
GEOCHEMISTRY

Complex Interpretation of Geophysical and Geochemical Data for the Prognosis of Mineralization: A Case Study of the Upper Amur Region

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The present paper is devoted to the complex interpretation of geochemical and geophysical data on the upper Amur region. The available data have made it possible to recognize anomalous geochemical fields (AGF) of the ore node rank and stable geophysical parameters that can be used to outline ore districts and nodes with a high degree of probability. The results of the complex interpretation of geochemical and geophysical data were used to predict areas with gold, silver, copper, and molybdenum mineralization. Several promising areas have been recommended for prospecting works.

The complex geological setting and long-term evolution suggest a high potential of various mineral resources in the upper Amur region. This region incorporates eight gold deposits (Pokrov, Pioner, Bam, Berezitovoe, Kirov, Burinda, Kolchedannyi Utes, and Malomyr), as well as several occurrences of gold, silver, base metals, molybdenum, copper, nickel, and other metals. These ore occurrences are often insufficiently studied [2–5]. Therefore, reappraisal of the known deposits and discovery of new deposits is an urgent issue for the present-day geological service of Russia. This issue cannot be solved without comprehensive analysis of geochemical and geophysical data accumulated in recent decades.

GEOCHEMICAL ANOMALIES

In order to discriminate characteristics of the geochemical field of the upper Amur region, we ana-

lyzed the distribution of chemical elements in stream sediments and alluvial minerals. Therefore, we compiled series of monoelement (Au, Pb, Zn, Cu, W, Mo, Ag, Sn), multielement (Au × As × Pb × Zn × Cu × Bi × W × Mo × Sb × Ag, Au × Pb × Zn × Cu × Ag), and monomineral maps [1]. They are drawn as isolines based on the available database and estimates of parameters of normal and anomalous geochemical fields.

These materials served as a basis for the identification of AGFs of the ore node rank. At the second stage of investigation, we determined the geochemical specialization and formational affiliation of the predictable mineralization for all identified AGFs using qualitative and quantitative geochemical criteria. They were based on the analysis of similarities and dissimilarities between the spectra of materials under consideration and their supergene products. At the final stage of investigation, we carried out quantitative assessment of possible resources of gold, silver, base metals, and rare metals in the upper Amur region.

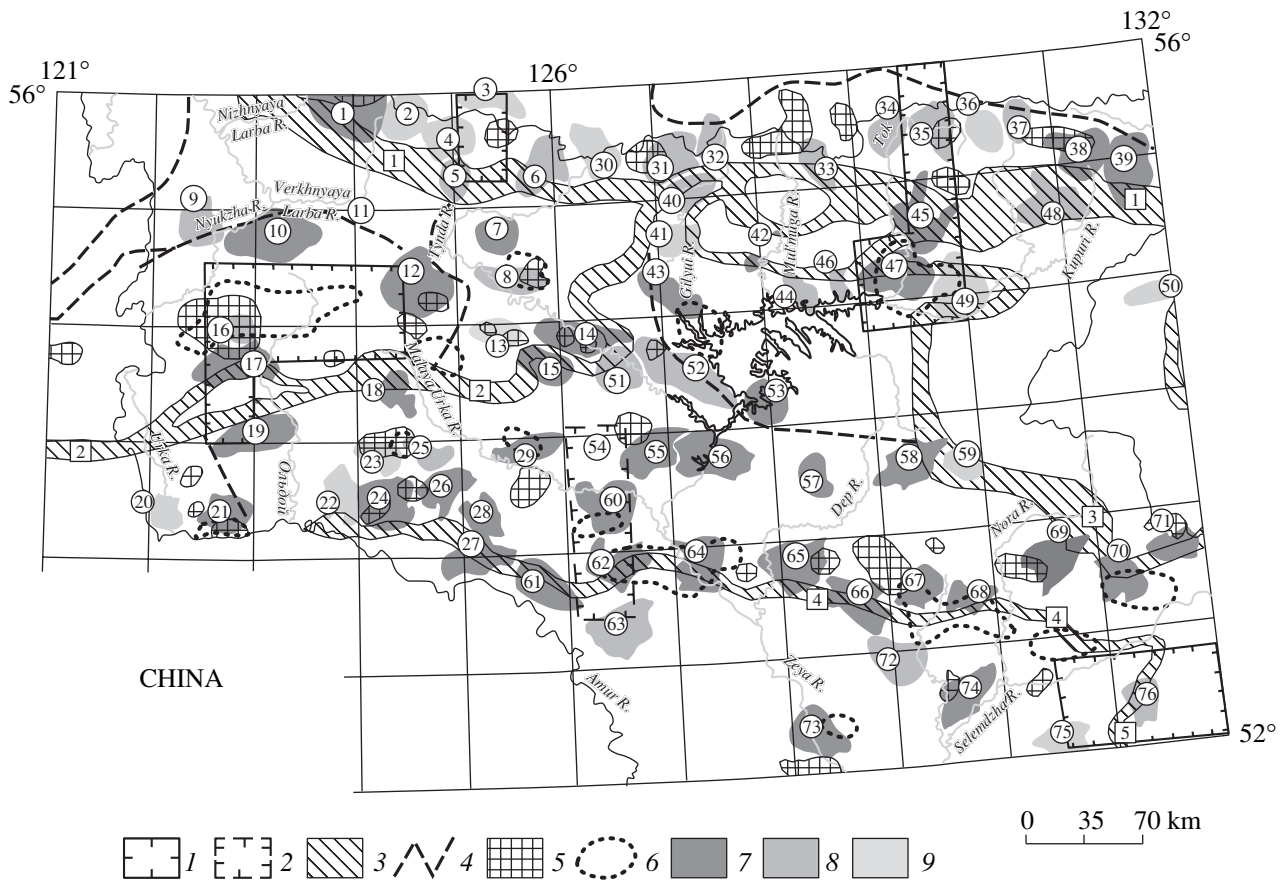
GEOPHYSICAL ANOMALIES

The complex analysis of geophysical data made it possible to distinguish a number of stable geophysical characteristics that can be used to outline ore districts and nodes with a high degree of probability.

The ratio of longitudinal (V_p) and transverse (V_s) seismic waves in the middle and upper sections of the Earth's crust is among the most informative seismic parameters that can be used to discriminate ore districts and nodes. The results indicate that ore districts are often confined to edges of zones with lower V_p/V_s values (1.60–1.69). Some ore nodes are characterized by anomalously high V_p/V_s values. At the same time, ore deposits and occurrences are sometimes confined to boundary zones with low V_p/V_s values. Such areas, from 40 to 80–100 km in diameter and up to 100 km long, probably reflect tectonically reworked blocks of the

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Schematic prognostic chart of hydrothermal mineralization (Au, Ag, Cu, and Mo) in the Upper Amur region based on geochemical and geophysical data. (1, 2) Zones with anomalous V_p/V_s values in the upper and middle sections of the Earth's crust (Nagornych and Poplavskaya, 1989): (1) lower values, (2) higher values; (3, 4) regional gradient zones of gravity field: (3) maximum amplitude (10n mGal); (1) Stanovoi, (2) Mongol-Okhotsk, (3) Selemdzha-Sugdzhazhar, (4) Ol'doi-Selemdzha, (5) Turan gravity steps; (4) lower amplitude (up to 10–15 mGal); (5) local minimums of gravity fields related to Mesozoic magmatic centers; (6) magnetic field maximums related to Mesozoic magmatic centers; (7–9) anomalous geochemical fields of the ore node rank: (7) high-grade, (8) moderate-grade, (9) low-grade.

Earth's crust with anomalously high fracturing. They served as conduits for heat and mass transfer in the course of ore deposition. Zones with high V_p/V_s values indicate fluid-saturated blocks characterized by intense tectonic disintegration.

The major part of ore districts and nodes in the upper Amur region is controlled by regional gradients of the gravity field with the following dimensions: length 350–800 km, width 20–50 km, and amplitude 10n mGal. The morphology of gradient zones is often complicated in the ore districts. The ore nodes are either located near a gravity step or split into two parts. In the study region, gold deposits and large ore occurrences inherit the position of the gradient zone: they are located at the gradient zone edge near the less dense block at an average distance of 10–12 km from the gravity step axis.

This regularity testifies to the crucial regional control of mineralization by deep faults of the crust–mantle level corresponding to gravity steps. Such fractures are

penetrative zones that connect the upper crustal horizons with the mantle in the course of ore formation. The localization of ores at such levels indicates that ore deposits are confined to boundaries of large blocks of the Earth's crust. The blocks with different values of density represent regional density barriers extending over hundreds of kilometers. Owing to specific features of the gravitational tectonics, the boundaries of these blocks foster long-term destructive processes in the Earth's crust. These processes are responsible for the disintegration and high permeability of the Earth's crust.

The control of gold ore nodes by local negative anomalies of the gravity field (gravity minimums) is an important geophysical indicator. The anomaly zones, 30–80 km wide and 30–100 km long, have an area of 1000n sq. km. The intensity of the gravity minimum is 10n mGal (average 15 mGal). These anomalies are generally isometric or slightly elongated (the ratio of axes is as much as 1: 2). The ore nodes usually occupy the edge of the gravity field minimum located between its

central area and the axis of gravity steps. The known gold deposits are nearly always located at the edge of the gravity field minimum. Such anomalies record zones of the concentration of Late Paleozoic–Mesozoic magmatic processes (intrusive magmatism and volcanism) that promote dilatation of the middle and upper sections of the crust due to the formation of large masses of near-surface and abyssal granitoid magmatites, on the one hand, and the tectonic disintegration of the crust, on the other hand. Granitoid domains correspond to zones of the long-term heating of the lithosphere and reflect thermal inhomogeneities in lower sections of the crust. This feature is manifested not only in the Stanovoi and Amur geoblocks, but also in the Mongol–Okhotsk fold system. In many places, low V_p/V_s zones are closely associated with this feature.

Intersection of gravity steps and submeridional transverse fracture zones is an important indicator of ore concentration. The transverse fracture zones are differently manifested in geophysical fields. They are often traced as fragments of their linear elements, short obscure gradient zones, and local anomalies of different signs. Such hidden extended fractures govern the location of ore nodes along gravity steps in some places.

Regularities in the distribution of ore objects of different ranks in the magnetic field are least studied at present. In order to solve this issue, we investigated the regional magnetic field with an average radius of 30 km.

The results show that ore nodes are confined to positive anomalies of the regional magnetic field with an area of 1000 n sq. km and intensity of 100–150 nT. The gold mineralization is associated with gradient zones of such anomalies and their edges.

Positive anomalies of the magnetic field define zones of Mesozoic magmatism and concentration areas of magnetic igneous bodies in the Earth's crust. This feature is more typical of districts with prominent volcanic activity and hypabyssal intrusive magmatism (e.g., the Aldan–Stanovoi and Amur geoblocks). Ore nodes of the Mongol–Okhotsk fold system are defined by prominent minimums in the regional magnetic field owing to the presence of nonmagnetic sedimentary rocks. In many cases, gradient zones of the regional magnetic field with a length of 100 n km and intensity of 50–100 nT serve as an additional regulator of the disposition of ore nodes.

PROGNOSIS OF ORE DEPOSITS

The results of the complex interpretation of geochemical and geophysical data served as a basis for the prognosis of hydrothermal mineralization (Au, Ag, Cu, and Mo) in the upper Amur region (figure).

This region is divided into the following reference areas (ore node number is given in parentheses): Berezitovoe (17), Kirov (18), Pokrov (62), Pioner (60), and Malomyr (71). Data on these areas testify to the validity

and efficiency of the complex analysis of geophysical and geochemical anomalies. This method makes it possible to locate the most promising areas even at the early (small-scale) stage of data processing. Such areas are characterized by the highest probability of the manifestation of ore-forming processes and, consequently, the discovery of gold, silver, copper, and molybdenum deposits.

The ore potential of other AGF areas defined in the prognostic AGF chart is as follows (figure). Areas 1–6, 30–40, and 42–48 are spatially assigned to the Stanovoi gravity step zone. These areas are composed of Early–Late Archean and Early Proterozoic metamorphic and intrusive rocks, as well as Jurassic–Cretaceous intrusions and volcanics. Granitoid dikes are abundant. Gold, silver, and molybdenum play an important role in the mineral resource base of these areas. Their deposits are associated with domains of Early–Late Mesozoic volcanic and intrusive rocks. The mineralization is represented by the gold–quartz, gold–quartz–sulfide, gold–silver, silver–base metal, and quartz–molybdenite associations. Early Mesozoic granitoid bodies are characterized by small volumes. Therefore, we predict the presence of economic porphyry Mo (or Cu–Mo) deposits in this zone. AGF areas 1, 38, 39, 42, 45, and 47 are the most promising ones.

The location of AGF areas 14, 15, 17–19, 41, and 43 (figure) is controlled by the regional Mongol–Okhotsk gradient zone of the gravity field. These areas can contain gold–quartz–sulfide and gold–quartz deposits of the porphyry Cu–Mo type. AGF areas 14, 15, and 43 are the most promising ones in this respect.

We have identified the Ol'doi–Selemdzha gravity step in the Amur geoblock. The sublatitudinal step is characterized by high amplitude of the gravity field (10 n mGal). This zone is accompanied by local gravity minimums and positive magnetic anomalies in some places (AGF areas 22–27, 61–68). The results of complex prognostic assessment show that the majority of these areas can contain gold and copper–molybdenum deposits.

The Selemdzha–Sugdzhazhar gravity step controls the location of AGF areas 49, 58, 59, and 69–71. Among them, areas 58 and 69 have the highest gold potential. The geophysical and geochemical features indicate that areas 7, 8, 12, 21, 73, and 74 also have a high gold potential.

Thus, the interpretation of geochemical and geophysical data has made it possible to outline several areas with the potential of gold, silver, copper, and molybdenum mineralization in the study region.

CONCLUSIONS

The results of the complex interpretation of geochemical and geophysical data show that the upper Amur region incorporates 76 AGFs of the ore node rank. We have defined their geochemical specialization

and estimated possible resources of gold, silver, base metals, and rare metals in these fields. Analysis of geophysical data (V_p/V_s , gravity field, and magnetic field) made it possible to locate the areas with the highest ore potential.

We have revealed that the spatial distribution of ore-bearing areas in the study region is recorded confidently by geochemical and geophysical anomalies. These data testify to the validity and efficiency of the joint analysis of geophysical and geochemical data.

Based on the principles discussed above, the upper Amur region is divided into a number of areas promising for gold, silver, copper, and molybdenum mineralization. We recommend some of these areas as top-priority objects. The complex interpretation of geochemical and geophysical data described in the present paper can be used to assess the potential for gold and other minerals in other regions.

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