

UDC 553.43/451.498 + 553.662(575)

MINERALOGY OF EPITHERMAL GOLD-SULFIDE-TELLURIDE ORES OF THE KAIRAGACH GOLD DEPOSIT, (Uzbekistan)

Vladimir A. Kovalenker

Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry (IGEM), RAS, Moscow, vak@igem.ru

Olga Yu. Plotinskaya

Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry (IGEM), RAS, Moscow, plotin@igem.ru

Rustam I. Koneev

Ulugbek National University of Uzbekistan, Tashkent, Republic of Uzbekistan

The Kairagach ore deposit is situated on the northern slope of the Kurama Ridge (East Uzbekistan), 3.5 km northeast of the well-known Kochbulak gold-telluride ore deposit. According to specific mineralogical features of the ores and hydrothermal alterations, it was assigned to the high-sulfidation (or acid-sulfate) type of epithermal mineralization. However, in contrast to typical gold deposits of this type with a pronounced Au-Cu specialization, the ores of the Kairagach deposit are characterized by the Au-Sn-Bi-Se-Te geochemical profile. This paper briefly summarizes original and published data on the Kairagach deposit, including its geological features and ore characteristics, sequence of the mineral formation, and the main mineral assemblages. Occurrence conditions and chemical peculiarities of the essential minerals of the gold-sulfide-selenide-telluride mineralization are considered. Data on the abundance and compositional variations of native elements (gold, tellurium, and tin), fahlores, Bi and Sb sulfosalts, Cu and Fe sulfostannates, and various selenides and tellurides are presented.

It is shown that the unique diversity of the ore mineralization is determined by the variety of state and occurrence forms (native, isomorphous, sulfide, selenide, and telluride) of their contained chemical elements.

6 tables, 5 figures and 15 references.

The Kairagach epithermal gold ore deposit of Late Paleozoic age is situated in the northern spurs of the Kurama Ridge, eastern Uzbekistan, 3.5 km northeast of the well-known Kochbulak gold-telluride deposit (Kovalenker *et al.*, 1997). In terms of its economic potential, the Kairagach deposit is not assigned to the rank of large objects: its resources are estimated to be 50 t Au and 150 t Ag (Islamov *et al.*, 1999). However, this object is of significant interest for studying epithermal ore genesis regularities, since it belongs to the acid-sulfate (Heald *et al.*, 1987), or high-sulfidation (White and Hedenquist, 1991), type of epithermal ore mineralization, that is very rare in the former Soviet Union territory, and its ores consist of a unique variety of minerals (sulfides, sulfosalts, tellurides, selenides, and oxides). Moreover, in contrast to typical high-sulfidation ore deposits characterized by Au-Cu specialization of their mineralization (Summitwill in the United States, El Indio in Chile, Nansatsu in Japan, Lepanto in Philippines, Chelopech in Bulgaria), the Kairagach deposit is characterized by a clearly pronounced Au-Sn-Bi-Se-Te geochemical profile of the ore mineralization.

The unordinary and complex mineral composition of the ores caused the fact that, even at early stages of studying the Kairagach deposit, the paramount attention was given to comprehensive mineralogical investigations. These works revealed here a number of rare minerals, including new mineral species (Badalov and Spiridonov, 1983; Badalov *et al.*, 1984; Kovalenker, 1986; Kovalenker and Geinke, 1984; Kovalenker *et al.*, 1984, 1986, 1987; Spiridonov and Badalov, 1983; Spiridonov *et al.*, 1983). At the same time, no summary work on the Kairagach ore mineralogy has been published until now. The present paper summarizes data accessible by the present time (including those we obtained in the last years), which generalize the occurrence conditions, parageneses, and variations of the chemical composition of minerals that form the unique ores of the Kairagach deposit (native gold and other native elements, various sulfosalts, tellurides, and selenides). It is believed that the data considered here substantially refine and expand the notion of mineralogical and geochemical features not only of the Kairagach deposit but also of epithermal ore mineralization as a whole.

Geology and Ores of the Kairagach deposit

The Kairagach deposit is confined to a Hercynian volcanic caldera. The caldera is composed of Middle and Late Carboniferous andesite, andesite-dacite, and dacite tuffs, lavas, and subvolcanic formations. In the central segment of the caldera effusive-pyroclastic rocks are intruded by the mushroom-shaped Kairagach subvolcanic extrusive stock of trachyandesite porphyrites (1.2 x 3 km in size), that supposedly fills the vent of an ancient stratovolcano. In the northern endocontact zone of the extrusive stock, NE-trending ore-bearing structures are located. The volcanosedimentary rocks are also intruded by dikes of diabase porphyrites and granodiorite porphyries of Late Carboniferous to Early Permian age. The deposit is bounded by the Karatash normal fault on the west and by the NE-trending Shaugaz (or Angren) thrust fault on the north (Kovalenker and Geinke, 1984). In the volcanic and subvolcanic rocks, weak propylitization (calcite-chlorite and albite-chlorite-calcite facies) is ubiquitously manifested.

The ore mineralization at the Kairagach deposit is concentrated within four 3-5-km-long zones of metasomatic silicification: the Diabasic, First, Chukurkatan, and Bedrenget ones. The commercial-grade ore mineralization has only been revealed in the Diabasic and First zones. These zones represent intricately constructed branching bundles of quartz, quartz-barite, and barite veins, as well as lenticular, veinlet-like, and breccia bodies, all of which contain nest-type, disseminated, and veinlet-disseminated ore mineralization. The host volcanites and diabase porphyrite dikes were subjected to intensive silicification, sericitization, and pyritization. Gold-sulfide-selenide-telluride mineralization mainly occurs in ore bodies of the Diabasic zone that has been most comprehensively studied by the present time, the bulk of resources of precious metals of the Kairagach deposit being related to this zone. It is confined to the northern contact of the Kairagach subvolcanic stock of trachyandesite porphyrites.

According to the mineral composition, two principal types among the ores localized within the Diabasic zone were distinguished. The first, *gold-quartz type* is represented by essentially quartz ores, in which sulfides (predominantly pyrite) commonly do not exceed 3–5 vol % in abundance. They are spatially associated with zones of monoquartzites and are characterized by the massive structure and relatively low concentration of the useful components.

Quartz of this ore type is cryptocrystalline to flint-like; as a rule, it is characterized by numerous caverns and high porosity, leaching cavities and contains sporadically distributed relicts of the host volcanites. The second, *complex gold-sulfide-selenide-telluride type* of the ore mineralization is represented by vein-shaped and lenticular bodies, veinlet-disseminated and nest-shaped accumulations of quartz, quartz-barite, and barite composition with sulfides, sulfosalts, selenides, and tellurides, that are unevenly distributed within the ore zone among both the monoquartzites and berisite-like formations. Ores of this type play an important role in the balance of reserves of the deposit. They are characterized by variable concentrations of gold, silver, and other useful components, as well as by a complex and variable mineral composition.

Sequence of Mineralogenesis and the Main Mineral Assemblages

Studying the structural and textural peculiarities of the ores revealed a certain sequence in formation of the ore mineralization in the Diabasic zone. It is shown that mineral assemblages of the ores and hydrothermal wall rock alterations formed during four main stages, including the Preproductive Metasomatic, Early Productive (or quartz-pyrite), Main Productive (or gold-fahlore-sulfosalt-telluride), and Postproductive (or quartz-carbonatebarite) stages (Plotinskaya and Kovalenker, 1998).

The Preproductive Metasomatic Stage is characterized by formation of secondary quartzite-type rocks with pyrophyllite, diasporite, kaolinite, and alunite, as well as of berisite-like quartz-carbonate-sericite rocks with pyrite.

The Early Productive Stage mineralization is dominated by minerals of the gold-quartz-pyrite assemblage, that are present in form of sulfide dissemination in gray metasomatic quartz. The sulfides are represented by predominant pyrite; minor chalcopyrite, and rare sphalerite, galena, and fahlores of the early generation. Native gold is present as ultradispersed inclusions in quartz and pyrite.

The Main Productive Stage includes several mineral assemblages that are commonly closely time-related and are often spatially telescoped. The earliest of them is the gold-quartz-barite assemblage. It is represented by segregations of native gold of high fineness, enclosed in quartz-barite aggregates, and is characterized by practically simultaneous

deposition of the gold, quartz, and barite. The assemblages of goldfieldite and famatinite-luzonite, which is encountered at upper levels of the deposit, attributed to the early ones. Goldfieldite and famatinite-luzonite commonly form small (up to a few hundreds micrometers in size) segregations within barite and quartz, or are present as relicts in later minerals. They are characterized by an appreciable (up to 1–2 wt. %) Sn admixture. The presence of famatinite, luzonite, and enargite among the ore minerals is considered to be a diagnostic feature of the high-sulfidation mineral-forming environment (White and Hedenquist, 1991). We believe that goldfieldite may also be assigned with certainty to indicator minerals of ore mineralization of this type.

Relatively later mineral assemblages include an assemblage of native gold with early tellurides (mainly altaite and calaverite as well as sylvanite, frobergite, coloradoite, telluranthimony, and others). This assemblage is distributed practically throughout the whole vertical interval of the ore mineralization, except for the very near surficial level. The gold-telluride assemblage is often spatially coincident with the native tellurium assemblage. This mineral is characterized by significant (up to 10 wt. %) admixture of Se. It forms small segregations (occasionally intergrowths with chalcopyrite) in barite or quartz. Another mineral association temporally close to and often spatially coincident with the telluride parageneses is the assemblage of Cu and Fe sulfostannates, that includes mawsonite, stannoidite, kesterite, nekrasovite, volfsonite, hemusite, as well as a number of poorly studied minerals with variable ratios of Sn, Cu, and Fe.

The sulfobismuthite assemblage is represented by minerals compositionally close to those of the bismuthinite-aikinite series and of the junote and pavonite homologue series, as well as by hodrushite. These minerals are characterized by wide variations in the chemical composition and by increased contents of Se. They form close intergrowths with Bi-containing fahlores. Minerals of the bismuth-sulfoselenide assemblage are relatively later. They are represented by native bismuth, laitakarite, tetradymite, and other sulfoselenides, sulfotellurides, and sulfoselenotellurides, as well as by chalcopyrite, that replaced the selenitic sulfobismuthites as a result of their decay caused by changing of physicochemical conditions of environment.

The most widespread mineral assemblage among products of the gold-fahlore-sulfosalt-telluride stage is the

assemblage of fahlores that are commonly intergrown with chalcopyrite to form relatively large (up to several millimeters) aggregates. Fahlores of the late generation commonly contain numerous inclusions of native gold, Bi-sulfosalts, sulfostannates, tellurides, and selenides.

One of the latest mineral formations of the Main Productive Stage is the assemblage of hessite, electrum, and chalcopyrite. Very fine particles of these minerals are commonly confined to barite or quartz.

Mineralization of the Postproductive Stage is represented by thin veins or veinlets, transecting mineral formations of all the preceding stages. These veins and veinlets are composed of quartz, carbonates, and barite and occasionally contain variable amounts of sulfides, mainly of galena and sphalerite and more rarely of chalcopyrite, pyrite, and tetrahedrite.

Occurrence and Chemical Composition of the Essential Minerals of the Gold-Sulfide-Selenide-Telluride Ores

The chemical composition of the minerals was studied using the electron-probe microanalysis (EPMA) on Cameca MS-46 (analysts V.S. Malov and N.V. Troneva), Camebax-Micro (analyst S.M. Sandomirskaya), and SX-50 (analyst A.I. Tsepina) probes. The experimental conditions were as follows: (1) MS-46: accelerating voltage 20 kV; absorbed electron current 15–25 nA (depending on minerals analyzed); beam diameter 1–2 μm ; analytical lines: K_{α} (for S, Fe, Cu, and Zn), K_{β} (for As); L_{α} (for Ag, Sb, Te, Bi, and Se); standards: stoichiometric FeS_2 , CuFeS_2 , NiAs, Ag_8SnS_6 , and PbSe and metallic V, Zn, Sb, Ag, Te, and Bi; (2) Camebax-Micro: accelerating voltage 20 kV; absorbed electron current ~15 nA; beam diameter 1–2 μm ; analytical lines: K_{α} (for Cu, As, S, and Se) and L_{α} (for other elements); standards: synthetic PbTe, CdSe, CuSbS_2 , and GaAs and chemically pure Au, Ag, and Bi; (3) SX-50: accelerating voltage 20 kV; absorbed electron current 20 nA; beam diameter 1–2 μm ; analytical lines: K_{α} (for Cu, As, S, and Se) and L_{α} (for other elements); standards: synthetic PbTe, HgTe, FeS_2 , ZnS, and GaAs and chemically pure metals.

Native Gold, Tellurium, Bismuth, and Tin

The native gold particles are quite diverse in their morphology. There are xenomorphic,

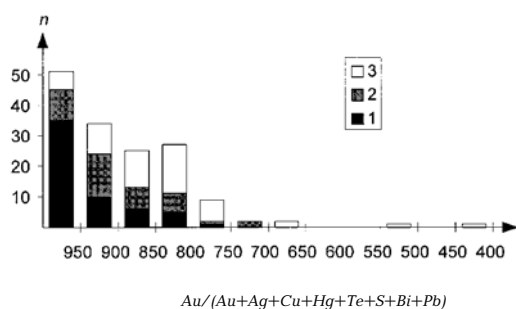


Fig. 1. Distribution of the fineness of native gold from different mineral assemblages of the Diabasic zone: (1) associated with quartz and barite, (2) with early tellurides and sulfobismuthites, and (3) with hessite, chalcocopyrite, and tetrahedrite

elongated, cloddy, stringer, rounded, oval, and amoeboid particles of this mineral. More than 70% of the native gold particles are less than 20 μm in size, while the number of relatively large (more than 100 μm in size) gold particles does not exceed 10%.

Sulfides commonly contain isolated native gold inclusions, while the vein minerals host their aggregates often confined to the barite-quartz boundaries. The same parts of ore bodies contain, as a rule, increased amounts of minerals of the productive assemblages (tellurides, selenides, and sulfobismuthites).

A characteristic feature of native gold from ores of the Diabasic zone is its extremely high fineness determined as the ratio $\text{Au}/(\text{Au} + \text{Ag} + \text{Cu} + \text{Hg})$. The fineness varies from 992 to 900 in more than 50% of the gold particles studied and exceeds 800 in no less than 85% of the gold particles (Table 1, Fig. 1).

Gold particles characterized by the highest fineness are confined to quartz (fineness 937–965 on the upper levels and 974–995 on the lower ones) and to barite (795–946 and 880–989, respectively). The fineness of native gold associated with the early tellurides (altaite, calaverite, and others) increases from 806–944 to 971 with depth. Hessite, one of the late tellurides, is associated with electrum and gold of a relatively low fineness (from 670 to 850) on the upper levels and with gold of a higher fineness (950–960) at the lower levels. Later native gold that is present in intergrowths with minerals of the bismuthinite-aikinite series and Bi tellurides is characterized by a fineness of 838–943. Native gold associated with tetrahedrite and chalcocopyrite exhibit wide variations of the fineness (790–956). Relatively small particles of native gold are, as a

rule, characterized by a low fineness; larger gold particles often possess a zonal structure: the central zones are represented by gold of high fineness, while the rims, by gold of low fineness, the differences in the Au concentrations reaching 27 wt.%. The highest Ag concentrations were registered in particles of electrum (fineness from 401 to 834) that forms veinlets in fahlore. As opposed to native gold from other mineral assemblages, this electrum additionally contains high concentrations of Hg (mainly 1–5 wt.%; up to 10–11 wt. % in rare cases).

In addition to gold, other native elements – tellurium, bismuth, and tin – were revealed in the ores under consideration. *Native tellurium* forms small separate grains within barite or quartz; occasionally, it grows on segregations of earlier tellurides; in some cases, native tellurium was noted to be overgrown by chalcocopyrite. *Native tellurium* that forms small segregations in barite is characterized by high (up to 10.25 wt. %) admixtures of Se. *Native bismuth* is represented by small segregations associated with Bi sulfosalts, Bi-containing fahlores, sulfostannates, and chalcocopyrite. In its chemical composition, small admixtures of S, Cu, Fe, and Ag were revealed. *Native tin* forms very fine grains intimately intergrown with V-containing cassiterite and sulfostannates of Cu and Fe (Badalov *et al.*, 1984).

Fahlores

Fahlores belong to widespread minerals of the Kairagach deposit. Their 4 principal generations were revealed with respect to the relative formation time, which are substantially different from each other in chemical composition (Table 2, Figs. 2 and 3). *Fahlores of the early generation* are predominantly represented by tennantite and As-rich varieties of the tennantite-tetrahedrite series minerals. They are rather rare and compose small segregations intergrown with pyrite formed during the early quartz-pyrite stage. *Fahlores of the second generation* represented by minerals of the goldfieldite-tennantite-tetrahedrite series are relatively more widespread. They predominantly occur at the upper levels of the deposit and intimately associated with calaverite, altaite, coloradoite, frobergite, tellurantimony, native tellurium, and famatinite-luzonite. The Te content of these fahlores reaches 17 wt. % (decreasing up to 2–8 wt. % with depth); some their segregations are characterized by high concentrations of Ag (up to 11 wt. %) and Se (0.2–1.1 wt. %). The high-Te goldfield-

Table 1. Limits of variations of the chemical composition of native gold from the Kairagach ore deposit (wt. %).

Associated minerals	n*	Au	Ag	Cu	Bi	Te	Hg
Quartz	38	79.38-	0.12-	0.00-	0.00-	0.00-	0.00-
		99.41	17.77	0.21	1.46	0.62	0.30
Barite	11	79.19-	0.99-	0.00-	0.00-	0.00-	0.00-
		97.25	20.23	0.78	0.87	0.07	0.17
Early tellurides (calaverite, altaite, frobergite, petzite, etc.)	19	84.64-	0.39-	0.00-	0.00-	0.00-	0.00-
		97.01	18.42	1.15	1.55	2.70	0.30
Late tellurides (hessite) and chalcocopyrite	12	67.11-	4.96-	0.00-	0.00-	0.00-	0.00-
		94.05	29.26	1.87	0.61	1.11	0.09
Sulfobismuthites and rare Bi	18	71.78-	0.53-	0.0-	0.00-	0.00-	0.00-
		97.98	27.14	0.49	2.02	0.24	0.20
Fahlores, sulfostannates, and chalcocopyrites	28	79.01-	2.86-	0.26-	0.0-	0.0-	0.0-
		95.56	22.05	2.52	1.11	0.19	1.28
Electrum stringers in fahlore	7	40.02-	14.42-	0.69-	—	—	0.00
		83.44	46.58	2.35	—	—	11.26

Notes: *) n – number of determinations; (–) – not analyzed

ite-tennantite-tetrahedrite series minerals studied are characterized by a predominance (relative to the stoichiometry) of monovalent metals over divalent ones and of Fe over Zn among the latter (Fig. 3). In this case, As and Sb are present in approximately equivalent quantities (Fig. 2). It is important to note that Te in the chemical composition of the Te-containing varieties of fahlores is characterized by the positive charge 4+; therefore, this element is in the oxidized state here and, in contrast to its position in tellurides, belongs to the cationic part. *Fahlores of the third generation* are intimately associated with Bi sulfosalts as well as with native gold of high fineness, native bismuth, and selenides and are represented by minerals of the tennantite-tetrahedrite-annivite series (Fig. 2). They are characterized by high (up to 9 wt. %) contents of Bi (its concentration decreases up to 2–5 wt. % with depth), increased (1–3 wt. %) contents of Te, and low (<1 wt. %) contents of Ag (Table 2). Their As and Sb contents are approximately equal to each other, and Fe prevails over Zn (Figs. 2 and 3). As a rule, fahlores of the second and third generations occur as relicts within other minerals, including *fahlores of the fourth generation*. The latter are predominantly revealed in central zones of the ore bodies in form of rather large (up to several millimeters in size) segregations, often intergrown with chalcocopyrite, sulfostannates, and chalcostibite and occasionally with bournonite. Fahlores of this generation usually contain segregations of native gold with relatively low fineness and some tellurides. The chemical composition of fahlores of the late generation is characterized by a prevalence of the tetrahedrite end member, by a predominance of Zn over

Fe, and by low (<1 wt. %) Ag and Se concentrations (commonly on the order of 0.1 wt. %) (Table 2, Figs. 2 and 3). However, the Ag content of tetrahedrites associated with bournonite and chalcostibite at deep levels of the deposit reaches up to 10 wt. %.

Sulfosalts of Bismuth and Antimony

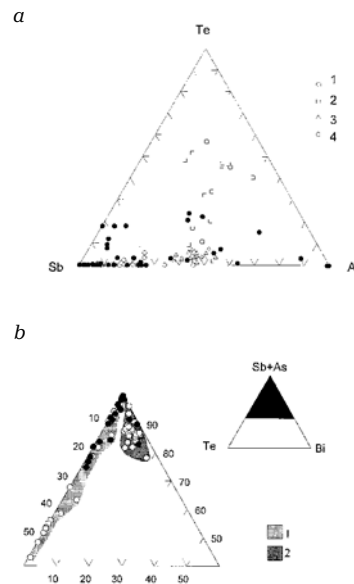


Fig. 2. Diagrams of the chemical composition of fahlore group minerals from the Kairagach deposit: (a) General variations of metalloids in fahlores of different (1-4) generations (at. %); (b) chemical composition of Bi- and Te-containing fahlores of the (1) second and (2) third generations. Open symbols are for the upper levels (+1340, +1300, and +1220 m); filled symbols are for the lower levels (+1100 and +1000 m)

Table 2. Limits of variations of the chemical composition of fahlore group minerals of different generations from the Kairagach deposit

	Fahlore generation							
	1 (n=5)*		2 (n=23)		3 (n=33)		4 (n=48)	
	a	b	a	b	a	b	a	b
Cu	42.65-40.42	10.28-9.40	44.32-34.27	11.29-9.35	41.55-36.67	10.56-9.50	42.63-30.99	10.96-8.62
Ag	0.78-0.01	0.11-0.00	11.18-0.00	1.80-0.00	0.60-0.00	0.09-0.00	9.53-0.00	1.56-0.00
Fe	5.68-3.16	1.57-0.85	7.11-0.15	2.00-0.04	6.84-1.20	2.04-0.35	5.89-0.04	1.67-0.01
Zn	6.10-2.89	1.39-0.64	4.29-0.03	1.04-0.01	6.28-0.08	1.59-0.02	7.58-0.41	1.90-0.10
Te	1.78-0.00	0.22-0.00	17.16-2.45	2.27-0.30	2.26-0.00	0.28-0.00	4.89-0.00	0.61-0.00
Sb	13.25-0.06	1.68-0.01	22.56-2.94	2.98-0.40	30.58-12.50	4.19-1.62	29.98-10.54	4.17-1.32
As	19.45-9.56	3.87-1.97	12.86-1.71	2.68-0.00	9.95-0.19	2.06-0.04	12.94-0.29	2.64-0.00
Bi	0.45-0.00	0.03-0.00	5.08-0.00	0.40-0.00	9.54-0.55	0.77-0.04	3.34-0.00	0.26-0.00
S	29.31-26.87	13.50-12.92	28.19-22.92	14.17-12.10	26.90-23.42	13.21-12.19	28.17-22.25	14.08-12.00
Se	0.41-0.00	0.08-0.00	1.28-0.03	0.27-0.00	0.59-0.00	0.12-0.00	0.58-0.00	0.12-0.00

Notes: (n) number of determinations, (a) wt. %; (b) formula coefficients (calculation based on 29 atoms in a formula unit).

Table 3. Chemical composition of Bi sulfosalts (wt. %).

№ os.	Sample no.	Bi	Pb	Sb	As	S	Cu	Ag	Se	Total	+/- (%)
1	27/85	62.49	12.32	0.33	0.00	17.56	3.66	0.00	1.12	97.50	-3.34
2	8/83	36.66	35.12	0.00	0.00	14.92	10.32	0.06	2.78	99.86	2.47
3	8/83	35.68	35.23	0.00	0.30	15.06	10.43	0.04	2.21	98.97	3.14
4	1050/82b	34.28	36.34	0.33	0.05	16.02	9.52	2.66	0.00	99.33	3.00
5	65/82	57.77	0.02	0.14	0.15	16.84	19.92	0.00	4.83	99.67	1.93
6	65/82	58.17	0.00	1.54	1.49	17.69	18.96	0.08	4.07	102.00	-1.89
7	65/82	58.80	0.00	0.22	0.16	17.52	18.97	0.08	2.78	98.53	0.87
8	42/85	55.31	19.68	0.09	0.00	16.20	4.36	0.08	3.12	98.87	3.38
9	147/81a	64.45	0.41	0.07	0.41	17.16	12.82	0.74	3.47	99.53	-1.17
10	8/83a	54.82	12.01	0.11	0.00	15.42	7.94	3.83	4.07	98.20	-0.25
11	8/83a	55.21	11.56	0.00	0.84	15.58	8.28	3.74	5.06	100.27	-0.09
12	8/83a	56.51	11.27	0.00	0.00	15.65	9.38	1.83	4.11	98.75	-0.46
13	8/83a	66.78	1.93	0.37	0.62	15.69	4.92	4.45	4.49	99.25	-3.54

Notes: (*) valence balance; (1-4) bismuthinite-aikinite series, (5-7) emplectite, (8) junoitte, (9) hodrushite, (10-12) cupropavonite, and (13) makovickite («Cu-benjaminite»).

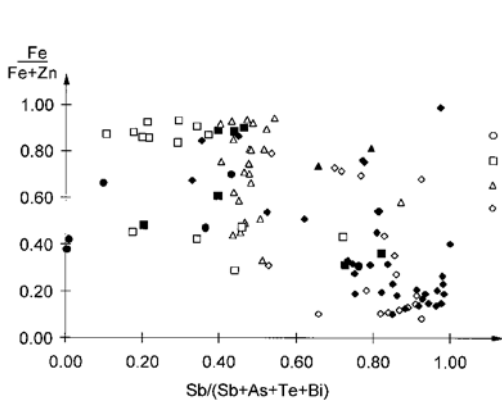


Fig. 3. Variations in the chemical composition of fahlores of different generations from the Kairagach deposit. Same symbols as in Fig. 2a

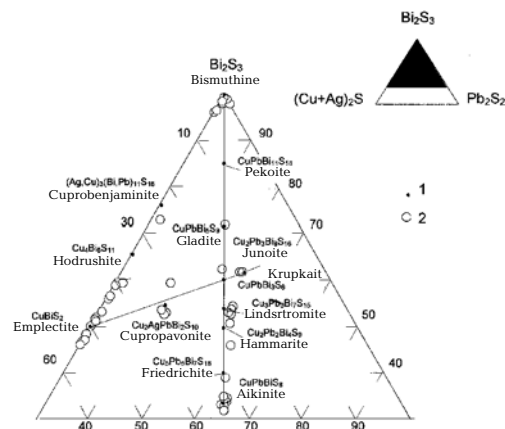


Fig. 4. Variations in the chemical composition of Bi sulfosalts (at. %): (1) theoretical compositions and (2) minerals from the Kairagach deposit

Bismuth sulfosalts belong to minerals widespread in ores of the Diabasic zone. Among different sulfobismuthites found here, we can distinguish emplectite, hodrushite, junoite, and several minerals assigned to the bismuthinite-aikinite series (Table 3, Fig. 4). Several natural phases of the Ag-Cu-Pb-Bi-S-Se system was also revealed here, whose chemical composition allows to assign them to the pavonite series. Because of the fact that minerals of the aikinite-bismuthinite and pavonite series commonly form intimate intergrowths with each other and with other ore and gangue minerals, it was impossible to extract pure material for their X-ray phase analysis. Therefore, they were mainly identified based on a closeness of the chemical composition of the phases studied to that of known minerals (Table 3, Fig. 4), because of which the identification of the sulfobismuthites considered here was substantially arbitrary. The sulfobismuthites are commonly characterized by high (up to 5 wt. %) contents of Se and are often intimately intergrown with native gold or contain its very fine (a few micrometers in size) inclusions; they are also associated with native bismuth, tetradymite, altaite, and other minerals of the productive assemblages. The bulk of the sulfobismuthites formed after the high-Te fahlores, together with the sulfostannates, but before the sulfoselenotellurides (Plotinskaya and Kovalenker, 1998).

Bismuthinite-aikinite series ($\text{Bi}_2\text{S}_3\text{-PbCuBiS}_3$). The composition of the sulfobismuthites studied is grouped near figurative points of theoretical compositions of minerals of this series, including bismuthinite, aikinite, gladite, lindströmite, krupkaite, hammarite, and friedrichite (Fig. 4). All of them are characterized by high contents of Se (up to 2 wt. %) and appreciable admixtures of As (up to 2–2.5 wt. % in bismuthinite and lindströmite; up to 1 wt. % in aikinite). Substantial admixture of Sb were only revealed in bismuthinite: up to 1.5% Sb at the upper levels and up to 2–8 wt. % Sb at the lower ones. At deep levels of the Diabasic zone, the following mineral phases have also been revealed: a sulfosalts within the chemical composition (in wt. %): Bi 66.50, 66.17; Sb 14.07, 11.55; S 19.94, 16.42; and Se 0.00, 7.40, that is intermediate between bismuthinite (Bi_2S_3) and chorobetsuite ($\sim\text{BiSbS}_3$), and a mineral ($\text{Cu}_3\text{Pb}_3\text{Bi}_7\text{S}_{15}$) compositionally close to lindströmite, that is intimately associated with native gold and tetradymite. It forms tabular segregations in barite and at the quartz-barite boundary. In peripheral zones of the ore bodies, sulfobismuthites are predominantly represented by aikinite that is intimate-

ly intergrown here with galena and contains practically no Se admixture.

Junoite series ($\text{Pb}_3\text{Cu}_2\text{Bi}_8(\text{S,Se})_{16}\text{-CuBiS}_2$). The predominant mineral of this series is Se-containing emplectite (CuBiS_2) associated with fahlores of the third generation. It forms large aggregates growing on fahlores, as well as intergrowths with Cu sulfostannates. The emplectite is characterized by admixtures of Sb and As and by high contents of Se (Table 3). At the deep levels, in common with the above-considered example with the bismuthinite-aikinite series minerals, Sb-containing (up to 8 wt. % Sb) varieties of emplectite are found, which are also characterized by high Se contents (3–4 wt. %). Microprobe analysis for one of such minerals are as follows (wt. %): Cu 22.67, Bi 26.78, Sb 25.27, S 22.36, and Se 0.79. Its idealized formula can be represented as $\text{Cu}_5\text{Sb}_3\text{Bi}(\text{S,Se})_{10}$ or as $\text{Cu}(\text{Sb}_{0.6}\text{Bi}_{0.4})(\text{S,Se})_2$, if to consider this minerals as Bi-chalcostibite. High concentrations of Se (up to 3 wt. %) (Table 3) have also been revealed in junoite, $\text{Pb}_3\text{Cu}_2\text{Bi}_8(\text{S,Se})_{16}$, that is significantly more rare mineral in the Kairagach ores than emplectite.

Pavonite group. To minerals of this group we can assign a mineral compositionally close to cupropavonite ($\text{AgPbCu}_2\text{Bi}_5\text{S}_{10}$) (Table 3, Fig. 4). This mineral is associated with hodrushite and other Bi sulfosalts. It forms very fine (50–60 μm in size) rounded and oval segregations in Bi-Te-containing fahlores. We also found here rare small (no more than 30 μm in size) grains of a mineral that, being generally close in chemical composition to benjaminite, was characterized by a predominance of Cu over Ag. Previously we arbitrarily named this mineral «Cu-benjaminite». At the same time, its chemical composition at the compositional diagram (Fig. 4) is situated in the immediate proximity to the figurative point of makovickite (Zak et al., 1994). At the present time, however, a correct identification of the sulfosalts considered without additional investigations is impossible. Minerals of this group, in common with other sulfobismuthites developed in Kairagach ores, are characterized by high (4–5 wt. %) concentrations of Se.

Hodrushite ($\text{Cu}_4\text{Bi}_6\text{S}_{11}$) is closely similar in its chemical composition and crystal-chemical properties to the above-considered minerals of the pavonite series. It forms aggregates of acicular and tabular grains in quartz and barite or among fahlores of the late generation; it is

Table 4. Chemical composition of Au and Ag tellurides (wt. %)

No os.	Sample no	Te	Ag	Au	Cu	Se	Sb	S	Hg	Pb	Bi	Total
1	42/85	58.68	0.34	39.75	0.09	0.06	0.44	0.00	0.00	0.41	0.00	99.72
2	232-9	55.86	0.09	42.96	0.00	0.05	0.40	0.00	0.00	0.00	0.32	99.68
3	232-9	56.38	0.02	42.83	0.01	0.16	0.37	0.00	0.00	0.00	0.00	99.77
4	Kai-32	55.95	0.13	42.31	0.02	0.14	0.07	0.00	0.00	0.04	0.00	98.66
5	Kai-38	55.72	0.43	42.24	0.54	0.10	0.00	0.00	0.00	0.51	0.00	99.54
6	Kai-32	56.11	0.00	42.22	0.09	0.13	0.00	0.00	0.00	0.00	0.19	98.74
7	Kai-32	56.21	0.62	41.65	0.42	0.00	0.00	0.00	0.00	0.00	0.00	98.90
8	Kai-32	54.80	0.24	41.60	0.02	0.34	0.37	0.00	0.00	0.00	1.27	98.64
9	Kai-32	54.63	0.67	41.60	0.89	0.19	3.00	0.20	0.00	0.00	0.00	101.18
10	Kai-32	55.14	0.15	41.26	0.06	0.32	1.64	0.13	0.00	0.03	1.15	99.88
11	232-9	57.08	0.00	39.94	0.00	0.09	0.51	0.00	0.00	0.10	1.58	99.30
12	147/81	56.28	0.95	41.62	0.20	0.10	—	0.01	0.39	—	—	99.55
13	147/81	56.62	0.39	42.14	0.07	0.87	—	0.04	0.49	—	—	100.62
14	Kai-32	63.25	7.31	24.27	3.15	0.00	0.00	0.00	0.38	0.21	0.12	98.69
15	147/81	62.46	12.39	23.89	0.51	0.64	—	0.03	0.24	—	—	100.16
16	147/81	62.03	11.76	23.62	0.86	0.57	—	0.02	0.33	—	—	99.19
17	147/81	62.03	11.79	23.62	0.86	0.57	0.01	0.02	0.33	—	0.17	99.40
18	64/84	36.87	61.86	1.42	0.02	0.07	0.05	0.23	—	0.32	0.12	100.96
19	66/84	36.32	60.88	1.16	0.27	0.07	—	0.18	—	—	—	98.88
20	1050/82B	36.08	64.42	—	—	—	0.25	0.24	—	—	—	100.99
21	59/86	37.75	61.83	—	—	—	—	—	—	—	—	99.58
22	59/86	38.81	62.82	—	—	—	—	—	—	—	—	101.63
23	64/84	36.87	61.86	1.42	0.02	0.07	0.05	0.23	—	0.32	0.12	100.96
24	66/84	36.32	60.88	1.16	0.27	0.07	—	0.18	—	—	—	98.88
25	48/85	39.20	60.26	—	—	—	—	—	—	—	—	99.46
26	64a/84	39.06	60.63	0.17	0.58	0.20	0.38	0.22	—	—	—	101.24
27	27/85	36.82	61.55	0.24	0.08	0.04	0.24	0.10	0.00	0.26	0.14	99.47
28	147/81	41.01	57.39	—	—	0.06	—	0.03	0.71	—	—	99.20
29	64a/84	46.69	17.46	—	—	—	2.21	—	—	—	33.52	100.14

Notes: Analyzes: (1–13) calaverite, (14–17) sylvanite, (18–27) hessite, (28) stutzite, and (29) volynskite; (—) not analyzed.

often present in intergrowths with aikinite. Hodrushite from the Kairagach deposit is characterized by high concentrations of Se (up to 3.47 wt. %) and Ag (0.51–2.18 wt. %), as well as of Pb and As (up to 1.44 and 1.31 wt. %, respectively) (Table 3).

Sulfoantimonites are mainly represented in ores of Kairagach by bournonite and chalcostibite and occur here significantly more rarely than sulfobismuthites, predominantly in peripheral areas of the ore shoots. They are intimately associated with fahlores of the late generation, galena, and chalcopyrite. The chemical composition of the samples of chalcostibite and bournonite studied is close to stoichiometry of these minerals.

Tellurides and Selenides

Selenides and tellurides are widespread in ores of the Diabasic zone, although they do not form large accumulations here. They incorporate a large group of binary, ternary, and more complex compounds, including rare and, probably, new ones (Table 4), that can be described within the limits of the systems

Au-Ag-Te, Ag-Pb-Bi-Sb-Te, and Bi-Te-S-Se. The tellurides mainly occur as small (30–300 μm in size) separate inclusions or aggregates in barite; at barite-quartz boundary; and, more rarely, among fahlore segregations. At deep levels of the deposit, they are commonly found in quartz.

Among *minerals of the Au-Ag-Te system*, revealed here, are calaverite, sylvanite, petzite, hessite, stutzite, native tellurium, and native gold. As a rule, these minerals form intimate intergrowths with each other among gangue and ore minerals; more rarely, they occur as separate segregations in barite, quartz, and sulfides. Peculiarities of their real chemical composition are presented in Table 4 and are demonstrated on a ternary compositional diagram (Fig. 5).

Calaverite. At upper levels of the deposit, calaverite is predominantly associated with native gold of high fineness and with petzite; at the lower levels, it is mainly associated with tellurantimony and frobergite and, occasionally, with native tellurium and sylvanite. The mineral is characterized by stoichiometric ratios between the principal components (Table 4, Fig. 5). At the same time, it incorporates appre-

ciable quantities of Ag whose concentrations increase with depth and commonly reach up to 1.7–1.8 wt. % at lower levels of the ore bodies. Small admixtures of Se (up to 0.34 wt. %) are practically permanently detected in the mineral composition; at the lower levels, admixtures of Cu (up to 0.5–0.9 wt. %) and Sb (up to 1.6–3.0 wt. %) are also noted. It is particularly remarkable that it is at the lower levels that several previously unknown natural *mineral phases of the Au-Sb-Te composition* with variable relationships between the components were found along with calaverite among minerals of the gold-productive assemblages. According to electron-microprobe data, the chemical composition of one of these phases is as follows (wt. %): Au – 79.47, Ag – 0.17, Te – 10.61, and Sb – 9.05, which corresponds to the ideal formula Au_5SbTe . Another Au-Sb-Te phase found here is composed of the same set of elements, but in the different ratios (wt. %): Au – 44.37, Te – 26.38, Sb – 28.04, and Se – 0.41. This analysis is well recalculated to the ideal formula AuSbTe . One more mineral phase found and studied at the deposit contains Bi in addition to Au, Sb, and Te and has the following chemical composition (wt. %): Au 31.58, Sb 8.87, Bi 5.81, and Te 54.23. The empirical formula of this compositionally complex mineral phase is close to the stoichiometry $\text{Au}_5\text{Sb}_2\text{Bi}_2\text{Te}_{13}$. It is possible that this mineral belongs to the nagyagite-buckhornite group; however, this question remains open now, since further investigations are impossible because of the very small (<20 μm) size of its particles. Sylvanite predominantly occurs in ores of the deep levels and is substantially exceeded in abundance by calaverite. A small (no more than 0.4 wt. %) Cu admixture is constantly detected in its chemical composition. One of sylvanite segregations within barite has the chemical composition (in wt. %): Au 24.27, Ag 7.31, Cu 3.15, and Te 63.26, that corresponds to the ideal formula $\text{Au}(\text{Ag}_{0.6}\text{Cu}_{0.4})\text{Te}_4$; that is, this mineral occupies an intermediate position in the isomorphous series sylvanite (AuAgTe) – kostovite (AuCuTe_4).

Minerals of the *Pb-Te-Se-S system* are represented in ores of the Diabasic zone by *altaite*, *clausthalite*, and *intermediate members of the galena-clausthalite series*. The most widespread of these minerals is altaite that belongs to early assemblages of the Main Productive Stage. Clausthalite and minerals of the galena-clausthalite series are associated with famatinite-luzonite, goldfieldite, chalcopyrite, and sulfostannates. The chemical composition of

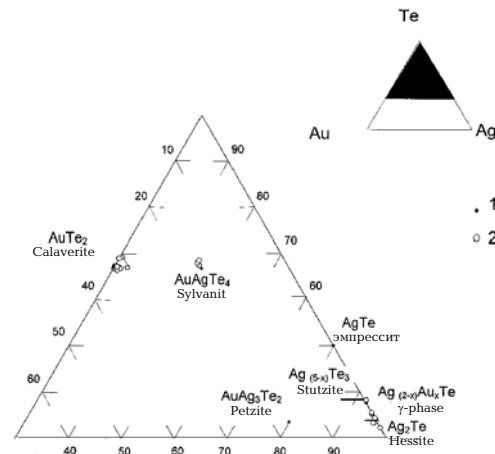


Fig. 5. Variations in the chemical composition of Au and Ag tellurides (at. %): (1) theoretical compositions and (2) minerals from the Kairagach deposit

the studied minerals of this system is presented in Table 5. Remarkable peculiarities of these minerals are as follows: the altaite contains appreciable admixtures of Ag, Cu, Fe, Sb, and, occasionally, Au; the galena-clausthalite series minerals are characterized by variable concentrations of Se and S and by the presence of small amounts of Bi (Table 5). In addition, *Bi-tellurantimony* was assigned to minerals of the early assemblages. Its chemical composition, according to electron-microprobe analysis, is as follows (wt. %): Bi 22.04, Sb 21.38, Te 55.82, and S 0.62.

Relatively later tellurides of the Kairagach deposit are represented by hessite, tetradyomite, volynskite, and rucklidgeite, which are associated with gold of low fineness, sulfoselenotellurides, and selenides of Bi. It is worth to note that among the latter such rare minerals as kawazulite $\text{Bi}_2\text{Te}_2\text{Se}$; laitarite $\text{Bi}_4(\text{Se},\text{S})_3$; nevskite $\text{Bi}(\text{Se},\text{S})$, Se-sulphotsumoite $\text{Bi}_3\text{Te}_2(\text{S},\text{Se})$, and the phases $\text{Bi}_2(\text{Te},\text{Se},\text{S})_3$ and $\text{Bi}(\text{Se},\text{S})_2$. All these minerals, whose chemical composition is presented in Table 6, occur as constituents of the gold-productive assemblages exclusively within ore shoots, mainly at the upper levels of the deposit. Although selenides proper are not widespread at deep levels of the deposit (a Bi selenotelluride, kawazulite, was only revealed there), some Bi sulfosalts, such as chorobetsuite-like minerals and Sb-emplectite, contain (along with appreciable amounts of Sb) significant (from 2.89 to 10.14 wt. %) concentrations of Se. Increased concentrations of Se are also characteristic for sulphotsumoite (chemical composition, wt. %: Bi 68.89, Sb 0.69, Te 24.06,

Table 5. Chemical composition of minerals of the system Pb-Te-Se-S (wt. %)

№ os.	Sample no	Pb	S	Se	Te	Sb	Fe	Cu	Ag	Au	Hg	Bi	Total
1	1020/86	59.41	0.00	0.03	38.25	0.24	0.36	0.66	2.40	0.00	0.00	0.00	101.35
2	130/87	61.67	0.00	0.22	36.34	0.29	0.58	0.78	0.17	0.18	0.00	0.00	100.23
3	130/87	60.79	0.03	0.30	36.86	0.30	0.70	0.66	0.15	0.60	0.00	0.00	100.39
4	1020/86	59.86	0.05	0.11	38.10	0.35	0.07	0.02	0.12	0.53	0.26	0.00	99.47
5	435/82	58.86	1.01	0.16	35.98	0.83	0.03	1.94	0.07	0.48	0.00	0.00	99.36
6	Kai-38	60.82	0.00	0.12	37.85	0.00	0.02	0.40	0.12	0.10	0.07	0.00	99.50
7	Kai-38	60.47	0.00	0.25	38.06	0.04	0.07	0.19	0.01	0.60	0.29	0.00	99.98
8	558/87	76.7	10.29	8.17	—	0.41	0.43	3.92	0.08	—	—	—	100.00
9	558/87	77.94	11.55	4.47	—	0.32	0.47	3.33	—	—	—	0.23	98.31
10	558/87	74.54	9.34	9.69	—	0.51	0.55	3.28	—	—	—	—	97.91
11	121/87	69.63	3.63	23.39	—	—	1.45	2.31	—	—	—	0.26	100.67
12	121/87	70.01	2.42	24.85	—	—	1.59	3.3	0.07	—	—	—	102.24
13	121/87	72.32	4.06	20.21	—	—	0.53	—	0.02	—	—	0.26	97.40

Notes: Analyzes: (1–7) altaite, (8–10) galenoclausthalite; (11–13) — clausthalite, (–) not analyzed

S 3.27, and Se 3.09), that was first revealed for the Kairagach deposit.

Sulfostannates represent one of mineral groups typomorphic for rich and bonanza ores. They include mawsonite, stannoidite, stannite, kesterite, nekrasovite, volfsonite, and hemusite, as well as several yet unnamed sulfosalts of Sn, Cu, and Fe, characterized by variable relationships between these elements (Kovalenker and Geinke, 1984; Kovalenker *et al.*, 1986). We included Sn-containing colusite and stibicolusite, interrelated with the isostructural nekrasovite through uninterrupted transitions, into this group as well (Kovalenker *et al.*, 1984). Sulfostannates do not make up large accumulations in Kairagach ores and are commonly represented by small (up to 50–100 μm in size) but numerous, rounded or xenomorphic segregations most often confined to fahlore, chalcopyrite, barite, or quartz. These minerals commonly occur in intimate intergrowths with each other, as well as with chalcopyrite, native gold, Se-emplectite, and other sulfobismuthites. Accumulations and separate grains of V-containing (up to 1 wt. % V) cassiterite, as well as of native tin, are often confined to the aggregates of sulfostannates (Badalov *et al.*, 1984). Chemism peculiarities and parageneses of sulfostannates in ores of the Kairagach deposit were comprehensively considered in special publications (Kovalenker and Geinke, 1984; Kovalenker *et al.*, 1984 and 1986; Spiridonov *et al.*, 1983); therefore, it would be sufficient to note here that the chemical composition of minerals of this group is characterized by permanent admixtures of Sb, As, and, to a lesser degree, Se, the typomorphic elements of the Kairagach ores.

Conclusions

1. In contrast to typical high-sulfidation epithermal ore deposits characterized by the

Au-Cu specialization of the ore mineralization, ores of the Kairagach deposit are complex, multicomponental, and exhibit a clearly pronounced Au-Bi-Sn-Se-Te geochemical profile.

2. The mineralogical complexity and originality of the Kairagach ores are caused by the variety of state and occurrence forms (native, isomorphous, sulfide, selenide, and telluride) of their contained chemical elements.

3. The typochemism of the Kairagach ores is determined by the presence of numerous and diverse minerals of Au, Ag, Bi, Sn, Sb, Se, and Te, that often possess a complex variable chemical composition and not infrequently make up series of solid solutions, or belong to homologue series.

4. Formation of the diverse, compositionally complex ore minerals of the Kairagach deposit was related to a high variability of the physicochemical parameters (T, P, pH, Eh, and component activities) under conditions of mineral-forming processes that dynamically developed near the Earth's surface.

Acknowledgements

This work was supported by the Russian Foundation for Basic Research, projects nos. 01-05-64081 and 02-05-06196 MAS.

References

- Badalov A.S. and Spiridonov E.M. *Bleklye rudy i samorodnoe zolotorudoproyavleniya Kairagach (vostochnyi Uzbekistan)* (Fahlores and native gold of the Kairagach ore occurrence, eastern Uzbekistan) // *Uzb. Geol. J.*, 1983, no. 2, p. 74–78. (Rus.)
- Badalov A.S., Spiridonov E.M., Geinke V.R., Pavshukov V.V. *Mineraly — samorodnye elementy i telluridy vulkanogennogo rudoproyavleniya Kairagach (Uz. SSR)* (Minerals of the volcanogenic Kairagach ore occurrence, Uzbekistan) // *Uzb. Geol. J.*, 1983, no. 2, p. 74–78. (Rus.)

Table 6. Chemical composition of minerals of the system Bi-Pb-Te-Se-S (wt. %)

№ os.	Sample no.	Bi	Pb	Sb	As	Cu	Ag	S	Se	Te	Au	Hg	Fe	Total
1	147/81	80.19	0.26	0.10	1.17	0.34	0.15	2.44	17.00	—	—	—	0.10	101.75
2	147/81	82.88	0.25	0.18	1.55	0.58	—	3.90	13.10	—	—	—	—	102.44
3	147/81	77.50	0.60	0.03	0.66	0.71	0.04	1.33	18.10	0.07	—	0.11	—	99.15
4	147/81	78.75	—	—	0.28	0.44	0.09	1.86	16.01	0.39	0.18	0.38	0.12	98.50
5	231/81	78.00	0.07	0.11	1.15	0.75	0.04	3.49	15.80	—	—	—	0.06	99.47
6	·	76.61	0.69	0.39	—	0.50	—	5.36	15.98	0.00	—	—	—	99.53
7	·	78.67	0.00	0.00	—	0.84	—	5.89	15.33	0.00	—	—	—	100.73
8	1031/86	66.15	6.48	—	—	3.80	3.80	13.90	6.24	0.61	—	—	—	100.98
9	1031/86	64.96	6.46	—	—	3.85	3.72	14.37	5.82	0.37	—	—	—	99.55
10	8/83	66.78	1.93	0.37	0.62	4.92	4.45	15.69	4.49	0.22	—	0.06	—	99.53
11	147/81	75.49	1.67	0.21	0.14	3.20	0.02	1.31	17.72	0.36	—	0.06	—	100.18
12	1020/86	56.28	0.12	0.25	0.00	0.00	0.45	4.36	0.13	37.04	0.19	0.00	0.01	98.83
13	1020/86	56.47	0.02	0.25	0.00	0.04	0.24	4.37	0.74	36.31	0.57	0.00	0.08	99.09
14	1020/86	55.74	0.00	0.26	0.00	0.00	0.07	4.46	1.03	36.44	0.25	0.00	0.48	98.73
15	42/85	54.59	0.07	0.56	0.32	0.03	—	3.69	0.99	34.44	—	—	—	94.69
16	232-9	56.02	0.00	0.73	0.00	0.00	0.00	4.11	1.15	36.91	0.37	0.00	0.04	99.33
17	232-9	56.78	0.00	1.05	0.00	0.00	0.00	3.96	1.24	36.94	0.00	0.00	0.00	99.97
18	Kai-38	56.27	0.00	0.00	0.00	0.07	0.00	4.30	1.84	35.38	0.81	0.23	0.02	98.92
19	27/85	50.74	3.50	0.26	0.00	1.01	0.63	4.31	2.69	34.55	0.00	0.00	0.76	98.45
20	·	73.64	2.04	0.61	—	—	—	0.91	5.79	18.16	—	—	—	101.15
21	147/81	55.92	—	0.44	—	1.39	0.29	1.75	9.12	30.58	0.37	0.71	—	100.57
22	Kai-38	57.07	0.00	0.03	0.00	1.10	0.00	2.52	9.51	29.69	0.00	0.33	0.00	100.25
23	8/83	52.88	—	0.86	0.02	3.22	0.57	2.91	7.32	29.73	0.60	—	0.63	98.74
24	K-12/1	56.42	—	0.81	—	1.06	—	3.25	6.11	33.01	—	—	—	100.66
25	K-12/2	68.89	—	0.69	—	—	—	3.27	3.09	24.06	—	—	—	100.00
26	232-9	53.86	0.03	1.37	0.00	0.04	0.00	2.64	7.04	32.42	0.72	0.11	0.00	98.23
27	Kai-38	53.39	0.00	0.00	0.00	0.78	0.14	3.71	3.75	32.62	4.72	0.28	0.07	99.46
28	Kai-38	55.74	0.00	0.00	0.00	0.90	0.06	2.96	6.40	32.19	0.19	0.00	0.36	98.80
29	·	62.58	1.48	0.50	—	—	—	2.94	6.23	28.08	—	—	—	101.81
30	64a/84	36.10	14.20	1.04	0.55	0.89	0.73	0.24	0.35	45.46	—	—	0.08	99.64

Notes: (·) after Spiridonov and Badalov, 1983; Analyzes: (1–5) laitakarite, (6–7) phase Bi_2SeS , (8–10) phase $\text{CuBi}_3(\text{S,Se})_5$, (11) phase $\text{Cu}_2\text{Bi}_{15}(\text{S,Se})_{11}$, (12–19) tetradyomite, (20) phase Bi_3TeSe , (21–24) kawazulite, (25) tsumoite, (26–29) phase $\text{Bi}_3\text{Te}_2\text{SeS}$, and (30) rucklidgeite; (–) not analyzed

kistan: native elements and tellurides) // Zap. Uzb. Otd. VMO, 1984. No. 37. P. 64 – 67 (Rus.).
Heald P., Foley N.K., Hayba D.O. Comparative anatomy of volcanic-hosted epithermal deposits: Acid – sulfate and adularia-sericite types // *Economic Geology*, 1987, v 82, No 1, .P. 1–26.
Islamov F., Kremenetsky A., Minzer E., Koneev R. The Kochbulak-Kairagach ore field // Au, Ag, and Cu deposits of Uzbekistan. Excursion Guidebook. GFZ. Potsdam, 1999. P. 91 – 106.
Kovalenker V.A. and Geinke V.R. Novyi Cu-Sn-Bi-Se tip mineralizatsii v Kuraminskoi podzone Sredinnogo Tyan'-Shanya (A new Cu-Sn-Bi-Se type of mineralization in the Kurama subzone of the Median Tien Shan area) // *Izv. Akad. Nauk SSSR, Ser. Geol.*, 1984, no. 5, p. 91 – 104. (Rus.)
Kovalenker V.A. Nipomorfnye mineraly rud maloglubinnykh zoloto – serebryannykh mestorozhdeniy verkhnepaleozoiskoi vulkanicheskoi oblasti Srednei Asii // *Metosomatizm, mineralogiya i voprosy genesis a zolotykh i serebryannykh mestorozhdeniy v vulkanicheskikh tolshchakh* (Typomorphic ore minerals of near-surface gold-silver ore de-

posits in the Upper Paleozoic volcanic area of Central Asia // *Gold and silver ore deposits in volcanic rock sequences: Metasomatism, mineralogy, and genesis problems*). Moscow: Nauka, 1986. P. 111 – 145. (Rus.)
Kovalenker V.A., Evstigneeva T.L., Malov V.S., Trubkin N.V., Gorshkov A.I., Geinke V.R. Nekrasovit $\text{Cu}_{26}\text{V}_2\text{Sn}_6\text{S}_{32}$ – novyi mineral gruppy colusita (Nekrasovite, $\text{Cu}_{26}\text{V}_2\text{Sn}_6\text{S}_{32}$, a new mineral of the colusite group) // *Mineralog. J.*, 1984, no. 2, p. 88 – 97. (Rus.)
Kovalenker V.A., Nekrasov I.Ya., Malov V.S. Mineralogiya i paragenезisы sulfostannatov medi i zheleza v zoloto – serebryannykh mestorozhdeniyakh (Mineralogy and parageneses of copper and iron sulfostannates in gold-silver deposits) // *Geol. Rudn. Mestorozhd.*, 1986, no. 2, p. 67 – 84. (Rus.)
Kovalenker V.A., Safonov Yu.G., Naumov V.B., Rusinov V.L. Epitermalnoe zoloto – telluridnoe mestorozhdenie Kochbulak (Uzbekistan) (Epithermal Kochbulak gold-telluride deposit, Uzbekistan) // *Geol. Rudn. Mestorozhd.*, 1997, v. 39, no. 2, p. 127 – 152. (Rus.)
Kovalenker V.A., Trubkin I.V., Malov V.S. Khodrushit $\text{Cu}_8\text{Bi}_2\text{S}_{22}$ – pervaya nakhodka v

- SSSR (Hodrushite, $\text{Cu}_8\text{Bi}_2\text{S}_{22}$: The first find in the Soviet Union) // New data on minerals. No. 34. Moscow: Nauka, 1987. P. 76–81. (Rus.)
- Plotinskaya O.Yu. and Kovalenker V.A.* Epitermalnoe zoloto – teluridnoe mestorozhdenie Kairagach: mineralogo – geokhemicheskaya zonalnost' // Zolotorudnye mestorozhdeniya Uzbekistana: geologiya i promyshlennyye tipy (Epithermal Kairagach gold-telluride deposit: the mineralogical-geochemical zonality // Gold ore deposits of Uzbekistan: The geology and economic-geological types). Tashkent: IMR, 1998. P. 57–60. (Rus.)
- Spiridonov E.M. and Badalov A.S.* Novye sulfoselenotelluridy i sulfoselenidy vismuta iz vulcanichescogo mestorozhdeniya Kairagach (Vostochnyi Uzbekistan) (New bismuth sulfoselenotellurides and sulfoselenides from the volcanogenic Kairagach ore deposit, eastern Uzbekistan) // Uzb. Geol. J., 1983, no. 6, p. 82–84. (Rus.)
- Spiridonov E.M., Chvileva T.N., and Badalov A.S.* Sur'myanistyi kolusit $\text{Cu}_6\text{V}_2\text{As}_2\text{Sb}_2\text{S}_{32}$ mestorozhdeniya Kairagach I o ego raznovidnostyakh (Sb-Colusite, $\text{Cu}_6\text{V}_2\text{As}_2\text{Sb}_2\text{S}_{32}$, from the Kairagach ore deposit and on colusite varieties) // DAN SSSR, 1983, v. 269, no. 3, p. 706–712. (Rus.)
- White N.C., Hedenquist J.W.* Epithermal environments and styles of mineralization: variations and their causes, and guidelines for exploration // Journ. Geochem. Explor., 1990, V.36, P. 445–474.
- Zak L., Fryda J., Mumme W.G., Paar W.H.* Makovickite, $\text{Ag}_{1,5}\text{Bi}_{5,5}\text{S}_9$, from Baita Bihorului, Romania: The ^4P natural mineral member of the pavonite series // Neues. Jahrb. Mineral. Abh., 1994, V. 168, P. 147–169.