Estimating gold-ore mineralization potential within Topolninsk ore field (Gorny Altai)

T Timkin[1,3], V Voroshilov[1], O Askanakova[1], T Cherkasova[1], A Chernyshov[2] and T Korotchenko[1]

[1] National Research Tomsk Polytechnic University, 30 Lenin Ave., Tomsk, 634050, Russia
[2] National Research Tomsk State University, 36 Lenin Ave., Tomsk, 634050, Russia

E-mail: [3] timkin@tpu.ru

Abstract. Based on the results of ore and near-ore metasomatite composition analysis, the factors and indicators of gold-ore mineralization potential were proposed. Integration of the obtained data made it possible to outline magmatic, structural, and lithological factors, as well as direct and indirect indicators of gold-ore mineralization. Applying multidimensional analysis inherent to geochemical data, the spatial structure was investigated, as well as the potential mineralization was identified. Based on the developed and newly-identified mineralization, small (up to medium-sized) mineable gold-ore deposits in skarns characterized by complex geological setting was identified.

1. Introduction

Topolninsk ore field is situated on the right bank of the rivers Anui and Karama between Topolnoye and Stepnoye villages in Soloneshensky region of the Altai Territory (figure 1).

Structurally, this ore field is concentrated within the Anui-Chuya structural-formation zone. It is confined to NE and NW fault systems. The first is characterized by the large plastic Sarasino-Insk fault classified as left-lateral fault. This fault is perfectly traced on geophysical logs and is associated with dykes and intrusions of Topolninsk and Ust-Belovo complexes. The width of this zone is about several dozens of kilometers, while its extension is more than 500 km. Heterochronous intrusive formations, as well as associated gold-ore bodies are identified at the zones where the fault is intersected by NW and near N-S fractures [1].

Contact metamorphic and hydrothermal metasomatic rocks of different composition and occurrences locally extent throughout the ore field located at the contact of Topolninsk granitoid complex (D_2) and carbonate, carbonate-terrigenous sequences (D_2). According to the data, skarns, propylites, and beresites are identified within the ore field [2], where two types of ore have been identified: gold-skarn ore and gold-quartz ore. The content of sulfides varies between 1-5%, with pyrite, arsenic pyrite, magnetic pyrite, and copper pyrite being well developed. Sphalerite, molybdenite, erubescite, chalcosine, galena, fahlite, tellurides and Bi, Pb, Ag sulfotellurides are rarer [3, 4].

The purpose of the present study is to reveal basic localization features of gold-ore mineralization within Topolninsk ore field.

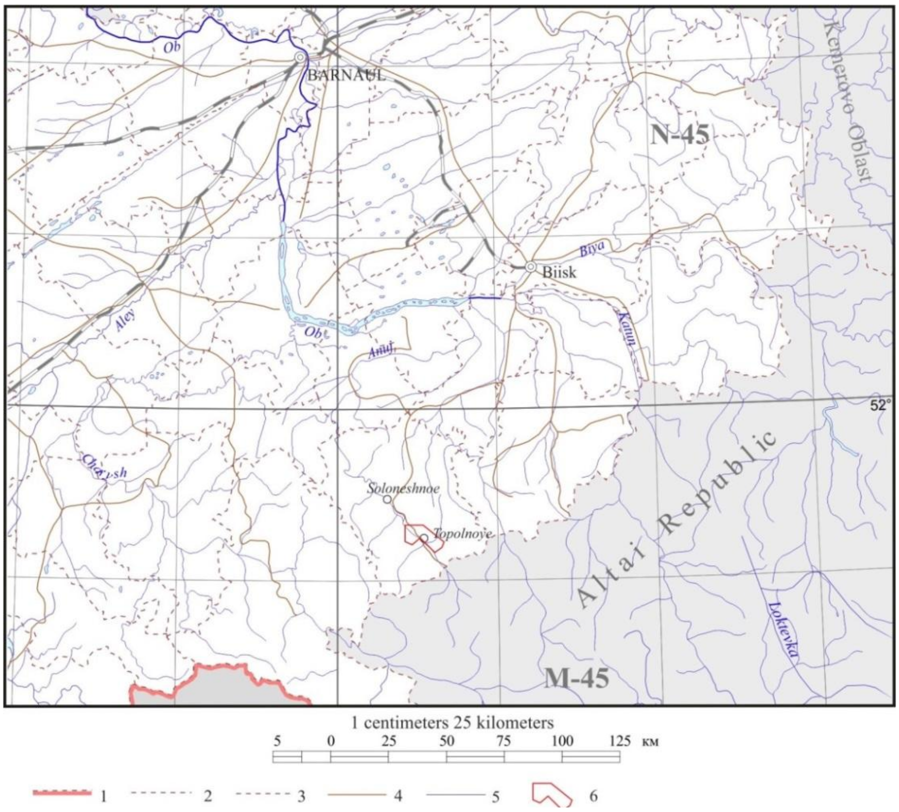

Figure 1. Location map: 1 – state boundaries; 2 – boundaries of RF territorial entities; 3 – boundaries of administrative districts; 4 – roads; 5 – hydrographic network; 6 – exploration area contours.

2. Research technique

The present study is based on the data collected during the research work aimed at investigating the composition of ore and metasomatic formations within Topolninsk ore field over the period of 2012–2014. The work was carried out by Geology and Mineral Prospecting Department, Tomsk Polytechnic University on request of JSC “Gorno-Altaiskaya Ekspeditsiya”, Biysk [2-4].

The conducted research involved both office studies and field investigations. The purpose of the field investigations was the rock sampling analysis in correlation with recorded information of trench channel samples, core samples and surface samples. Besides the traditional methods applied in petrography and mineragraphy, the following types of analysis were used as a part of the office studies: inductively coupled plasma optical emission spectrometry (ICP-OES), inductively coupled plasma mass spectrometry (ISP-MS), X-Ray Diffraction Analysis (XRD) of ore metals and metasomatites, scanning electron microscope (SEM), electron microprobe analysis (EMPA) of ore metals, analysis of gas-fluid inclusions within minerals by thermobarogeochemistry methods (TBG) [3].

The processing of geochemical mapping data was carried out on the basis of standard statistical methods of multidimensional analysis [5]. Geometrization was performed by ArcGis, Surfer in accordance with generally accepted methods and techniques [6-9].

3. Research results

The combination of magmatic, geo-structural, lithologic-and-stratigraphic, geochemical, and metasomatic factors, as well as physicochemical properties of ore-forming solutions considerably influenced the gold-ore mineralization localization. Based on the available data on Topolninsk ore field, it is possible to outline the factors and indicators of gold-ore mineralization listed in table 1.

Table 1. The contribution of factors and indicators to localizing gold-ore mineralization within Topolninsk ore field.

Factors and indicators	Gold-skarn mineralization	Gold-quartz mineralization
Magmatic factors:		
gold-ore mineralization is confined to the contact zone of Topolninsk complex intrusive;	+++	++
gold-ore mineralization is confined to dykes and stocks of rhyolite-dacite-andesite Kuyagansk complex.	+	++
Structural factors:		
a) ore localization control is due to NW, near N-S, and NE faults;	+++	+++
b) zones of increased skarn fracturing;	+++	–
c) folded limestone and siltstone beds, delamination in fold curves.	+++	–
Lithological factors:		
Carbonates and aluminosilicate rocks contacts	+++	–
Direct mineralization indicators:		
mineralogical gold haloes	+++	+++
geochemical gold haloes	+++	+++
Indirect mineralization indicators		
Metasomatites a) skarns	+++	–
b) propylites	+++	++
c) steeply dipping linear zones of beresite metasomatites.	++	+++
Concentric-zonal anomalies with accumulations of Cu, Ag, Mo, W, Sb, Bi, As in nuclear zone concentration and Co, Ni, Cr, V in frontal enrichment zone.	+++	+++
Ore mineralization represented by sulfides (pyrite, arsenic pyrite, magnetic pyrite, copper pyrite, erubescite, sphalerite, etc.), tellurides and sulfotellurides of lead, bismuth, silver, oxides and hydroxides of these minerals	+++	+++
Geophysical indicators:		
a) low electric resistivity;	+	–
б) high electric resistivity;	–	+
в) positive anomalies in contact zone with intrusives	+++	–

Note: +++ - strong defined; ++ - moderately defined; + - poorly-defined; – non-defined

Magmatic factors of gold-ore mineralization involve the fact that gold-bearing skarns are confined to endo- and exocontact massifs of Topolninsk complex. The strong positional connection of gold-quartz mineralization is associated with silicic and intermediate dykes of the Middle Devonian Topolninsk and Kuyagansk complexes.

Structural factors are different for gold-ore mineralization types. For gold-skarn mineralization, tectonic traps scattered within the skarns are important structural factor: folded limestone and siltstone beds, delamination in fold curves [4]. Skarn ore deposits are confined to the intersection of the above-mentioned structures and zones of increased fracturing, NW, near N-S, and NE faults. The basic structural factor for gold-quartz mineralization is the intersection of NW, near N-S, and NE faults.

Lithological factors are due to the fact that ore deposition environment had a significant influence on different mineralization types. Lithological contrasts in carbonates and aluminosilicate rocks, i.e. favorable conditions for skarn formation, were of great importance for gold-skarn mineralization. Gold-quartz vein mineralization is basically identified within igneous rocks, and to a smaller degree, in clastic sedimentary rocks. This is explained by physico-mechanical characteristic features of gold-quartz vein mineralization. Despite silicification, persistent quartz veins do not form in skarns which are easily subjected to the increased fracturing of various orientations.

The *direct prospecting indicators* are as follows:
1) mineralogical gold haloes;
2) primary and secondary geochemical gold haloes.

The following *indirect indicators* are the most significant: altered areas, haloes of minerals associated with gold-ore mineralization, geochemical haloes of mineralization trace-elements, geophysical anomalies.

The ore bodies are characterized by definite geological position in ore-metasomatic structures. The strong positional connection of gold-skarn mineralization is associated with skarns of different composition located within Topolninsk ore field. The propylitic alteration is developed in the pinching-out zone of skarn bodies and cross-cutting skarns. This type of alteration was identified within the well-known ore occurrences. The temperature zoning was identified in propylites, changing in distance from skarn bodies, i.e. from medium-temperature epidote-actinolitic facies (305–250º C) to low-temperature epidote-chloritic facies (225–165º C).

Propylite formation results in thin calcite veinlets (up to 1.5 cm) which in most cases cross skarned and propylitized rocks.

Quartz-sericitic metasomatites (beresite type) commonly occur in gold-quartz type; in skarns, beresitization is in the form of silicification, carbonization, and chloritization. The ore mineralization represented by sulfides (pyrite, arsenic pyrite, magnetic pyrite, copper pyrite, erubescite, sphalerite, etc.), tellurides and sulfotellurides of lead, bismuth, silver, gold nuggets is associated with beresites. The beresites associated with gold-quartz mineralization are confined to the same porous structures that control skarn and propylites localization, where propylites are defined as an important prospecting indicator.

The gold nuggets are directly associated with a wide range of ore minerals such as sulfides, tellurides, and sulphosalts. Their mineralogical haloes are an important indirect prospecting indicator of the above-studied mineralization type. Under supergene conditions, these minerals alter to oxides and hydroxides which are also considered as a prospecting indicator. In addition, the typomorphic characteristics of vein minerals which are associated with gold in quartz and calcite are also very informative. The thermometric characteristics and salinity of fluid inclusions in these minerals allow more accurate identification of the mineralization type and zoning.

Geochemical characteristics are of great importance in hydrothermal mineralization prospecting. Gold in ore bodies exposed by prospecting wells №№ 46, 32 correlates with Ag, As, Bi, Co, Cu, Cu, Mn, Mo, Ni, Sn, W, Zn (table 2).

Table 2. Correlation coefficients for Au and trace-elements in ore bodies.

Ore hole	Elements													
	Ag	As	Bi	Co	Cr	Cu	Mn	Mo	Ni	Pb	Sn	V	W	Zn
46	0.49	0.44	0.37	0.56	0.34	0.38	0.55	0.31	0.72	-0.37	0.64	0.57	0.52	0.64
32	0.74	0.32	0.13	0.68	0.26	0.36	0.70	0.56	0.40	0.34	0.71	0.21	0.77	0.48

Note: significant correlations are in red ($r_{crit.}$ = 0.35).

In the secondary geochemical field, Au is also associated with a wide range of trace-elements. The characteristic feature of gold-ore occurrence is concentric zonal abnormal geochemical fields (AGF) with accumulations of Au, Cu, Ag, As, Bi, (W, Mo) in the nuclear zone concentration, and Ni, Cr, V – in frontal enrichment zone [1]. Based on the factor analysis [2], the elements accumulating in the central zones of AGF are classified into three associations: W, Mo, Mn – As, Ag – Au, Cu, Bi, which are confined to both discovered and newly-identified gold-ore mineralization (figure 2).

As correlation of elements is the synchronism of their behavior in geological processes, the identified associations can be interpreted in the following way.

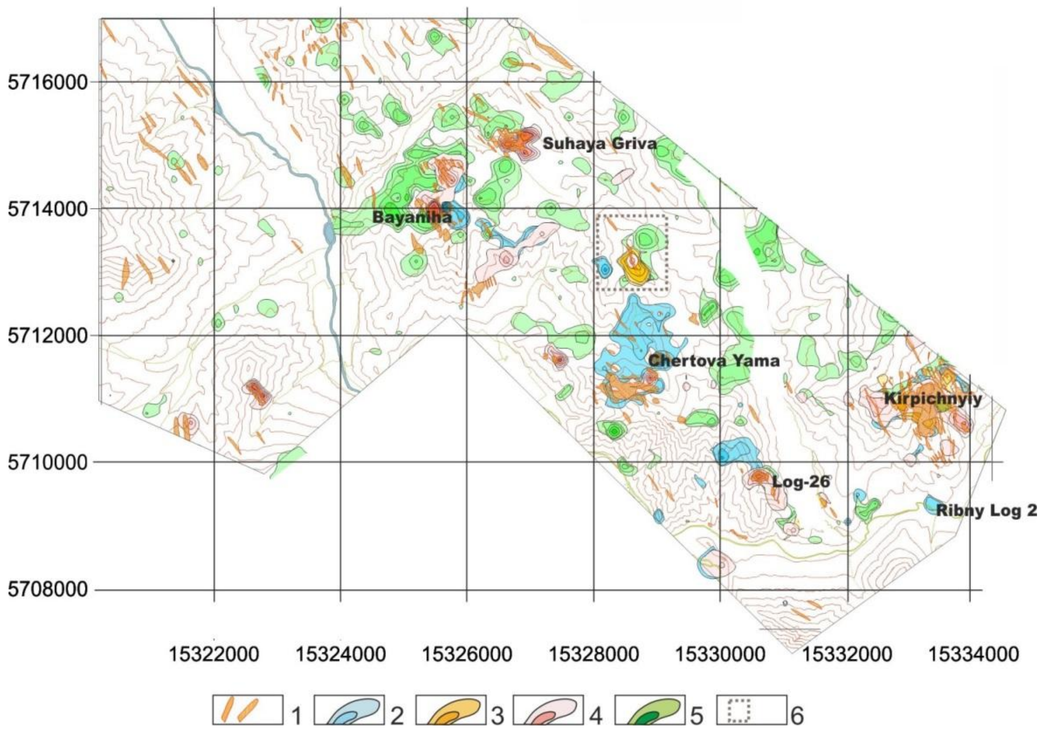

Figure 2. Location of ore manifestation within abnormal geochemical fields of Topolninsk area (secondary lithochemical haloes); 1 – gold anomalies; 2-5 – geochemical associations identified by factor analysis: 2 – W, Mo, Mn; 3 – As, Ag; 4 – Au, Cu, Bi; 5 – Cr, Ni, V; 6 – potential ore manifestation.

The first association of granitophile elements W and Mo with Mn (carbonate deposits) is due to the impact of ganitoid intrusions on the clastic-carbonate sequence, indicating skarnization.

The ore association of As and Ag can be confined to sulfide mineralization developed on the flanks of ore bodies and in the above-ore zone, with the role of gold being insignificant. In this respect, it is essential to consider the area located 2 km northward from ore manifestation Chertova Yama, where the mentioned association is obvious and there is a halo of run-of-mine gold that can be within the above-ore zone (figure 2).

The association Au, Cu, Bi is most strongly associated with developed ore deposits. The correlation of gold with Cu and Bi (also peculiar feature of Sinukhinsk gold-skarn mineralization) indicates that they are synchronously formed during the stage of gold accumulation accompanied by sulfides, bismuth tellurides, and sulphosalts.

The accumulation of Ni, Cr, V in the zones of frontal enrichment is a characteristic feature of all types of hydrothermal deposits and can be applied for the delineation of AGF confined to different geological bodies. This can be used for ranking geochemical fields of ore objects.

The geophysical indicators of localization of different mineralization types have their own peculiarities. Unlike other gold-skarn fields of the investigated area, ore-generating intrusions are not identified in gravitational field due to the absence of massive mafic volcanic rocks in the host thickness.

The weakly magnetic granitoids of Topolninsk intrusion, as well as medium-magnetic diorites of Karaminsk massif in endo- and exocontact zones of which magnetic differences are prominent, are identified on the magnetic field map. In addition, the intensity (up to 670 gamma) of anomalies over

Karaminsk intrusion are displaced to its eastern contact, i.e. skarn zone of ore manifestation Ribny Log 2. The negative anomaly is identified above Topolninsk massif, which could be explained by the predominance of nonmagnetic rocks throughout the massif. Three positive anomalies with the intensity of up to 50 gamma comparable to the negative ones of 100-500 gamma are identified along the contacts of Topolninsk massif. Such values of magnetic susceptibility are characteristic features of thermally altered rocks that have undergone decompaction with decreasing magnetization intensity.

Identification of ore mineralizationin electric fields is conditioned by the association of gold with high-conductivity sulfides. In general, Topolninsk ore field is located in the periphery of extreme positive anomaly of natural electric field.

4. Conclusion

Thus, based on the revealed factors and indicators essential for estimating gold-ore mineralization potential and with due regard to the characteristic features of geo-structural location within Topolninsk ore field including both developed and newly-identified mineralization, it is possible to forecast small (up to medium-sized) mineable gold-ore deposits in skarns characterized by complex geological setting.

Acknowledgement

The investigations were supported by National Research Tomsk Polytechnic University, project №: ВИУ_ИПР_114_2014.

References

[1] Gusev A I, Gusev N I, Tabakaeva E M, Dzagoev E A, and Kukoeva M A 2013 *Petrologiya i rudonosnost' magmo-rudno-metasomaticheskikh sistem Soloneshenskogo rudnogo rayona Altaya* (Biysk: AGAO) p 200 (in Russian)

[2] Timkin T V, Lavrov D S, Askanakova O Y and Korotchenko T V 2014. Structure-geochemical zoning of Topolninsk gold-ore field (Gorny Altai) *IOP Conf. Ser.: Earth Environ. Sci.* **21 (1)** 1–6

[3] Logvinenko O V, Timkin T V 2014 Material composition and sequence of mineral ore manifestation Log-26 Topolninskogo gold field (Gorny Altai*) Tomsk State University Journal* **383** 212–20

[4] Cherkasova T Y, Timkin TV and Savinova O V 2015. First native silica findings in bismuth from garnet skarns of Ribny Log-2 gold ore target in Topolninsk ore deposit (Gorny Altai) *IOP Conf. Ser.: Earth Environ. Sci.* **24** 1–5

[5] Reis A P, Sousa A J and Cardoso Fonseca E 2003 Application of geostatistical methods in gold geochemical anomalies identification (Montemor-o-Novo, Portugal) J. *Geochem. Explor.* **77** 45–63

[6] Voroshilov V G 2009 Anomalous structures of geochemical fields of hydrothermal gold deposits: formation mechanism. Methods of geometrization, typical models, and forecasting of ore mineralization. *Geology of Ore Deposits* **51 (1)** 1–16

[7] Harraz H Z, Hamdy M M 2015 Zonation of primary haloes of Atud auriferous quartz vein deposit, Central Eastern Desert of Egypt: A potential exploration model targeting for hidden mesothermal gold deposits. *J. Afr. Earth Sci*. **101** 1–18

[8] Cheng Zh Zh, Xie X J, Yao W Sh, Feng J Zh, Zhang Q, Fang J D 2014 Multi-element geochemical mapping in Southern China. J. *Geochem. Explor*. **139** 182–91

[9] Gavrilov R Y, Rudmin M A 2015 Methodological approaches in estimating anomalous geochemical field structure *IOP Conf. Ser.: Earth Environ. Sci.* **24** 1–6