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**GOLD FINENESS AS INDICATOR  
OF PHYSICAL-CHEMICAL CONDITIONS OF MINERALIZATION  
AT THE KOKKIYA GOLD DEPOSIT (KYRGYZ RIDGE)**

**Abstract.** The article describes the results of microscopic studies of ores at the Kokkiya deposit. The mineral composition of deposit's ore is determined with the identification of main, secondary and rare minerals. Fineness of gold is determined, the variability of which is determined by depth, as well as the processes of mineral formation from early associations to late ones. The fineness of native gold is accepted as a typomorphic sign by many scientists of the world and indicating the physical-chemical conditions for the formation of gold deposits. Founding rare microminerals also carry basic information about the physical-chemical conditions of ore deposition. Causal relationships between the composition of minerals and the characteristics of mineral-forming processes are revealed, which is the most important task of genetic mineralogy. It is equally important in practical terms for the development of mineralogical forecasting and evaluation criteria.

**Key words:** gold probability, pyrite, tellurides, gold-concentrating minerals.

**Introduction.** The Kokkiya deposit is located on the northern slopes of the Kyrgyz Ridge, within the Kyrgyz-Terskei Mineragenetic Zone. This zone includes six gold-ore formations in the territory of Kazakhstan: gold-quartz-vein; gold-sulphide-quartz; gold-sulphide-skarn; gold-sulphide-quartz-berezitic; gold-quartz-propylitic and gold-bearing placers.

The Kokkiya deposit is associated with the gold-quartz-propylitic formation and is confined to the rocks of the Devonian volcanic-plutonic association (andesites, rhyolites, and their lava-breccias). Their spatial distribution is controlled by tectonic dislocation and small intrusions of syenites, syenite-diorites, monzogranodiorites of the Middle Devonian intrusive complex. As a whole, it has a linear-nodal pattern. Mineralization is confined to lavas and lava-breccias of the Taldysusubvolcanic complex of rhyolite composition. These zones are overlaid with zones of hydrothermal-metasomatic alterations and veined silicification.

The Kokkiya field is divided into two sections: Kokkiya block and Yuzhnyi block, they located in one metasomatic zone. Genetically, these are the same types of ores, but are spatially separated by 2 km.

The northern part of the Kokkiya deposit is located in the zone of intensive hydrothermal alteration. Area of deposit is broken into numerous blocks by faults. Faults strike is very diverse. The distribution of gold mineralization in the deposit is immense complexity. Isolation of ore bodies within the outer homogeneous zone of quartz-sericite metasomatites is possible only by analysis of samples. Ore bodies are separate out by the cut-off grade 0.3 g/t. The shape of the bodies is linearly extended in the north-east direction. The dip of main ore zones is south-west at angles of 65-75°. The thickness of ore bodies varies from 0.5 to 60 m in the wells, in ditches from 1 to 22 m, with an average thickness of 5-6 m.

The following vertical metasomatic zoning is planned on the ore field of the Kokkiya deposit: the elevated parts of relief form secondary quartzites, and propylitized rocks bed beneath them. Sericite facies

are most fully and widely manifested here. The amount of quartz and sericite is variable in the rock. Transition to monomineralic quartz rocks (monoquartzite) is observed with a decrease in the amount of sericite. As amount of sericite increases, which is typical for ore bodies, secondary quartzites transform into sericite-pyrite rocks (sericitolites). Sericite which is an essential constituent of quartzites, often partially transforms into hydromica and is associated with montmorillonite. Metasomatic and vein silicification, chloritization and carbonatization are superposed on the sericite facies. Quartz veins contain chlorite, ferrous carbonate, dolomite, carbonate and carry polymetallic mineralization in association with gold.

Microscopic studies have allowed to separate out the following zonal facies from the periphery to the center: 1) propylitic, combining strongly chloritized, sericitized, albitized, kalishipatized, carbonatized and pyritized rocks; 2) kaolinite; 3) sericite; 4) diaspor; 5) monoquartz [1, 2].

Gold-pyrite mineralization tends to the sericite facies. The wide development of the sericite facies in the section created favorable prerequisites for manifestation of gold-silver mineralization. The monoquartz facies develops within the sericite facies, where it forms short lenses or nodular concretions. The thickness of lenses does not exceed the first meters, and the extension is not more than first tens of meters. Strong monoquartzite rocks carry an equal impregnation of pyrite and are released in the relief by positive forms.

**The main gold-concentrating minerals** are pyrite, quartz, sericite. Native gold is a valuable component. A number of ore minerals that determine the geochemical specificity of ore formation at the deposit are referred to minor and minor rare occurrences (table 1). Among the rare, special should be mentioned tellurides: gold (calaverite), bismuth (tsumoite), gold and silver (petzite).

Table 1 – Mineral composition of ores of the Kokkiya deposit

Main minerals	Secondary and seldom met minerals	Valuable and rare micro minerals
Ore minerals		
Pyrite (some generation)	Chalcopyrite, Galenite, Sphalerite, Pyrrhotite, Tetrahedrite, Tennantite, Goldfieldite*, Rutil, Ilmenite, Cassiterite, Magnetite, Hematite, Molybdenite, Scheelite, Arsenopyrite, Jarosite*, Covellite, Goethite, Hydrohematite, Leucocene	Gold, Calaverite, Tsumoite*, Petzite*, Altaite Bismuthite*, Tellurobismuthite, Native Tellurium, Mawsonite?*
Non-metallic minerals:		
Quartz Sericite	Pyrophyllite, Calcite, Chlorite, Muscovite, Barite, Kaolinite, Montmorillonite	Zircon, Monacite, Crandallite *, Hornblende, Sphene, Zunyite, Albite, K-feldspar
*Minerals established to study the technological sample of primary ore of the Kokkiya deposit.		

According to the results of microscopic studies, the most common quartz-sericite metasomatites are pyritized to a varying degree, down to sericitolites. Chlorite-quartz-sericite metasomatites are very rare. Sericitolites are most enriched with native gold among them. Visually, they are differed by the presence of spots or pyrite veinlets of light yellowish color in the mass of sericitolite, which can transform into densely impregnated pyritic ore. Spots or pyrite veinlet are thickness up to 2.5 cm. Metasomatites are silicified in various degrees and partly carbonatized.

**Pyrite** - is the main ore mineral. It forms scattered impregnation in metasomatites, from rare to dense. It occurs in the form of nests and lenticular secretions up to 1-2 cm in size. Pyrite is represented by several generations.

**Pyrite I** - cubic form in the form of fine scattered impregnation (from 0.01 to 0.05 mm and sometimes up to 0.1 mm) in a mass of chlorite-quartz-sericite metasomatite of dark green color, confined to chlorite and sericite (figure 1/1).

**Pyrite II** is sharply subordinate in quantity fine-grained, in the form of vein-like-chain formations. It is developed, apparently, along unstable marcasite and as a result of recrystallization, transforming into pentagonal dodecahedral, octahedral, and less often cubic **pyrite III** (figure 1/2).

**Pyrite III** is a pentagon dodecahedral, octahedral, cubic forms in the form of impregnation and intergrowths. It confines mainly to sericite, larger grains contain inclusions of rutile (figure 1/3). In pyrite III, later chalcopyrite, galena, with a size from 0.01-0.015 to 0.03 mm, develop along the cavity. Single inclusions of arsenopyrite in pyrite III and intergrowth of molybdenite with pyrite in quartz are noted. Densely impregnated pyrite III in sericitolite, intensely corroded, porous, littered with inclusions of nonmetallic, preserved pentagonal dodecahedron and cubic faces is noted. The grain size is up to 0.4 mm. In such a corroded pyrite, gold is found in close intergrowths with tellurides of gold, silver and lead.

**Pyrite IV** is larger (from 0.1 to 0.3 mm) in the form of intergrowths and aggregative release in the metasomatic mass. Aggregative pyrite is broken by cavities along which later sphalerite, galena and chalcopyrite develop (figure 1/3). Intergrowths and aggregate release of pyrite are up to 0.5x1.5 and 0.5x2.0 mm.

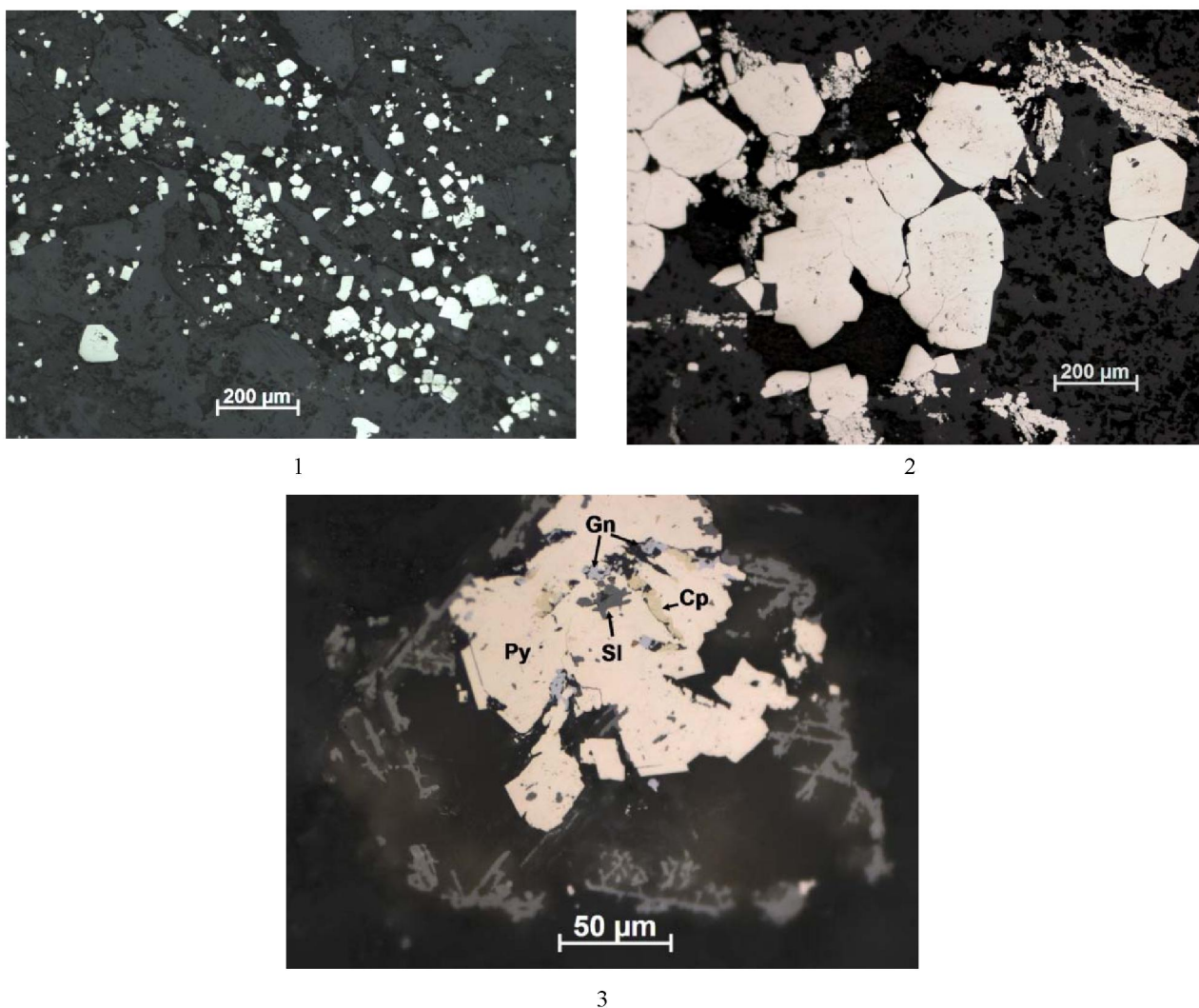


Figure 1 – Pyrite in several generations:

1 – Pyrite I fine-grained cubic form in chlorite and sericite. Polished section 84; 2 – Pyrite II streak-like and pyrite III pentagonal dodecahedral. Polished section 86; 3 – Pyrites IV aggregative (Py). Its grains are replaced by titanium minerals. Between the grains, it is galena (Gn), chalcopyrite (Cp) and sphalerite (Sl). Polished section 84

**Fineness of native gold** attracted the attention of scientists of the world since ancient times. They have considered it as a typomorphic feature due to the physical-chemical conditions of gold deposits formation. In particular, Shcherbina V.V. [3] half a century ago gave the Au/Ag relation the value of the geochemical indicator of gold and silver migratory ability and reasons for their geochemical differentiation in various geological processes. The importance of this parameter is noted in numerous works of many researchers [4, 5], as a criterium for certain conditions for the formation of specific gold ore and gold-silver deposits during their classification and formational identification. Classification of gold deposits has been proposed for six main types for the fineness of native gold. According to their estimates, for plutogenic type, the variation range of Au fineness is 650-970‰, for porphyry - 650-1000‰, for volcanogenic - 520-870‰, for epithermal - up to 1000‰. Selected scholars consider that fineness of gold increases with increasing temperature and depth of ore formation. In particular, Petrovskaya I.V. and her co-authors state that gold in high-temperature deep deposits is high-carat, medium-deep - medium-carat, and shallow - varies in a wide range and is determined by the temperature regime, although it does not negatively affect the composition of Au pH and Eh medium. On the basis of detailed studies on the solubility of Au-Ag alloys, the other consider that fineness of gold is mainly influenced by the acidity-alkalinity of hydrothermal solutions and sulfur content in them. Only to a lesser extent depends on temperature, as well as the oxidation-reduction potential, the composition of fluids, pressure, without providing a sufficient thermodynamic justification [5, 6]. The understanding fineness of gold dependence on the physical-chemical conditions of ore formation, a significant contribution was made by experimental studies on the solubility of gold-silver alloys carried out in the last decade and the thermodynamic modeling of joint transport and deposition of Au and Ag compound in chloride, chloride-sulfide and sulfide hydrothermal solutions [7, 8]. However, basically, they concerned only systems which are in equilibrium with pyrite-pyrrhotine buffer.

Another approach based on the application of physical chemistry methods is substantiated by fundamental studies thermodynamics of mineral formation processes by geological scientists [9-11]. They are based on the results of an experimental study obtained with these thermodynamic constants and mainly on the electrochemical analysis of oxidation-reduction processes of formation, migration, and destruction of gold and silver complexes in hydrothermal solutions with different acidity-alkalinity and redox potential. Calculation of free energy and oxidative potential of noble metals various complexes allow to contour the fields of their stability in Eh-pH diagrams and to determine the evolution of hydrothermal system during the formation of gold deposits. Such studies allow considering the direction of various compounds oxidation-reduction reactions, the stability and reactivity of which is predetermined by Eh- pH of the hydrothermal system [12, 13].

The composition of minerals serves as one of the main information sources on the physical-chemical conditions of ore deposition. For that reason, the identification of cause-effect relationships between the composition of minerals and characteristics of mineral-forming processes is the most important task of genetic mineralogy. It is equally important in practical terms for the development of mineralogical forecasting-estimated criteria.

From Petrovskaya N.V. [3], temperature effect on the occurrence of Ag in the structure of crystallized gold is not decisive. There are also no reliable grounds for inferring the significance total Ag concentration in the upper parts of hydrothermal activity zone, that is, there is no direct dependence of gold alloy on the wealth of deposits with silver. In addition, a large amount of factual material is accumulated, which contradicts the well-known conclusion of Fersman A.E. on the regular purification of minerals in the late stages of ore deposition (autolysis principle). Another factor in the literature is the degree of solutions supersaturation, at which the crystallization of this mineral [14]. On the basis of typomorphic features detailed study of gold ore deposits main minerals, authors of this work concluded that between the parameters of hydrothermal solutions and the final result (composition of minerals), solutions supersaturation degree takes place, which regulates the behavior of isomorphic impurities.

Notions of low-carat and high-carat gold took root in the lexicon of mineralogical and technological descriptions, replacing the digital notations of silver content in the mineral (table 2). Sometimes the boundary of such content is determined differently by different researchers. At the same time, electrum is excluded, as a special mineral form.

Table 2 – Fineness of gold (from Petrovskaya N.V.)

Borders content	Fineness of gold, ‰
Very high-carat, almost pure	998-951
High-carat	950-900
Moderately high-carat, medium fineness	899-800
Relatively low-carat	799-700
Low-carat	699-600
Very low-carat, high-silver	<600

**Fineness of native gold is in the Kokkiya deposit.** In figure 2 gold is contained in the pentagonal-dodecahedral pyrite III (depth 60-61 m) chlorite-sericite quartz metasomatite. In close association with pyrite III on the deposit there are rare occurrence high-temperature molybdenite and arsenopyrite. Gold is bright yellow color, reflecting it can be attributed to high-carat gold (approximately 950‰).

Tellurides of gold, silver, lead appear in sericitolites with depth (140-143 m), which are closely associated with native gold and developed in intergranular spaces of intensely corroded pyrite III.

Gold was found in the polished section №11: 1) vein-shaped (0.01x0.05 mm) in sericite along the edge of a large corroded pyrite grain; 2) small irregular forms in sericite (0.01 mm); 3) in intergrowth with fine grains of pyrite in sericite (0.01x0.1); 4) in intergrowth with fine grains of vein-shaped pyrite and tellurides (0.01x0.1 mm); 5) in sericite - 0,005x0,025 mm; 6) in sericite intergrowth with tellurides and pyrite (8 grains of irregular shape - 0.01-0.02x0.03 mm); 7) along the edge of pyrite grain (0.01 mm); 8) 3 in the grain of pyrite (0.005-0.01 mm); 9) gold (2 grains - 0.01-0.02 mm) in intergrowth with tellurides between pyrite grains, cementing pyrite; 10) gold veins (0.01x0.1 mm) in the interval of pyrite grains in sericite; 11) 2 veins-shaped separate out of gold in sericite (0.01x0.05 mm); 12) in intergrowth with telluride and sericite in pyrite (0.01x0.02 mm); 13) veins-shaped in sericite next to pyrite grain (0.01x0.06 mm); 14) in intergrowth with pyrite and between pyrite grains (2 grains 0.01-0.005x0.01 mm). Figures 4-7 show gold and tellurides.

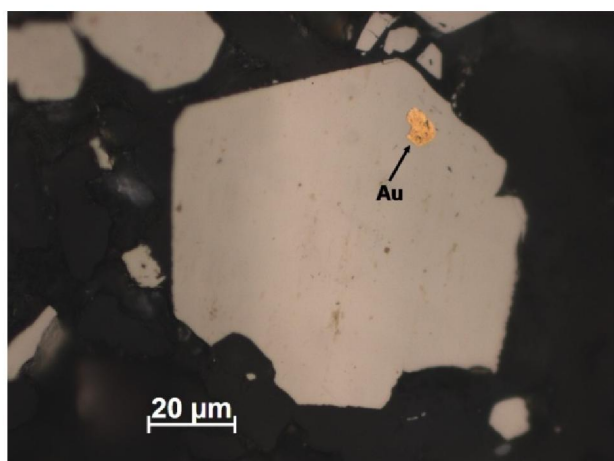


Figure 2 – Gold (Au) in the pentagonal dodecahedron grain. Polished section 38

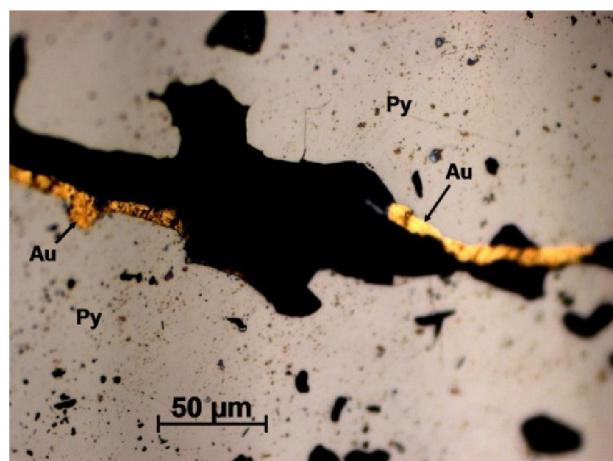


Figure 3 – Gold (Au) vein-shaped in the interval of grains of pyrite or along the edge of pyrite grains (Py) in sericitolite

**Calaverite and altaite** - develop between pyrite grains, veins-shaped, oval, prismatic. Occur separately in the mass metasomatite, in intergrowths with gold and pyrite, penetrate into the pyrite, corroding it. Dimensions - up to 0,04x0,07 and 0,03x0,1 mm (figures 4, 5). Minerals are confirmed analytically. In addition, altaite is found in corroded grains and intergrowth of pyrite, sometimes in association with galena.

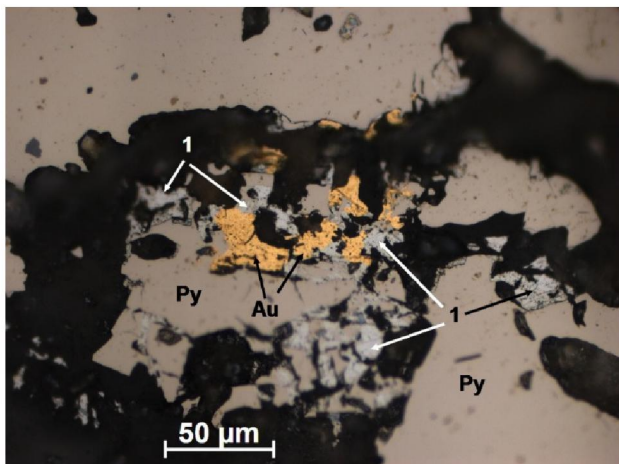


Figure 4 – Gold (Au) in intergrowth with altaite, calaverite (1) and pyrite (Py) in sericitolite. Polished section 11

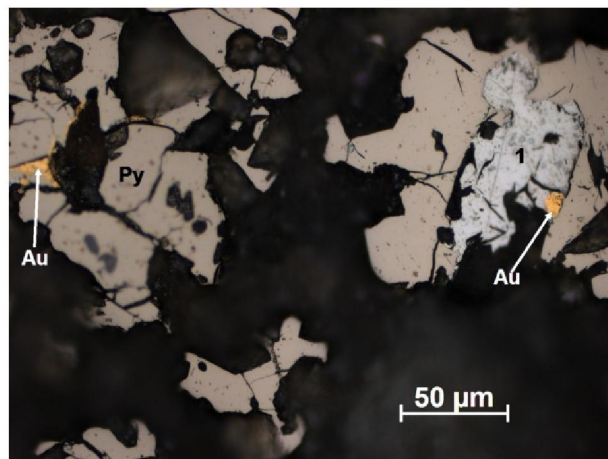


Figure 5 – Gold (Au) in conjunction with altaite (1) and pyrite (Py) in sericitolite. Polished section 11

The fineness of gold (figures 3, 6) is given in table 3 and performed by Popov Yu.V. ("Center for Studies of Mineral Raw Materials and the State of Environment" of the Southern Federal University). Scanning electron microscope Tescan Vega LMU with X-ray fluorescent microanalysis systems INCA Energy 450, INCA Wave 700 (from OXFORD Instruments Analytical). Iron is determined from the calculation results. Gold refers to the high-carat (940-944‰).

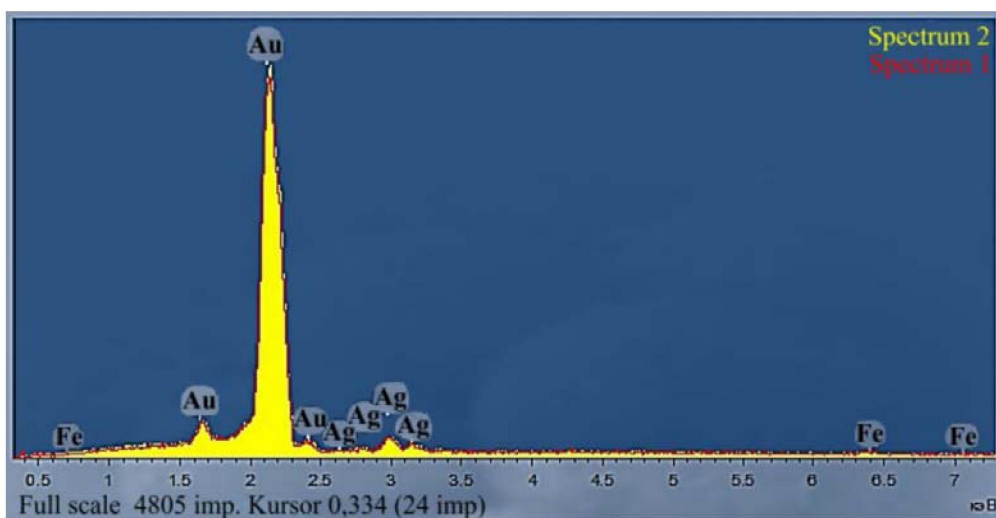
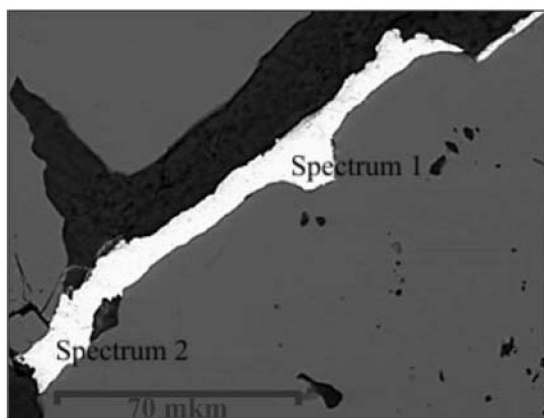


Figure 6 – Gold (Au) vein-shaped in the interval of grains of pyrite or along the edge of pyrite grains (Py) in sericitolite. Polished section 11

Table 3 – Gold composition from a scanning electron microscope (wt.%)

Polished section 11	Elements		Sum	Fineness of gold, ‰
	Au	Ag		
Analysis 1 – Gold (Au) vein-shaped	93,57	6,0	99,57	940
Analysis 2 - Gold in intergrowth with altaite between grains of pyrite	92,60	5,47	98,07	944

The results obtained from the microprobe according to the fineness of gold in the intergrowth with tellurides were close to those performed on a scanning electron microscope (figures 3–5, table 4). Gold refers to the high-carat and very high-carat (941 and 977‰).

Table 4 – Gold composition according to micro-X-ray spectral analysis (wt.%)

Polished section 11 – Gold in intergrowth with tellurides (altaite and calaverit) between grains of pyrite, (wt.%)				
Au	Ag	Fe	Sum	Fineness of gold, ‰
97,04	2,27	0,69	100	977
92,23	5,77	2,0	100	941

\*Analysts Levin V.I. and Kotelnikov P. E. The analysis was performed on a microprobe JCSA-733 (Japan).

Chemical composition of ore and veined minerals was studied using a scanning electron microscope "S-3700N" equipped with an energy dispersive X-ray spectrometer (EDS) with a microanalyzer in the laboratory of the Adam Mickiewicz University, Poland (figure 7).

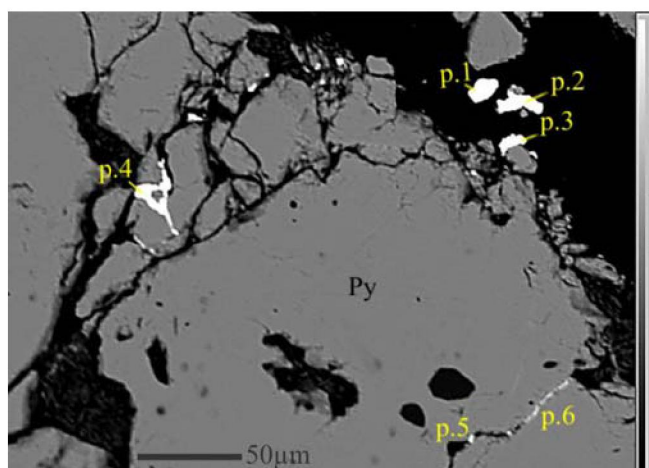


Figure 7 – Gold (Au) in the grains of pyrite (Py). Polished section 11

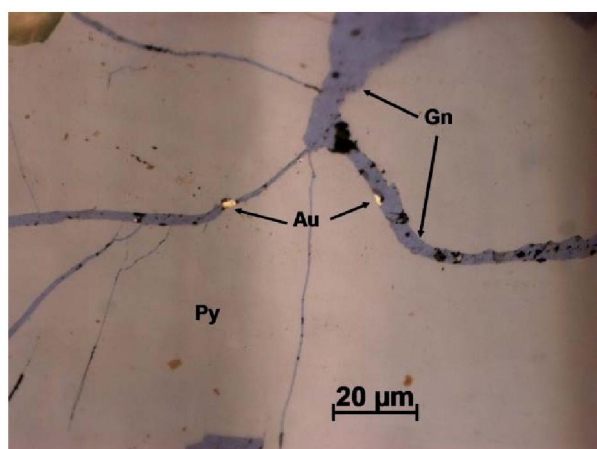


Figure 8 – Gold (Au) light yellow in galena streak (Gn). Py is pyrite. Polished section 94/2

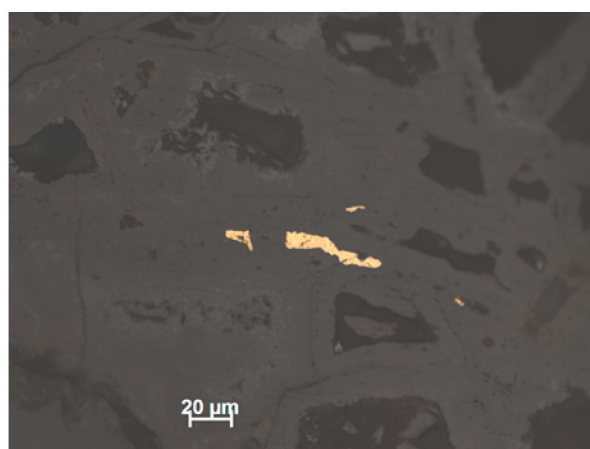


Figure 9 – Gold in iron hydroxides. Polished section 194/2

Vein-impregnated pyrite-polymetallic ore in the quartz-sericite metasomatite appearance on the deeper horizons of the deposit (175-176 m), in which gold is closely associated with galena. Galena with gold encased in it develops in the form of thin veins between grains of aggregate pyrite IV (figure 8). Gold refers to a medium, moderately-high-carat (810‰).

At shallow depths (6-8 m), finely-dispersed gold is encased in impregnated of pentagonal dodecahedral pyrite III in sericitolites is distinguished by a decrease in the fineness (table 5). Gold refers to the base and relatively low-carat (634-717‰).

Table 5 – Gold composition according to micro-X-ray spectral analysis (wt. %)

Polished section 199 – Gold in pyrite, (wt.%)			
Au	Ag	Sum	Fineness of gold, ‰
71,66	28,34	100	717
63,39	36,61	100	634
*Analysts Levin V.I. and Kotelnikov P.E. The analysis was performed on a microprobe JCSA-733 (Japan).			

Pyrite III is susceptible to oxidation at such shallow depths (6-10 m), and the gold contained in it is purified and becomes high-carat (figure 9).

#### Conclusions.

1. Sericitolites with impregnation of pentagonododecahedral pyrite III are the most gold-bearing minerals. Gold concentrates in both pyrite and sericite.

2. Gold associated with pentagonododecahedral pyrite III is high-carat, but with a decrease in depth (6-10 m), silver content as the main impurity element of native gold increases.

3. With depth (140-143 m) pyrite III is subjected to intense corrosion, becomes porous and native gold in close association with tellurides of gold, silver and lead penetrates into it. Gold is high-carat and very high-carat.

4. The content of silver in native gold, enclosed in late galena veins in aggregate pyrite IV, naturally increases and is characteristic of many gold deposits.

5. Native gold of high assay is found in oxidized pseudomorphs of pyrite III and in iron hydroxides.

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### **КӨКҚИЯ АЛТЫНРУДАЛЫ КЕНОРНЫНЫҢ (ҚЫРҒЫЗ ЖОТАСЫ) АЛТЫН СЫНАМЫ МИНЕРАЛ ЖАРАЛУДЫҢ ФИЗИКАЛЫҚ-ХИМИЯЛЫҚ ЖАҒДАЙЛАРЫНЫҢ КӨРСЕТКІШІ РЕТІНДЕ**

**Аннотация.** Мақалада Көкқия алтын кенорнының рудаларын микроскоптық зерттеу нәтижелері сипатталған. Кенорын рудаларының минералдық құрамы, екінші дәрежелі және сирек минералдары анықталған. Алтын сынамының өзгергіштігі кенорынның жайға су тереңдігі, сондай-ақ минерал жаралу процестерінің бастапқыдан соңғыға дейінгі сатысы бойынша анықталады. Алтын сынамын элементтің көптеген ғалымдары алтын рудалы кенорындар жаралуының физикалық-химиялық жағдайларын анықтайтын типоморфтық белгі ретінде қабылдайды. Руда жаралудың физикалық-химиялық жағдайлары туралы негізгі ақпарат бералатын сирек минералдар да анықталған. Минералдардың құрамы мен минерал жаралу процестерінің сипаттамалары аралығындағы себептік-салдарлық байланыстар сипатталған. Бұл анықталғандар практикалық жағынан минералогиялық болжамдық-бағамдық критерийлерді әзірлеу үшін де маңызды.

**Түйін сөздер:** алтын сынамы, пирит, теллуридтер, алтын шоғырландырушы минералдар.

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### **ПРОБНОСТЬ ЗОЛОТА КАК ИНДИКАТОР ФИЗИКО-ХИМИЧЕСКИХ УСЛОВИЙ МИНЕРАЛО-ОБРАЗОВАНИЯ НА ЗОЛОТОРУДНОМ МЕСТОРОЖДЕНИИ КОККИЯ (КЫРГЫЗСКИЙ ХРЕБЕТ)**

**Аннотация.** В статье изложены результаты микроскопических исследований руд на месторождении Коккия. Установлен минеральный состав руд месторождения, с выявлением главных, второстепенных и редких минералов. Определена пробность золота, изменчивость которой определяется глубиной, а также процессами минералообразования от ранних ассоциаций к поздним. Пробность самородного золота принимается многими учеными мира, как типоморфный признак, указывающий на физико-химические условия образования золоторудных месторождений. Найденные редкие микроминералы также несут основную информацию о физико-химических условиях рудоотложения. Выявлены причинно-следственные связи между составом минералов и характеристиками минералообразующих процессов, что является важнейшей задачей генетической минералогии. Не менее важно это и в практическом отношении для разработки минералогических прогнозно-оценочных критериев.

**Ключевые слова:** пробность золота, пирит, теллуриды, золотоконцентрирующие минералы.

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