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Up-dated ore composition data (Central ore-field, Kuznetsk Alatau)

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Abstract Applying scanning electron microscope (SEM), energy-dispersive microanalyzer and X-ray fluorescence microscope the ore mineral composition in Central gold-ore field (Kuznetsk Alatau) was investigated. Eleven new minerals were detected in this ore field. The differentiated behavior of mineral formation stages in veins and near-veined beresites was determined. The composition of native gold was studied, as well as the distribution of trace elements in pyrite.

1. Introduction

Based on the investigation of ore mineral composition and their zonation it is possible to identify the mineralization zoning genesis, to predict the ore bodies on the flanges and depth and to reveal new deposits. Previously, the ores in Central gold-ore field were investigated by optical microscopes. Such methods as scanning electron microscope (SEM) and X-ray fluorescence microscope revealed new mineral habits and their interrelationship behavior. Ore mineralization genesis and its distribution zoning were also considered [1,2,3].

2. Research methods

Ores and metasomatites in the Central ore field were studied via a detailed mapping of underground mining and analysis of numerous drill-hole cores. The selected ore samples were studied under optical, scanning electron microscope (SEM) and X-ray fluorescence microscope.

Scanning electron microscope Vega3 Tescan with energy-dispersive microanalyzer AZtec Energy X-max 50 were used to study the specific composition and structure of ore minerals and their behavior , as well as revealing new minerals. The polished section surfaces reflected the spectrum representing the chemical composition of every mineral habit. The petrochemical equivalent of each mineral formula was based on obtained data.

The distribution of the chemical elements within pyrite grains, a prevailing ore mineral, was studied by X-ray fluorescence microscope XGT-7200. The following modules were

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applied: spectrum analysis of the chemical composition (Spectrum) and areal mapping of the sample to identify the chemical element distribution in the sample (Mapping).

3. Results and discussion

Central ore-field is located near deep Kuznetsk Alatau fault in the northern part of Kuznetsk Alatau. The most ancient rocks in this ore-field are Prokopevsk-Vendian suite marmorized limestones with overlying Lower Cambrian Ust-Anzassk suite metamorphosed slates (fig. 1).

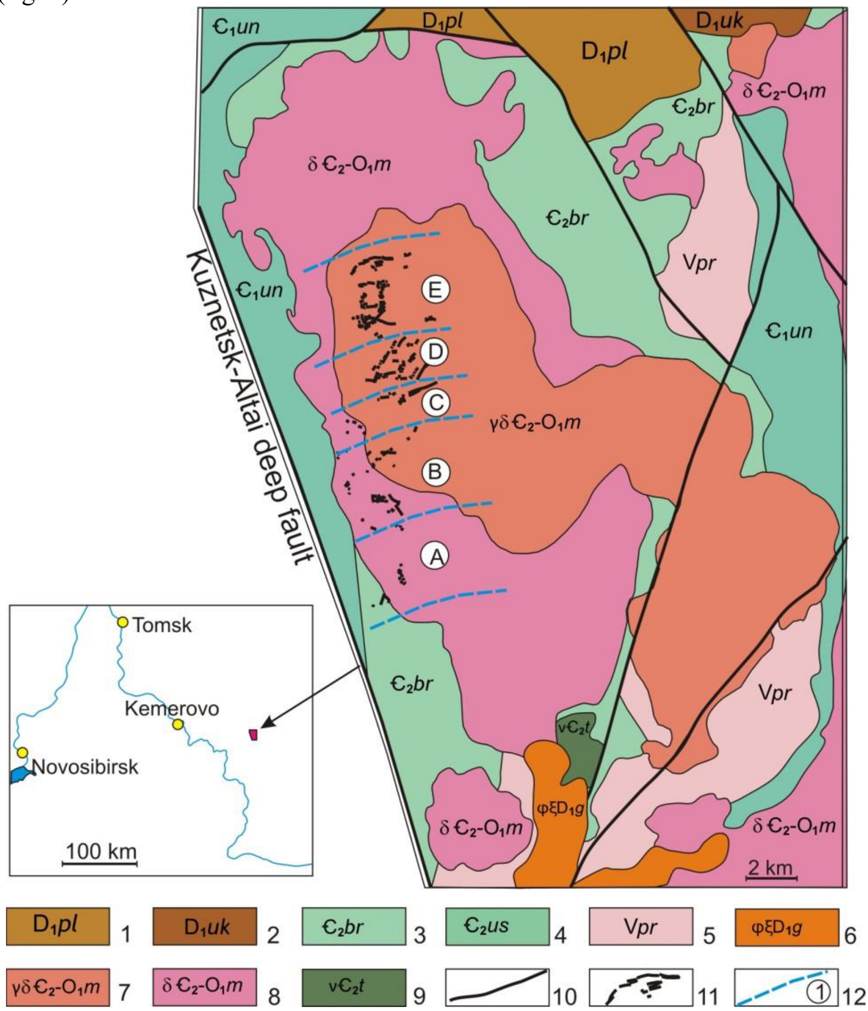

Figure 1. Geological map diagram of Central ore-field

1 – Palatine suite: basalt, andesite-basalt, rarely andesite, tuff sandstone; 2 – Ust-Kundusolskaya suite: conglomerates, sandstone, siltstone; 3 – Berikul suite: basalt, andesite basalt; 4 – Ust-Anzassk suite- chlorite- epidote-actinolite-albite orthoschist, carbon-siliceous schist; 5 – Prokopevsk suite: marmorized bitumen limestones; 6 – Goryachegorsk alkai-gabbroid complex: nepheline syenite; 7- Martaiginsk granitoid complex: granodiorite; 8 – diorite; 9 – Taskilski gabbro-pyroxenite complex: gabbro; 10 – basic ruptures; 11 –gold-sulphide-quartz veins; 12 – ore-field mineral zones: A- tourmaline; B- scheelite; C- molybdenite-chalcopyrite; D- sphalerite-galena; E-arsenopyrite

Mid-Cambrian island-arc basalt and Berikul suite andesite-basalt are overlyingVendian-Early Cambrian sediment cross-beddings. Centralninsk granitoid massif (Martaiginsk complex), resembling intruding south-eastward harpolith, is confined to the surface of the cross-bedding. This massif intrusion formed in the Mid-Cambrian to Lower Ordovician period during the collision stage of the territory development.

Devonian sediments in the northern area embrace two suites: Palatine volcanic suite and Ust-Kundusolyskaya terrigenous suite. Underlying Devonian sediment thicknesses revealed a tectonic contact [4].

Ore bodies include predominately east-west and north-east trending gold-sulphide-quartz veins which are within near N-S zone extending up to 15km. There are more than 200 known veins, some of which extend up to 2 km. and dipping downward to 1000m. Host rocks include Central massif granitoids. Areal and near-vein metasomatic processes preceded ore deposition, the earliest of which were quartz-feldspar metasomatites as mature thickness zone series from tens to hundreds of meters in extent. In the central parts of these zones intensive granodiorite K-feldspathization could be observed, while peripherally-postmagmatic biotitization. The reduced zones, where early potassium metasomatism was revealed, provided conditions for further propylitized solutions resulting in the intensive development of epidotization and chloritization within the central K-feldspathization zones.

Beresites with associated quartz-gold-sulphide veins extent towards the same increased permeability zones as propylites which are predominately located peripherally in echelon fractures. The beresite columns, forming along granodiorite (quartz-muscovite-ankerite facies) include the following 8 metasomatic zones:

1. plagioclase, K-feldspar, chlorite, quartz, magnetite;
2. plagioclase, K-feldspar, chlorite, quartz, pyrite;
3. plagioclase, K-feldspar, quartz, ankerite, sercite, pyrite;
4. ankerite, sercite, K-feldspar, quartz, pyrite;
5. ankerite, sercite, quartz, pyrite;
6. muscovite, quartz, pyrite;
7. muscovite, quartz;
8. quartz.

Progressively as the vein structures pinch out, the immature zones successively settle out of the beresite columns. Near- vein beresite column thickness decreases from 1-3m to 0.5-0.7m north south of the ore-field towards the deep fault. At the same time quartz-muscovite-ankerite facies grade to quartz- muscovite. In beresite-ankerite facies progressing along lamprophyre dykes the amount of sercite significantly increases (from 5–10 % to 30 %) from north to south [5, 6].

The gold-bearing vein composition involves 60 minerals the major ones of which are quartz, pyrite, arseno-pyrite, galena, sphalerite, calcite, chalcopyrite; as well as secondary minerals – tetrahedrite, molybdenite, scheelite, pyrrhotine, magnetite, tourmaline, telluride and sulphosalts, gold. Ore formation in the veins are subdivided into 4 successive steps:

- quartz-pyrite;
- arseno-pyrite;
- polysulphide;
- telluride-sulphosalt

Gold is associated with all sulphides and its maximum concentration being confined to the spatial overlapping areas of several mineral associations.

Mineral zonation throughout the ore-field is exceedingly contrasting. North south of the ore-field towards the deep fault these zones alternate (according to characterizing mineral): arseno-pyrite, galena-sphalerite, chalcopyrite-molybdenite, scheelite, tourmaline (fig.1). The sulphide content in the veins decreases from 50–80% to 5–8% in described direction. Horizontal zoning is distinctly observed and, even, along the vein strike, which is conditioned by the distribution of late gold-bearing paragenesis in the central parts of the veins, as well as early prevailing quartz-pyrite mineralization on the periphery of the veins.

Contrasting mineralization zoning is vividly observed in the properties of pyrite itself (one of the most abundant ore minerals). Besides Fe and S, it embraces such element impurities as As, Co, Ni, Pb, As, Zn, Cu and rarely, Cs, Sm, Zr, Sn, Pr, Mn. In the north south of the ore-field pyrite composition varies significantly- from increasing Co and Ni content to decreasing concentrations of element impurities.

The evidence of mineralization zoning within ore-bodies is marked by relative intersecting vein areas embracing fluid leading faults. Such areas of ore mineralization involve only quartz and pyrite, which are significantly enriched in Ni and As. Progressively from the leading ore structures mineralization becomes more and more diverse, while pyrite becomes enriched in Pb, Zn, Cu. Microscopically investigated pyrite grains showed that enriched Pb, Zn, Cu pyrite is governed by such mechanical impurities as galena, sphalerite, chalcopyrite and fahlerz. Ni and As are evident as impurities in the pyrite crystal lattice and is distributed zonal-concentrically (fig. 2). Such an oscillating distribution pattern of element-impurities is generally typical of genetically different pyrite [7, 8, 9].

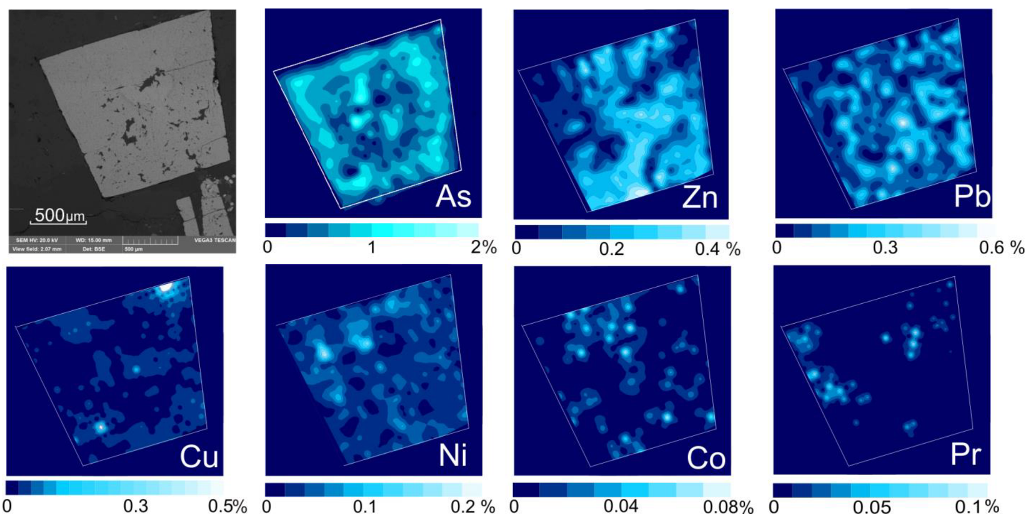

Figure 2. Distribution of element-impurities in pyrite grains

It was established that the mineral formation steps in veins and beresites demonstrate different behavior tendencies. Although arsenopyrite precipitates later than pyrite in the veins, both intersect the veinlets of late sphalerite-tetrahedrite- chalcopyrite -galena associations. However, within beresites arsenopyrite precipitates simultaneously with chalcopyrite, tetrahedrite, sphalerite, galena into carbonate-sulphide veinlets and intersecting pyrite, i.e. arsenopyrite mineralization step in beresites has not been identified (fig. 3).

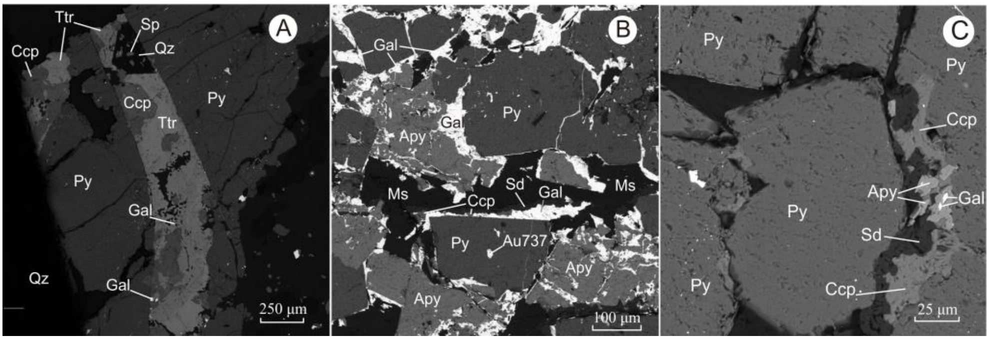

Figure 3. Interrelationship behavior of ore minerals in veins (A, B) and in near vein beresites (C): Py – pyrite; Apy – arsenopyrite; Gal – galena; Ttr – tetrahedrite; Ccp – chalcopyrite; Sp – sphalerite; Qz – quartz; Cal – calcite; Sd – siderite

Noble metal mineralization in veins and beresites is diverse. Native gold with rather high purity (730–788) is characteristic of these veins. Silver can be found in native gold and tetrahedrite as a concentration of 3.5 % to 13.4 %.

Only low-grade gold (500–560)and electrum (including silver content of 50-80%) can be found in beresites (fig. 4). Silver is also evident as argentite and as an impurity in tetraherite. Electrum and chalcopyrite often react resulting in the formation of a unique alloy composition: from $7(Ag,Au)*2CuFeS_2$ to $7(AgS)*2CuFeS_2$.

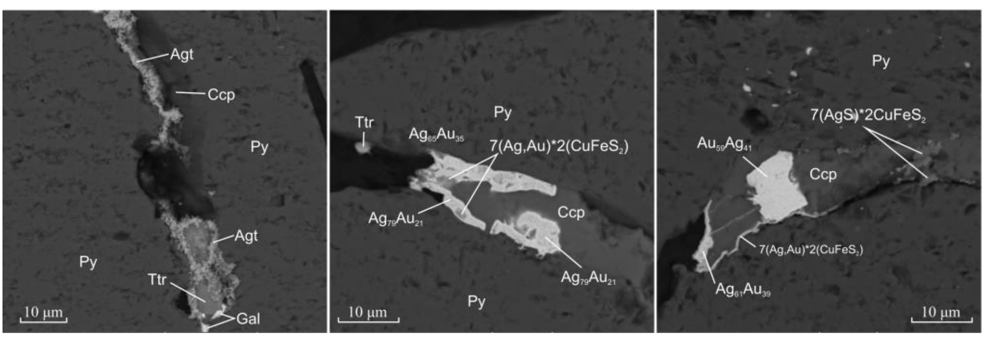

Figure 4. Gold-silver mineralization in beresites : Py – pyrite; Agt – argentite; Gal –galena; Ttr – tetrahedrite; Ccp – chalcopyrite

Late gold-galena-tellurium-bismuth mineralization was identified in two areas, i.e. Burlev and Khrebtov areas. Comparable to the total ore-field structure these two areas are centrally localized with respect to the developing mineralization zoning temperature. The presence of tellurium indicates the stabilizing convergent behavior of zoning in the late ore deposition stages. Tellurium-bismuth mineralization involves the following minerals: joseite (Bi_4Te_2S), pilzenite ($Bi_{11}Te_{10}$), wehrlite (Bi_3Te_2), tellurium-bismuth (Bi_2Te_3), gustavite (Bi_3S_6), volynskite ($AgBiTe_2$), matildite ($AgBiS_2$), stuetzite (Ag_5Te_3), hessite (Ag_2Te), tetradymite (Bi_2Te_2S), cosalite ($Pb_2Bi_2S_5$), tellurite (TeO2), native bismuth. Above-mentioned minerals, except for tellurium-bismuth and tetradymite, have been discovered in this ore-field for the first time. Gold in tellurites is often associated with hessite. Average purity of gold is more than 700, however, one can find electrum with a silver content of up to 50 % (fig. 5). There are no other impurities in gold, except for silver. One can find Fe and Cu rarely (less than 1 %).

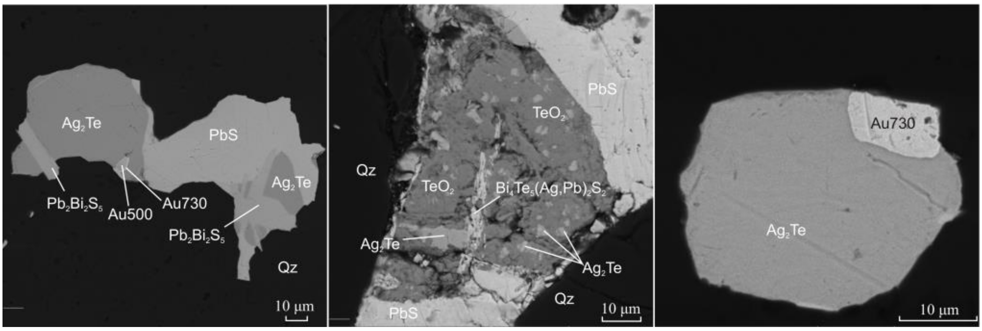

Figure 5. Precipitation and interrelationship behavior of mineral associations: gold-galena- tellurite-bismuth

Tellurite-bismuth minerals were not detected within other ore-field areas. Late galena is associated only with stibnite fahlerz (tetrahedrite) and sometimes accompanied by native bismuth. Zonal composition sequence of tellurite-bismuth mineralization was also revealed within other gold-ore deposits [10]. Spatial isolation of gold-galena-tellurite-bismuth and gold-galena-sulphosalt (fahlerz) associations, parallel in formation time, could possibly reflect the zonation of sediments in later gold-bearing mineralization and, in this case, could be used in predicting future mineralization.

4. Conclusion

Based on the investigation data results from Central ore-field, 11 previously undiscovered minerals were revealed. The distribution behavior and impurity deportment in pyrite were determined. Differential tendency of mineralization in veins and beresites was identified. The composition of native gold was studied. The zonation of sediments in gold-bearing tellurite-bismuth mineralization was established which could be used as a mineralogical prospecting criterion.

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