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Au-Ag-Te-Se deposits
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Gold ore deposits of Uzbekistan: Geochemistry and nanomineralogy of tellurium and selenium

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Abstract. The geochemistry and forms of occurrence of Te and Se in the primary gold ore of the main deposits of Uzbekistan (Muruntau, Charmitan, Kochbulak, Kyzylalma) have been studied by means of mass spectroscopy and electron microprobe. These deposits represent the four main exploited types of gold ore: /Au-W/Au-As/Au-Te/Au-Ag/. Abundances of Te, Se, Bi, As and Sb define the geochemistry of gold and silver throughout all the deposits. Tellurides and selenides are widely distributed in the ores, but tend to be dominantly present in micro- (<100 µm) or nanoscale (invisible) forms. Gold is generally present in native form. Tellurides and selenides form a number of microassemblages which are specific to the genetic type, reflecting bulk geochemistry, physicochemical conditions of formation, deposit zonation, as well as the formational depth, as seen from the present day exposure levels of the systems.

Key words: Uzbekistan, Muruntau, Charmitan, Kochbulak, Kyzylalma, gold deposits, tellurium, selenium, geochemistry, nanomineralogy

Introduction

The application of highly sensitive research techniques (ICP-mass spectrography, electron probe microanalysis etc.) in mineralogy and geochemistry has resulted in a revision of some traditional concepts concerning the mineralogy and geochemistry of gold ore deposits. Research based on the methods and principles of natural nanotechnologies and micro- and nanomineralogy has shown, that the role of Te and Se in the gold ore deposits of Uzbekistan is much greater than was previously recognised. The new data form the basis for the development of new approaches to the problems of ore formation, prognosis and the search for additional gold deposits.

Ore geology, mineralogy and geochemistry

Uzbekistan is among the leading gold-producing countries in the world, ranking fourth in terms of ore reserves and 8-9th in terms of current gold production. Well-known deposits such as Muruntau, Charmitan, Kochbulak, Kyzylalma and others, form the basis of the raw material resources of the republic. All the economic and exploited gold deposits are concentrated within the so-called Beltau - Kurama volcano - plutonic belt (BKVPB, Fig. 1) which stretches in an arc for 1300-1350 km from the Valeryanov zone of the Urals in the west to the Chatkal ridges in the east. The width of the belt is 150-200 km.

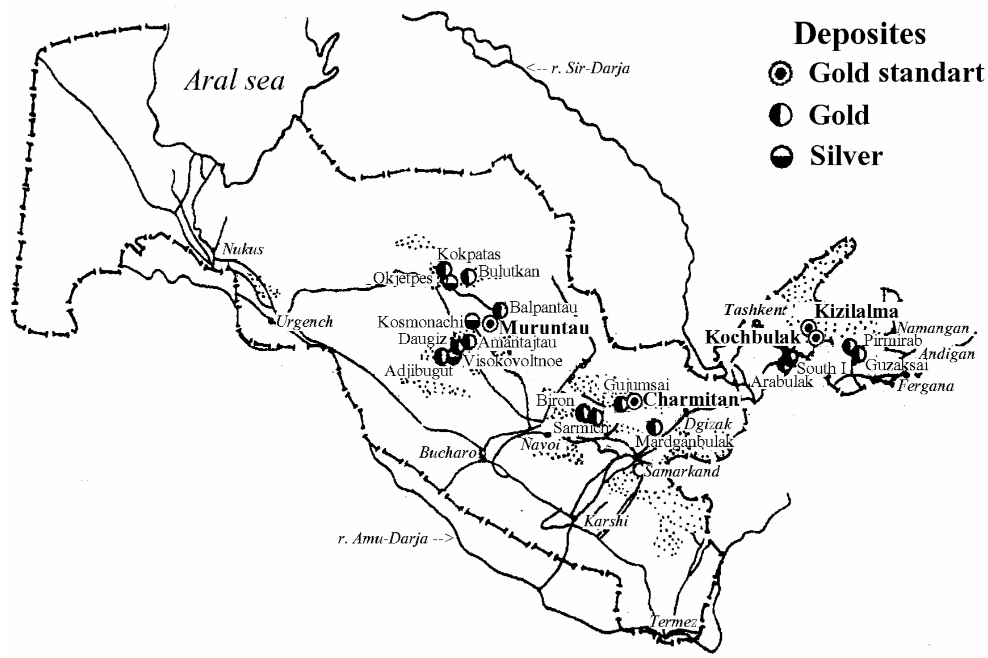

Fig. 1. Location of gold deposits on territory of Uzbekistan

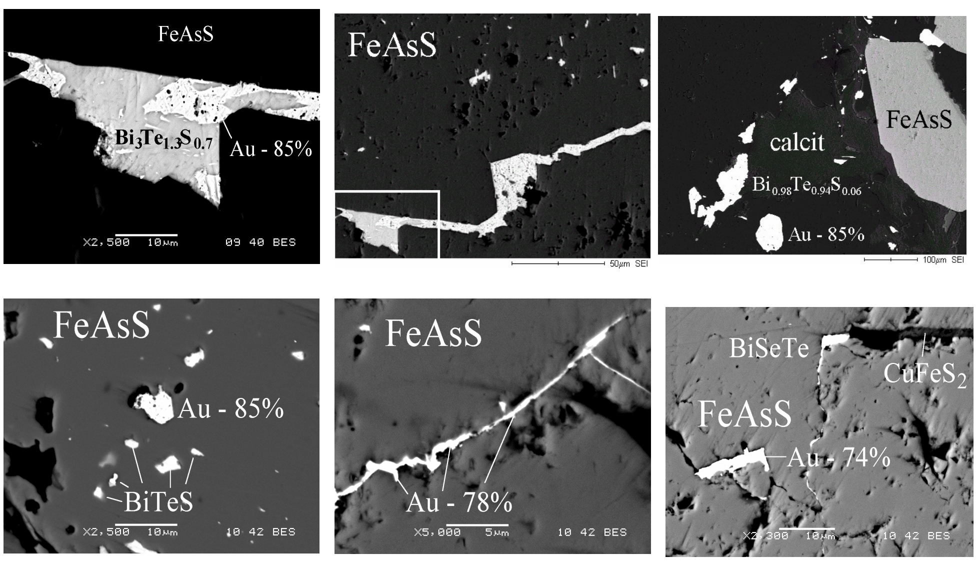

Fig. 2. Microassemblages of gold and tellurides, Muruntau deposit

Table 1. Composition of mineral associations of gold in the main ore deposits of Uzbekistan

Deposit, type	Mineral Association					
Muruntau Au-quartz	scheelite-Au-graphite-chlorite-quartz	Au-arsenopyrite-pyrite- quartz	polysulphide-graphite-quartz	silver-adularia-graphite-quartz	stibnite- pyrite-calcite	cinnabar-quartz-dickite
Charmitan Au-sulphide	scheelite-Au-quartz	Au-arsenopyrite-pyrite	polysulphide-tellurides	galena-sphalerite-electrum	quartz-calcite-antimonite	quartz- calcite-fluorite
Kochbulak Au-sulphide-quartz	tungstate-quartz	Au- pyrite-quartz	Au-tellurides-polymetallic	sphalerite-galena-Au-Ag	calcite- stibnite	quartz- barite-calcite-cinnabar
Kyzylalma Au-quartz	scheelite-molybdenite	Au-arsenopyrite-pyrite	Au-sulphides-tellurides	electrum-selenides-polysulphides	?	barite- fluorite
Paragenesis	Au-W	Au-As	Au-Te	Au-Ag	Au-Sb	Au-Hg
Key micro minerals	wolframite, molybdenite, cassiterite, tungstenite	gersdorfite, löllingite, nickeline, cobaltine	tetradymite, calaverite, petzite, tsumoite, joseite, coloradoite.	polybasite, stephanite, argentite, naumannite	jamesonite, bournonite, owyheeite, diaphorite.	aktashite, livingstonite, getchellite, galkhaite,
Gold Compounds	Au_3Ag Au_8Ag	AuAsS AuS	$AuTe_2$, Au_2Bi, Au_8Ag, Au_3Ag	AuAg $AuAg_3$	$AuSb_2$, Au_8Ag	Au_2Hg_3, Au_8Ag

Table 2. Distribution of ore elements, tellurides and selenides in ores of deposits (mean concentrations, ppm)

Deposit	Muruntau	Charmitan	Kochbulak	Kyzylalma
Au	9.25	10.42	61.08	8.1
Ag	3.85	4.31	218.82	199.1
Se	26.45	10.13	11.2	3.6
Te	19.26	15.17	282.2	1.0
As	1591	15700	1680	426
Sb	21	140	2638	132
Bi	42	30	221	3
Cu	154	200	6921	1825
Pb	26	400	986	572
Zn	62	300	1613	761
W	225	78	15	26
Mo	35	10	35	23
Sn	12	10	33	4
Au:Ag	2:1	2:1	1:3.6	1:25
Se:Te	1.3:1	1:1.5	1:25	3.6:1
Tellurides, selenides	tsumoite, pilsenite, tellurobismuthite, hedleyite, joseite-B, hessite, tetradymite, altaite, kawazulite	tsumoite, telluro-bismuthite, pilsenite, hedleyite, wehrlite, tetradymite, joseite B, hessite, petzite	calaverite, sylvanite, petzite, hessite, tellurantimony, coloradoite, tetrady-mite, nagyagite.	hessite, cervelleite, stützite, clausthalite, naumannite, aguilarite, bohdanowiczite, petzite
Intensity sequence of accumulation of elements in ores				
Muruntau	Te-Bi-Au-As-Se-W-Ag-Sb-Mo-Sn-Cu-Pb-Co-Ni-Zn			
Charmitan	Te-As-Bi-Au-Sb-Se-Ag-W-Pb-Mo-Sn-Cu-Zn-Co			
Kochbulak	Te-Bi-Au-Sb-Ag-As-Se-Cu-Pb-Mo-Zn-Sn-W-Co			
Kyzylalma	Ag-Au-Te-Bi-Sb-As-Se-Cu-Pb-Mo-W-Zn-Sn-Co-Ni			

Note: According to data provided by authors and analyses of technological tests (samples)

The BKVPB is considered to be the northern margin of the Turkestan paleoocean basin. The following geodynamic evolutionary stages are recognized (Dalimov et al., 2002):

1. Rift genesis and destruction of Precambrian basement (Є-O).
2. Spreading and formation of oceanic basin (O_1-S_1)
3. Subduction of oceanic crust under the northern Kazakhstan-Kyrghiz microcontinent (S_2-D_1)
4. Carbonate pause (D_2-C_1)
5. Collision of Baisun and Kazakhstan-Kyrghiz microcontinents (C_2-P_1)
6. Development of intraplatform (P_1-K_1).

The BKVPB, which formed as a result of these processes, is characterized by the development of late Carboniferous granitoid and Permian gabbro-monzonite-syenite magmatism. The gold ore deposits in the territory of Uzbekistan form three clusters (Fig. 1): *Kyzylkum*, (Muruntau, Daugyztan, Amantaitan and other deposits); *Nuratin* (Charmitan, Guzhumsa, Marzhanbulak and others); *Kurama* (Kochbulak, Kyzylalmasay, Kayragach and others). The clustering of the gold deposits is determined by intersection of the BKVPB with transform faults which can be readily identified in satellite images.

The Kyzylkum deposits are mainly located within metamorphosed 'black shale' sequen-ces, including carbonates and other sedi-mentary rocks. Deposits of the Nuratin cluster are hosted within shale sequences, but also intrusive rocks, whereas those of the Kurama area are dominantly within trachy-basalts, -andesites and -dacites, intrusives and others (Akhmedov, 2001).

The timing of formation of all the major economic deposits in the BKVPB falls into the period Upper Carboniferous to Permian, according to geological data and analytical data providing absolute ages. In all deposits, Au-bearing quartz veins are accompanied by propylitization, beresitization and argillization. Metasomatism forms a favourable physico-chemical environment for gold deposition by homogenizing the composition and properties of the various host rocks. The metasomatites themselves contain gold and are often the subject of recovery. In accordance with traditional mineralogical investigations, the ores consist of gold-quartz and gold-sulphide-quartz types, rarely by gold-sulphide types with six mineral associations (Table 1). These associations shown are composed of a standard series of geochemical parageneses (Koneev, 2003): /Au-W / Au-As / Au-Te / Au-Ag / Au-Sb / Au-Hg/. The more of these parageneses are present, the less eroded the deposit (orefield) is. Nevertheless, economic resources and the scale of a given deposit are usually represented by 1-3 paragenesis, even though others may be present in lesser amounts.

Within the BKVPB, the role of late parageneses increases from west to east. Au-Sb-Hg mineralization at an economic scale manifests itself further east still, on the territory of Kyrgyzstan and Tajikistan. The ores of all deposits typically contain pyrite, arsenopyrite, chalcopyrite, galena, sphalerite, tetrahedrite, pyrrhotite, molybdenite, quartz, carbonates, barite and scheelite in various proportions. It is thought that the geochemistry of ores is defined by the following elements: Muruntau – Au, W, As, with lesser Sb, Ag, Bi, Zn, and Pb; Charmitan – Au, W, Bi, Ag, lesser Zn, Pb, Sb; Kochbulak – Au, Ag, Pb, Cu, Sb; Kyzylalma – Ag, Au, Sb, As, Cu, Pb, Mo.

Data on the distribution of Te and Se is not available, except for the Kochbulak deposit in which tellurides are widespread. In the other deposits, tellurides are generally considered as rare minerals.

Research techniques

Nowadays, nanotechnology and nanoscience are among the leading trends in science and technology, especially with respect to the field of studying and obtaining substances with specific properties. The physical, mechanical, electrical, thermodynamic and other properties of a given substance change greatly as the size of the individual structures decrease from the micron to the nanometer scale, occupying an intermediate position between classical and quantum fields (Hochella, 2002). A change in properties is due to size effects, the appearance of which is associated with intensive increase in specific surface energy, starting from sizes of <100 µm (Koneev, 2001). We suggest that processes of mineral formation at this scale be called natural nanotechnology, and the minerals themselves, nanominerals, since their properties, compositions and formation mechanisms differ from those considered by classic mineralogy (Koneev, 2004). Gold and its assemblages with tellurides and selenides are among the typical focuses of nanomineralogical study. In the gold ore deposits of Uzbekistan, 70-95% of gold particles are <100 µm in size, and are often 'invisible'. Studies were carried out using electron microscopy and electron probe analysis. On the µm- and nm-scales, gold, tellurides and selenides have mainly spheric and laminar (film) forms. The composition of minerals is generally non-stoichiometric. In the 21st Century, nanomineralogy has become the main method of studying the ore composition of deposits with element contents in the 0.0000n – 0.00n % range (Au, Pt, Pd, Os, Re, Se, Te and others).

Geochemistry and nanomineralogy

When analysing ore geochemistry and mineralogy in deposits of the Beltau-Kurama volcano-plutonic belt from a traditional viewpoint, the general conclusion is that there are sharp differences between the black shale-hosted Kuzulkum deposits, deposits clustered around Nuratin (in granosyenites, shales) and those of the Kurama volcanogenic field. However, if ore geochemistry is considered with respect to Clarke values for the elements in the Earth's crust (Table 2), we arrive at the conclusion that elements like Te, Bi, As, Sb, Se determine the geochemistry of gold and silver.

These elements, as well as gold and silver, are basically accumulated in the economic ores irrespective of the composition of the host rocks and other geological factors. In the Muruntau and Charmitan deposits, gold always occurs in microassemblages together with tellurides and selenotellurides of Bi (Table 2, Fig. 2). In the Kochbulak deposit, gold occurs with tellurides of Au, Ag, Sb, Hg and Bi (Fig. 3) and in the typical Au-Ag Kyzylalma deposit, electrum and küstelite (Ag,Au) occur together with Ag-selenides and -sulphosalts (Fig. 4).

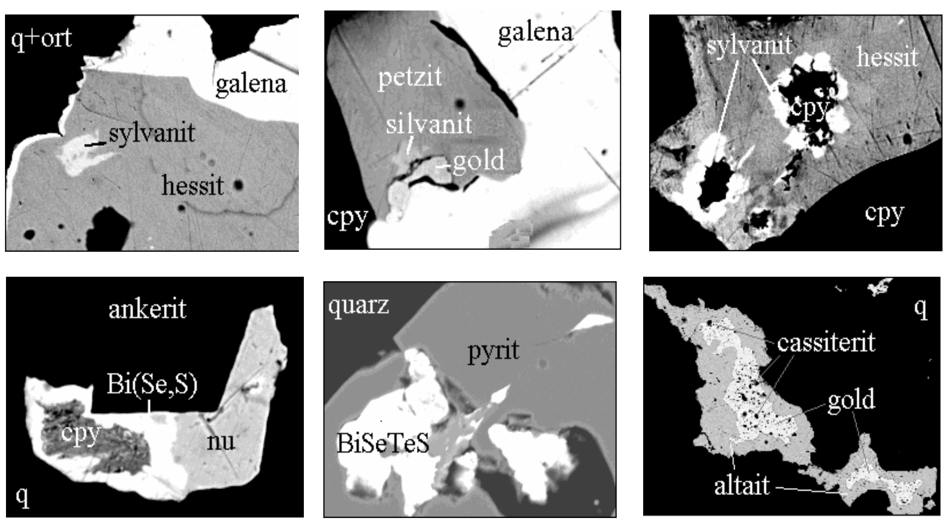

Fig. 3. Microassemblages of gold and tellurides, Kochbulak deposit

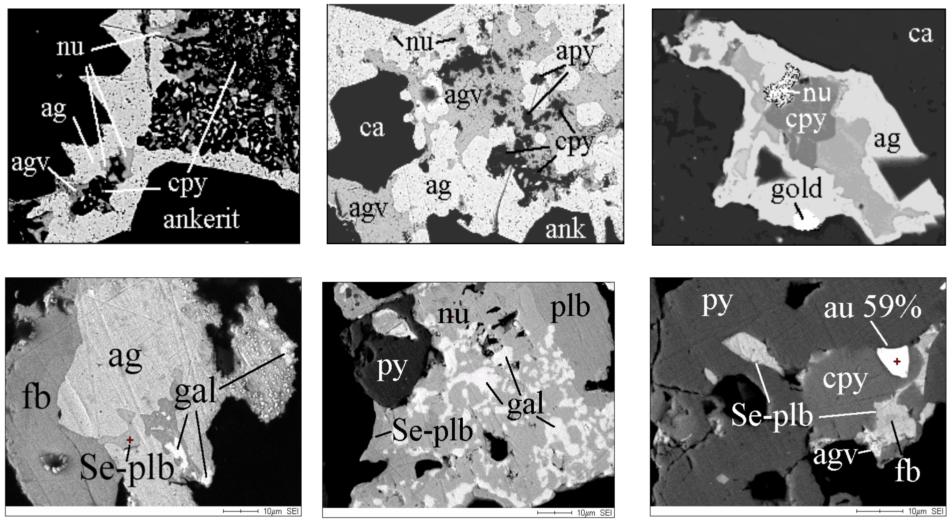

Fig. 4. Microassemblage of gold and selenides. Kizilalma. Abbreviations: py – pyrite, cpy – chalcopyrite, apy – arsenopyrite, gal – galena, au – gold, ag – silver, nu – naumannite, agv - aguilarite, plb- polybasite, ca – calcite, ort – orthoclase, ank – ankerite, q – quartz

Conclusions

By studying the economic gold ore deposits of Uzbekistan from a nanoscientific perspective, we have arrived at the following conclusions:

1. Formation of economic gold deposits of Uzbekistan resulted from geodynamic formation processes of the active continental margin (Beltau-Kurama volcano-plutonic belt) during C_3-P;
2. Geodynamic unity is responsible for the development of a standard sequence of geochemical parageneses in the ores: /Au-W/Au-As/Au-Te/Au-Ag/Au-Sb/Au-Hg/ and specific micro- and nanoassemblages of gold, tellurides and selenides;
3. Economic resources in a given deposit are defined by 1-3 paragenesis from the above standard series in accordance with lateral/ longitudinal and cross-sectional zoning inside the BKVPB and level of erosion;
4. The associations Te-Se-S and Bi-Sb-As probably have a single deep source, and are responsible for the formation of the economic concentrations.

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