Structure-geochemical zoning of Topolninsk gold-ore field
(Gorny Altai)

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Abstract. Geochemical zoning of prospective mineable gold-bearing skarns was carried out. The geochemical field abnormal structures of different hierarchy levels associated with gold-skarn formations were revealed. The interrelation between the structure of ore-geochemical fields and associated ring structures was studied. Complex structure-geochemical criteria for gold mineralization prospecting and evaluation were proposed.

Introduction
Topolninsk gold-ore field is located on the right bank of the rivers Anui and Karama between the Topolnoye and Stepnoye villages in Soloneshensky region of the Altai Territory (figure 1). Structurally, this gold-ore field is confined to the Anui structure block on the west by the Talitskiy and on the east by the Katunskiy blocks along the large-scale fault zones - Baschelakskiy and Kuyachinskiy, respectively. According to metallogenic zoning, Topolninsk gold-ore field is related to Anui copper-gold-ore alluvial cluster in Anui ore area within North Altai gold belt.

The investigated area is composed of lower Silurian deposits, basically terrigene-Chinetinsk, clastic-carbonate Polatinsk suite, dismembered clastic-carbonate Gromotukhinsk series, terrigene-Chesnokovsk, lower Devonian clastic-carbonate Kamyshensk and Baragashsk suites.

Intrusive formations occupy one third of Topolninsk gold-ore field. They are represented by two massifs (Topolninsk and Karaminsk) and numerous dykes of different composition within Topolsk gabbro-granodiorite-granite complex, as well as stocks and linear subvolcanic bodies of Kuyagansk rhyolite-dacite-andesine complex.

According to [1], host rocks are represented by hornfels and, in places, by skarns within the vast exocontact massif area. Dispersed skarnification is observed throughout the gold-ore field. According to the study results, propylitic type has altered within the ore deposit. These metasomatites are more local and confined to skarn peripheries, which allows classifying them as post-skarn metasomatites [2,3]. The overlying ore formation is basically concentrated in skarns, post-skarn propylites and partially sericitization. The basic ore mineralization occurs mainly in association with gold-skarns. The content of sulfides varies between 2\% and 7\%, with pyrite, arsenic pyrite, magnetic pyrites and copper pyrite being well-developed. Sphalerite, molybdenite, erubescite, chalcocite, galena, fahelite, tellurides and Bi, Pb, Ag sulfotellurides are rarer [4].

Ore mineralization is associated with the intense primary and secondary dispersion of a wide range of elements which are typical for this area and type of mineralization. However, the identified chemical composition of element assemblages and their distribution patterns unveil a rather specific composition feature of abnormal geochemical fields [5].
Research technique
The present study is based on the lithogeochemical surveys in scale 1:25000, 1:10000 along the secondary dispersion haloes (more than 8000 samples) within Topolninsk gold-ore field carried out by JSC “Gorno-Altaiskaya Ekspeditsiya” in 2012-2013 and geochemical sampling data. The collected data were processed by standard statistical programs, whereas geometrization was carried out by GIS-technology, in accordance with the developed procedures [6,7].

Besides, multiband satellite images Modis, Landsat ETM+, Aster, IRS and digital terrain models SRTM and Aster DEM were used. The interpretation and analysis of multi-band satellite images, as well as geological and ore-geochemical system modeling were carried out according to the recommended methodology and approaches [8].

As Topolninsk gold-ore field is characterized by complicated landscape conditions and interpretation of geochemical data can hardly be sufficient for complete reconstruction of abnormal geochemical field, the study of the interrelation between the ore-geochemical field structure and associated ring structures was carried out first. Thereafter, it helped to make forecast and accurate identification of the most perspective gold-ore areas.

Research results
The results of the study are as follows:
- background and minimum abnormal concentrations of gold and trace-elements in secondary dispersion haloes were identified;
- geochemical associations were revealed and association zoning within the gold-ore field was outlined;
- interrelation between ring structures and the ore-geochemical field structure, as well as the location of gold mineralization within the investigated area was revealed;
- structure-geochemical criteria for gold mineralization prospecting and evaluation were proposed.
Background and minimally abnormal concentrations of elements were calculated in accordance with standard methodology developed by A. Soloviev [9]. As element distribution does not correspond to the normal law (A/Sr > 3 or E/Sr > 3) in the investigated area, background and abnormal values were calculated based on the log-normal distribution model (table 1).

| Element | Background \( \bar{X} \) n*10^3 % | Standard multiplier | Minimum abnormal N content to correlate points (gradations of spectral analysis), in n*10^3 % (Au – in ppm) |
|---------|---------------------------------|-------------------|------------------------------------------------------------------------------------------------|
| Au      | 0.003                           | 2.05             | N=1 | N=2 | N=3 | N=4 | N=5 | N=6 | N=7 | N=8 | N=9 |
| Ag      | 0.005                           | 1.41             | 0.008 | 0.007 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 | 0.006 |
| Bi      | 0.05                            | 1.07             | 0.063 | 0.059 | 0.058 | 0.057 | 0.056 | 0.056 | 0.055 | 0.055 |
| Pb      | 1.4                             | 1.46             | 4.4 | 3.2 | 2.7 | 2.5 | 2.2 | 2.2 | 2.1 | 2.1 |
| Cu      | 3.04                            | 1.3              | 6.9 | 5.4 | 4.9 | 4.6 | 4.4 | 4.24 | 4.14 | 4.06 |
| Zn      | 4.03                            | 1.7              | 21 | 13 | 10 | 9.2 | 8.4 | 7.9 | 7.5 | 7.2 |
| Co      | 1.2                             | 1.57             | 4.7 | 3.2 | 2.7 | 2.4 | 2.2 | 2.1 | 2.0 | 1.98 |
| Ni      | 3.6                             | 1.3              | 8.7 | 6.7 | 6.0 | 5.6 | 5.3 | 5.1 | 5.0 | 4.9 |
| Cr      | 3.9                             | 1.4              | 11 | 8.4 | 7.3 | 6.7 | 6.3 | 6.1 | 5.9 | 5.7 |
| Mn      | 61.5                            | 1.18             | 102 | 88 | 82 | 79 | 77 | 76 | 75 | 74 |
| Sn      | 0.2                             | 1.4              | 0.5 | 0.4 | 0.3 | 0.29 | 0.3 | 0.3 | 0.3 | 0.3 |
| W       | 0.5                             | 1.1              | 0.71 | 0.66 | 0.63 | 0.62 | 0.61 | 0.6 | 0.6 | 0.6 |
| Mo      | 0.09                            | 1.4              | 0.26 | 0.19 | 0.16 | 0.15 | 0.14 | 0.14 | 0.13 | 0.13 |

Based on the factor analysis, 3 resistant associations of basic trace-elements which reflect spatial and temporal evolution of ore-forming fluids were identified throughout the ore field: F1–Au,Ag,Bi,Cu,(As,Sb), F2–Sn,Pb,Zn,W,Mn, F3–Cr,Ni,V. The first factor corresponds to gold-ore mineralization while the number of the second association elements can be related as “rock”. Factor 2 is spatially related to the intrusive rocks, which in its turn may identify temperature zoning of ore mineralization. Factor 3 identifies the zones of dispersed sulfide mineralization.

Based on the interpretation of the multiband high-resolution satellite image, the complex of hierarchically organized ring structures was revealed. Figure 2 illustrates spatial distribution of the identified associations, ring structures and faulting within the studied area.

According to figure 2, the following conclusion can be made: within the investigated ore field, ore occurrences are associated with Au,Ag,Bi,Cu,As,Sb anomalies, bounded on the north-west and on the north east by faults, small ring and bogen (up to 9.5 km) structures. The similar regularities are identified in Co, Ni and V distribution. They form the external zone in relation to Au,Ag,Bi,Cu,As,Sb haloes and are thrust to the frontal zones which is reflected in the contours of ring structure.

It is obvious that most contrasting anomalies Au,Ag,Bi,Cu,As,Sb are identified in the peripheries of the defined ring structures. This can be explained by the fact that the frontal enrichment zone of abnormal geochemical field is represented by a number of identified ore occurrences and dispersed mineralization zones confined to the tectonic structures which are less favorable locations for ore mineralization [10].

Figure 3 depicts the structure of abnormal geochemical field of the perspective area characterized by three main factors defining the total dispersion as 70 %. They form contrasting restricted structure, with central (nuclear), intermediate and frontal zones of different size, composition and concentration degree of major and trace-elements being identified. The central zone is characterized by gold-, silver-, copper-, bismuth-, wolframite-, algam associations having the largest concentrations. Within the
intermediate zone of abnormal geochemical field structure, such large element concentrations are not observed, however, it separates the central zone from the frontal one. Cobalt, nickel, chromium, and vanadium accumulate in the frontal zone, with some increase in concentrations of other elements being observed (figure 3).

Figure 2. Distribution of geochemical associations in ring and linear structures in Topolninsk gold-ore field: 1) granodiorites, granites, diorite; 2) calcareous sandstone, siltstone, mudstone, sandstone; 3) limestone; 4) ring structures; 5 lineation as faults: a) proved, inferred; 6) interpreted; anomalies; 6) Au-Ag-Bi-Cu-(As-Sb); 7) Co-Ni-V; 8) perspective zones.

The obtained results have revealed that element association distribution is concentrically zoned within the field. Zoning is defined by the distribution of high-contrast element halos: some in the central zones and some in the periphery.
Figure 3. Geochemical zoning model of perspective area: 1 – argillaceous slates siltstone, sandstones, limestones; 2 – sandstones, siltstones; 3–6 Topolsk gabbro-granodiorite-granite complex: 3 – granodiorite biotite-hornblend, 4 – leucogranite amphibole biotite, 5 – alkali-type leucogranite. 6 – granite-porphyry dykes, 7 – diorite-porphyry dykes; 8 – quaternary deposits; 9 – contact lines: a – proved, b – inferred; 10 – skarns and skarned rocks; 11 – central concentration zone (Au-Ag-Cu-Bi-W-Sn); 12 – frontal concentration zone (Co-Ni-Cr-V); 13 – intermediate zone

Conclusion

Based on the lithogeochemical surveys, multiband satellite images Landsat ETM+, IRS and radar mapping SRTM, geochemical zoning and cosmostructure of Topolninsk gold-ore field (Gorny Altai) has been studied.

Due to integrated use of geochemical data and medium/high spatial resolution satellite imagery, it was possible to specify geological structure and obtain absolutely new geochemical information:

- Gold-skarn formations is accompanied by Au,Ag,Bi,Cu,(As,Sb); Sn,Pb,Zn,W,Mn and Co,Ni,V associations in the secondary geochemical field within the investigated area.
- The zones of spatial overlapping of several geochemical associations, which form abnormal geochemical concentric structure in the secondary geochemical field, are the most perspective exploration of this type of mineralization.
The identified ring structures of ore deposit are associated with intrusive bodies, both blind, and exposed by erosion. The structures of higher level, i.e. field, demonstrate the interrelation of hydrothermal-fluid systems and host rocks.

The identified levels of ring structures are proved by geochemical data.

The number of revealed regularities could be regarded as forecasting and prospecting criteria of both future gold-ore deposits and ore fields.

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