including accumulation of metalliferous sediments within the Baikal–Patom area; (b) 500–600 Ma BP: initiation of convergent boundaries within the Central–Asian foldbelt, including those along the southern border of the Siberian Craton with continental-margin (?) magmatism in the Baikal–Muya zone (granitoids of the Lesnoi Complex), folding, and metamorphism of the Late Riphean rocks and metalliferous sediments of the Baikal–Patom area; (c) 320–290 Ma BP: impact of the mantle plume on the lithosphere—formation of riftogenic zones, Angara–Vitim batholith, zones of fluid-magmatic reworking of metalliferous sediments, and the Bodaibo group of ore deposits. (*1*) Granites of the Angara–Vitim batholith; (*2*) sedimentation area of the Late Riphean metalliferous sediments; (*3*) convergence zone (continental-margin magmatism of the Baikal–Muya zone); (*4*) folded framing of the Siberian Craton; (*5*) fold zones; (*6*) Paleoasian Ocean; (*7*) Siberian Platform; (*8*) contour of the mantle hot spot.

tions performed by B.M. Pis'mennyi (East Siberian Research Institute of Geology, Geophysics and Raw Minerals, Irkutsk) distinctly demonstrated the presence of high-density (presumably, mafic rocks) in the basement of the Bodaibo trough. They form a chain of bodies hidden beneath the high-contrast positive gravity anomalies, which are traced from the Vilyui trough to the Bodaibo trough. Based on this, Mitrofanov [14] suggests that the anomalies correspond to deep-seated magmatic bodies, which are similar to the Devonian alkaline basalts of the Vilyui rift and presumably served as a source for deep-seated ore fluid flow beneath the Bodaibo trough during Devonian rifting.

The Late Paleozoic stage was the most important in the formation of the Bodaibo group deposits. Based on analysis of the ore-bearing quartz, A.V. Chugaev and Chernyshev [2] established that ores of the Sukhoi Log deposit formed at the Late Paleozoic stage (315 Ma BP). They are represented by quartz, pyrite–quartz, and arsenopyrite–quartz ores of vein–stringer and patchy–disseminated types, as well as by pyrite with finely dispersed Au. The ores are accompanied by ferromanganese carbonate mineralization (primarily, ankerite and dolomite).

The postore granitoid magmatism within the Bodaibo trough (Fig. 1) was related to the emplacement of the massifs of the Konkuder–Mamakan Complex, which represent a part of the Angara–Vitim batholith. For example, the Konstantinov granitoid stock of the Konkuder–Mamakan Complex is located in the Sukhoi Log deposit area. Based on geophysical data [2], the Sukhoi Log deposit area is underlain by a gravity maximum at a depth of 3 km, which is interpreted as the Ugakhan granite pluton related to the aforesaid granites. According to [2], the thermal impact of the hidden pluton triggered the formation of ore-bearing hydrothermal fluids.

Thus, analysis of the geological setting of the Bodaibo group deposits indicates their formation in the marginal zone of the complex Angara–Vitim batholith with an age of 320–290 Ma [15]. Its marginal zones include products of the riftogenic alkaline and bimodal associations (Synnyr and Uda–Vitim riftogenic zones). Granite massifs in the central part of the batholith are dominated by synplutonic alkaline and subalkaline basaltic intrusions. Such an abundance of within-plate mantle magmatism suggests that the batholith was related to mantle plume and associated basic–alkaline melts, which influenced the thick lithosphere and provoked large-scale anatexis [15]. The presence of granitoids of the same age (298 Ma for the Konstantinov stock [5]) and associated mafic dikes near the Sukhoi Log deposit unambiguously indicate the fluid–thermal influence of plume and its derivatives (granites and other products) on the sedimentary rocks of the Bodaibo trough. According to [2], metalliferous hydrothermal solutions are associated with decomposition products of high-molecular nitrogen-bearing compounds in the organic matter of black shales. This association undoubtedly indicates a leading role of within-plate magmatism in the final formation of the ore deposits in the Bodaibo trough.

Thus, the Bodaibo group deposits formed in three autonomous stages, which spanned a large territory of the southern Siberian Craton and its folded framing (Fig. 2):

(1) Deposition of Au- and PGE-rich black shales in a passive margin setting (Fig. 2a).

(2) Redistribution of the ore material in the black shales of the Bodaibo trough owing to folding and metamorphism of the sedimentary basin at the Siberian continental margin. The geological processes of this stage were initiated by convergence as a result of the closure of the Paleoasian Ocean (Fig. 2b).

(3) Formation of the gold ore deposits owing to the impact of mantle plume on the continental lithosphere. The consequent large-scale magmatic processes provoked fluid–thermal reworking of the ore-bearing (Au-rich) rocks and facilitated formation of the ore-bearing hydrothermal solutions.

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