"NEW" GOLD IN WEATHERING CRUSTS AND TECHNOGENIC PLACERS OF THE LOWER SELEMDZHA GOLD-BEARING NODE (AMUR REGION)

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It has been established that in the weathering crust and technogenic placers of the Lower Selemdzha gold-bearing node of the Amur region, newly formed native gold is present both in the rock matrix directly associated with Au and on the surface of noble metal grains. In the weathering crust, film-like and isometric Au was found on the surface of native gold samples and porous gold formed by filling the free space of host loose rocks . Particle size ranges from 0.2 to 3 μm. The composition of authigenic gold is Au-Ag-Cu, Au-Cu, and chemically pure noble metal (1000 ‰).

In technogenic placers, film-like, spheroidal, dendritic, thread-like, vermiform, globular, and spongy newly formed gold has been identified. Particle size ranges from 0.1 to 1 μm. Gold composition varies from multicomponent (Pb-Au-Hg-Sn), (Au-Pb-Hg-Ag), (Au-Pb-Hg), (Au-Hg-Ag), (Au-Hg) to chemically pure Au.

Despite different compositions, the mechanism of newly formed Au formation in natural (weathering crusts) and technogenic objects (placer dumps) appears to be similar. During hypergene transformations, Au-concentrating minerals decompose, metals are released, and further precipitation occurs.

Geochemical barriers for precipitation and concentration of noble metal are the sorption properties of the host rock, as well as particles of newly formed ultrafine clusters of native gold,

mercury, lead, copper, tin, and their compounds. Organic/inorganic carbon plays the role of reducing agent.

Keywords: Chatkal-Kurama region, porphyry-epithermal systems, isotopic composition of Pb, MC-ICP-MS, sources of matter

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INTRODUCTION

The phenomenon of so-called "new" (autigenic, "in situ") gold in deposits of various genesis has been established for a long time (Petrovskaya, 1941, 1973). Such gold is revealed in the natural formations: in the oxidation zone of ore deposits (Elbow, 1980; Roslyakov, 1981; Sazonov et, 20191; Kalinin etc. 2022), gold-bearing weathering crusts (Petrovskaya, Yablokov, 1974; Novgorodova et al., 1995; Kalinin et al., 2009; Kalinin et al., 2018; 2019; Nikiforova, etc., 2020), and mineral deposits (Nikolaev, 1958; Yablokov, 1965; Neronski, Safronov, 1988; Khazov and others 2010; Barannikov, Osovetskiy, 2013; Shuster and Southam, 2015; Litvinenko and Shilina, 2017; Sokerin et al., 2023). In addition, newly formed gold has been found in man-made formations and various gold mining wastes (Kovlekov, 2002; Naumov and Naumova, 2013; Kirillov et al., 2018; Khusainova et al., 2020, 2021; Myagkaya et al., 2020; Sazonov et al., 20192).

The processes of formation of new gold are not yet fully understood. In this regard, obtaining new data on the morphological and chemical features of such gold is an urgent task.

As a rule, autigenic gold belongs to the class of so-called thin (<0.1 mm). It should be noted that the region under consideration is characterized by a rather high role of fine gold in the overall balance of the native precious metal. In weathering crusts, up to 78% belongs to Au < 12 microns in size (Kuznetsova and Dementienko, 2023), in technogenic placers, up to 83% of Au belongs to fine < 0.1 mm and submicron gold (Kuznetsova, 2011; Kuznetsova et al., 2019).

The presented work focuses on the study of gold "in situ" as one of the components of fine native gold of the weathering crust and man-made placers of the Nizhneselemdzhinsky gold-bearing node of the Amur region.The aim of the study: to determine the morphological and chemical characteristics of the “new” gold in the weathering crusts (WC) and technogenic placers of the Nizhne-Selemdzhinsky gold-bearing cluster (NZC) of the Amur region.

Research objects: samples of native gold, some of which represent close intergrowths of noble metal with fine-grained silicate rocks containing fine gold.

RESEARCH METHODS

Large-volume samples for research were collected from the weathering crust of Paleozoic granitoids (Tatarka River basin) (Fig. Tatar) (fig. 1, point 1), as well as in technogenic placers of NZU (Neklya River basin) (Fig. Neklya) (Fig. 1, point 2).

Native gold in the form of separate grains and intergrowths was isolated according to the published methodology (Moiseenko, 2007; Moiseenko V.G., Moiseenko N.V., 2012).

Studies of micromorphology and elemental composition of native gold and its host rock were conducted using analytical scanning electron microscopy (SEM). The main part of the work was performed on an "EVO 40XVP" electron microscope (Carl Zeiss, Germany), equipped with an INCA Energy energy-dispersive X-ray analysis (EDA) system (Oxford Instruments, UK), at IBM FEB RAS. Some samples of gold and host rocks were studied using an electron microscope JEOL JSM-6390LV (Jeol, Japan) at AC IGiP FEB RAS. The presented images were obtained in secondary (SE) and back-scattered electrons (BSE). Newly formed gold is very brittle; during sample polishing, it often deforms, and the possibility to establish its morphological and chemical characteristics is lost. Therefore, all presented analyses of the chemical composition of gold and associated mineral aggregates were obtained from volumetric grains. Although the obtained data cannot be considered quantitative, they are quite applicable for the purposes of this study, as they reflect the elements included in the mineral substance and their ratios. Some gold particles were carbon-coated to create a conductive film. Some samples were not coated to evaluate their carbon content. When determining the composition of the fine gold fraction, a previously developed methodology was used (Safronov, 2011). Measurements were conducted at an accelerating voltage of 20 kV, with a current of 600 pA in EDA mode, in SE microscopy mode from 20 to 50 pA, in BSE mode from 100 pA to 300 pA depending on the sample type.

BRIEF GEOLOGICAL CHARACTERISTICS

The Lower Selemdzha gold-bearing cluster belongs to the central part of the Zeya-Selemdzha gold-bearing region (Amur region) (Melnikov, Polevanov, 1995), which is confined to the Mamyn uplift of the Bureya median massif. The uplift covers the interfluve of the Zeya and Selemdzha rivers, to the south of the Dzhagdy Ridge. Here, Paleozoic granitoids predominate, among which relics of folded formations of the Archean, Riphean, Cambrian, Silurian, and Middle Devonian are preserved. At the same time, Mesozoic (predominantly Cretaceous) intrusive and volcanic formations are also developed within the uplift (Geological map, 2001) (Fig . 1).

The stratified formations of the Lower Selemdzha gold-bearing cluster form a large anticlinal structure of northeastern strike, in the core of which shales and metasandstones of Late Proterozoic-Early Cambrian age are exposed, intruded by granitoid intrusions of Ordovician, Carboniferous, and Cretaceous age, and on the flanks - sandstones with interlayers of conglomerates, gravelites, and siltstones of Silurian age. Within the LGC, occurrences of gold, silver, lead, tin, niobium, and other elements have been established.

The entire territory under consideration is characterized by placer gold content. Placer mining has been carried out since the beginning of the last century. The sources of native gold are thin quartz veins in sedimentary rocks metamorphosed under greenschist facies conditions, and products of chemical weathering of bedrock.

To date, most of the deposits have been mined out, but the exploitation of technogenic gold placers continues.

More detailed geological features and mineral composition of weathering crusts and technogenic placers of the region under consideration are presented in (Kuznetsova, 2011; Safronov, Kuznetsova, 2017; Kuznetsova et al., 2019; Kuznetsova, Safronov, 2021; Kuznetsova, Dementienko, 2023).

RESEARCH RESULTS

Weathering Crusts of the Nizhneselemdzhinskiy Gold-Bearing Node of the Amur Region

The weathering crust section (from top to bottom) is represented by silt-clay-sandy and quartz-hydromica-kaolinite layers. In the weathering crust on Paleozoic granitoids of NGN, the gold-bearing zone is quartz-hydromica-kaolinite. The heavy fraction contains ore minerals (in descending order): ilmenite, magnetite, martite, pyrite, zircon, sphene, scheelite, galena, cassiterite, monazite, chalcocite, rutile, covellite, and gold.

The morphology of native gold is quite diverse. Almost 2/3 of the examined grains have homogeneous structure, are partially rounded, and practically without inclusions. The fineness of such gold is 802–844 ‰, and it is likely of endogenic origin. Some gold appears as aggregates of intergrown Au grains of various morphology and fineness (fig . 2–4), but overall it is chemically purer (870–990 ‰) and probably has a hypergene origin.

The surface of gold grains is often covered with thin plates of higher fineness (fig . 2, 3). Also, plates of copper-rich gold were diagnosed on the surface of lower fineness gold (860–863‰) (fig . 2, table. 1, sp. 2, 3).

Sometimes the thin-plated formations represent chemically pure gold – 1000‰ (fig. 3, sp. 1–5), with numerous caverns filled with high-carbon aluminosilicate-ferruginous mineral mass (fig. 3, table 2, sp. 6–7)

Particularly interesting are samples with an openwork microstructure (fig . 4). The gold particle consists of multiple thin foliate (fig. 4c, d, Au_{pl}) and globular segregations, some of which have a hypidiomorphic appearance (fig. 4c, d, Au_{sf}). The composition of thin-plated formations corresponds to copper-rich gold of rather high fineness ~930–970‰ (table 3, sp. 2-7). Along the periphery of these films (fig . 4c) and on their surface (fig . 4d) numerous spheroidal formations of Au (Au_{sph}) have been established. Their size is ~0.2–1.0 µm. There are isolated specimens that reach ~2–3 µm in size. The spheroidal particles are characterized by a higher fineness of 985–992‰ and do not contain silver (fig. 4c, d, table 3, sp. 1, 8).

Technogenic placers of the Nizhneselemdzhinskiy gold-bearing node of the Amur Region

The technogenic placers of the Nizhneselemdzhinsky gold-bearing cluster are characterized by the predominance of the heavy fraction (in descending order): ilmenite, native lead, monazite, Fe oxides and hydroxides, galena, magnetite, zircon, mercury and gold (Kuznetsova, 2011; Safronov, Kuznetsova, 2017). The native gold of the technogenic placers of the NZU is a conglomerate of gold grains of various morphology and fineness, cemented together by a finely dispersed polymineral matrix of complex composition, and in some cases, gold amalgam. The following minerals have been identified in the aggregates cementing gold grains (in order of frequency of occurrence): kaolinite, halloysite, chlorite, sericite, goethite, limonite, quartz, adularia, pyrite, hydrogoethite, romaneshite; native lead and its compounds are also found: Pb oxides and hydroxides (red lead, massicot), Pb sulfates (anglesite) and carbonates (cerussite, phosgenite), Pb chlorides (cotunite, mendipite), phosphates (pyromorphite) and sulfides (galena), and a number of others (Safronov, Kuznetsova, 2017; Kuznetsova et al., 2019).

In one of the samples (fig . 5a), smaller gold particles were found in an aggregate of clay minerals (fig . 5b–e). Their size ranges from 0.1 to ~0.6 μm, and only isolated specimens reach ~1 μm.

The composition of the mineral aggregate associated with native gold is Fe-Mn-oxide-hydroxide-aluminosilicate with admixture of carbonaceous matter (table 4). Au, Hg, Pb, Sn were recorded in the composition of this mass (fig . 5c; table 4, sp. 1 – sp. 6).

Spherical gold particles identified in the non-ore mineral aggregate correspond (without considering the contribution of the matrix) to chemically pure gold, i.e., their fineness is 1000‰ (fig. 5d, f, sp. 7). In addition to these particles, ultrafine lead-mercurial gold that is invisible to SEM has been identified (fig . 5d, table 4, list 12) and, visible as light concentrations, microgold of the same elemental composition (fig . 5d, table 4, list 8–11).

Newly formed gold in technogenic placers has also been found on the surface of native Au grains. The composition of such authigenic gold varies.

Gold neoformations are found both with high lead content (fig. 6a, table 5, list 1) and with low content (fig. 6b, table 5, list 2, 3; fig. 7, table 5).

Lead is present in the composition of authigenic gold (fig. 6, table 5; fig. 7, table 5, list 1, list 2), in the rock associated with gold (fig. 7, table 5, list 3, 4), and in the form of anglesite on the surface of the precious metal (fig. 11, table 5, list 4).

Globular authigenic mercury-lead gold is also found (fig. 7, table 5, list 1, 2) with inclusions of aluminosilicate mineral rock, sometimes containing carbon (list 3, 4).

Some of the newly formed gold is only amalgamated (fig. 8, table 5). Mercury gold "fuses" grains together. Often, carbon is present in one form or another in the composition of authigenic gold (fig. 8, table 5).

Sometimes new Au is deposited on the grain surface in the form of thin filamentous formations (fig. 9). Their length ranges from several micrometers to 20 μm or more. The thickness varies from the first tens to tenths of a micron.

A significant part of the filamentous gold is mercuric high-fineness gold (>900 ‰) (fig. 9g). There are also areas with filamentous gold consisting of chemically pure Au (1000 ‰). Next to the "tangle" of pure filamentous gold, there is an almost rounded segregation of impurity-free gold (size ~ 4–6 μm) (fig.9e).

At the same time, high-fineness (up to 1000‰) newly formed gold has been identified on the surface of some gold particles, where it is represented by globular, spongy, and thin-plate formations (fig. 10, fig. 11, Table 5).

The newly formed spongy gold is heterogeneous in composition (Fig. 10). There are dense segregations of pure gold (Fig. 10, Table 5, sp. 1, 2). Some of them contain mercury – up to 6 wt. % (Table 5, sp. 4). Some formations contain lead ~ 4% (Table 5, sp. 5). The EDA spectra obtained from spongy gold show nitrogen lines (up to 3%) and carbon (~ 4–5%) (Table 5, sp. 1, 2, 4).

DISCUSSION OF RESULTS

Detailed studies of native gold from the weathering crust and worked-out placers of the Nizhneselemdzhinsky gold-bearing node in the Amur region have established the presence of newly formed precious metal.

Morphology of the studied samples unambiguously indicates the authigenic nature of native gold. New gold from the weathering crust and from technogenic placers has similar features and is characterized by a variety of morphological forms (lamellar, spheroidal, spongy, globular, rod-shaped, filamentous) (Fig. 2–11) (Petrovskaya, 1941, 1973; Yablokova, 1965). Some gold was formed on the surface of native Au grains. Another part of gold was probably formed directly in pores or voids of loose rocks (Fig. 4, 5) (Petrovskaya, Yablokova, 1974; Novgorodova et al., 1995; Sokerin et al., 2023).

Size of authigenic gold particles, documented using SEM, varies from tenths of a micron (Fig. 5, 9) to several micrometers and more.

The smallest (0.1–0.6 μm) Au particles are found in carbonaceous-clay aggregates associated with native gold from technogenic placers. Probably, there are also nanosized particles (<0.1 μm), which are not individualized under SEM but are detected by EDA and have a composition similar to gold-lead-mercury formations visible under the microscope (on the image, the latter appear as light concentrations) (Fig. 5, Table 4).

Chemical composition of newly formed gold shows wide variations both in the weathering crust and in placers. No relationship between Au composition and its morphology has been established.

Authigenic gold of WC (weathering crust) was identified in 2 forms. The first one (lamellar) is deposited on the surface, probably on hypogene gold grains of Ag-Au composition with lower fineness (860–863‰). Such new gold has a fineness from 890 to 922‰, and may contain Cu and Ag as impurities (Fig. 12) (Kalinin et al., 2009; 2022; Novgorodova et al., 1995; Osovetsky, 2012; Hough et al., 2008). Some film formations associated with high-carbon aluminosilicate-ferruginous formations are chemically homogeneous, with 1000‰ fineness.

The second authigenic gold (openwork) was probably formed directly in the weathering crust. Morphologically, it resembles the so-called "mustard" gold, but differs in color, composition, and brittleness (Gamyanin et al., 1987; Nekrasov, 1991) . It consists of gold, apparently of 2 generations, differing in form and composition: thin-plated Au-Ag-Cu (930–970‰) and spheroidal Au-Cu (985–992‰) (Fig. 12). The absence of silver in the spheroidal formations could be explained by leaching as a result of weathering. But the fact that spheroids are found on the surface of film formations of gold and the difference in compositions indicate their later crystallization. A distinctive feature of the new gold of WC is the presence of Cu in its composition, which is probably explained by the presence of copper minerals (covellite and chalcocite) in the WC deposits.

In the technogenic placers of the Nizhneselemdjinsky gold-bearing node, newly formed Au was found both on the surface of native gold samples themselves (Fig. 9–14) and in the mineral mixture cementing the noble metal grains (Fig. 6–8).

For the most part, the rocks associated with gold represent a finely dispersed mixture of clay minerals, as well as clay and Fe-Mn-oxide and hydroxide minerals characteristic of the supergene zone (Hough et. al., 2011; Vishitia et. al., 2015; Anand, Salama, 2019). Ore elements (Au, Pb, Sn, Fe, As, etc.) present in the rock are the result of the destruction of corresponding minerals, depending on the chemical composition of solutions draining technogenic placers. And the presence of mercury is characteristic of the tailings of placer gold mining in this area (Kuznetsova; 2011) .

In the ferromanganese aluminosilicate mineral mixture associated with native gold, visible formations of practically pure and lead-mercurial Au with sizes from tenths of a micron and invisible under SEM (fig. 7), but detected by EDA clusters of Au, Au-Ag and compounds of Au-Hg, Au-Hg-Ag, Au-Hg-Pb, Au-Hg-Pb-Sn compositions (fig . 13) (Safronov, Kuznetsova; 2017) have been established. Such particles can be active centers for the nucleation and growth of Au in host rocks. Probably, these clusters of gold and its compounds merge into ultrafine, and then micrometer-sized formations of the noble metal. This forms both chemically pure visible spheroids of native gold and Au compounds with a number of elements – Hg, Pb, Sn of various variations (fig. 13). Possibly, high-grade ultrafine Au formed at the last stages of mineral formation, and lead-mercurial gold crystallized even later. But it is not excluded that these processes occur simultaneously.

Among the impurities in the new gold of technogenic placers, the most common are Hg, Pb, Ag, Sn, and there is practically no Cu. Apparently, this is due to the absence of copper minerals in the considered technogenic deposits.

Gold "in situ" on the surface of the samples is identified as both low-grade and practically chemically pure. The composition of newly formed gold varies widely (fig. 14), with Au-Hg, Hg-Au-Ag, Au-Hg-Pb, Au-Hg-Pb-Ag, Au-Pb and Au phases established. The new gold, represented by Au-Hg complexes, not only covers the surface of the samples but also cements various gold grains into a single aggregate (fig. 8, 9).

Almost all spectra contain carbon (from 4.55 to 17.28 %) (table. 4, 5). It can be found both in intergranular spaces and in the atomic crystal structure of gold itself (Safronov et al., 2023). The presence of oxygen spectrum is probably explained by its connection with carbon. The presence of nitrogen and phosphorus, in combination with carbon, indicates the organic origin of the latter. Gold, lead, and mercury in varying amounts have been identified not only in the composition of gold but also in the mineral mixture associated with authigenic Au. Probably, sedimentary rocks, due to their high sorption properties (caused by the abundance of clay minerals having a developed surface with a negative charge), well adsorbed the above elements from draining solutions (Kalinin et al., 2019; Silyanov et al., 2021).

There is no consensus on *the formation* of authigenic gold. In our case, several processes likely took place.

The destruction of minerals during hypergene processes with the release of ore elements, their transition into solutions, and subsequent precipitation (Craw, Kerr, 2017; Stewart et al., 2017; Roslyakov, 1981) . Loose host rock, good water permeability, relative stability of groundwater, destruction of organic matter, presence of sulfides and manganese oxides, as well as the dispersity of gold in the mineral composition of weathering crust and technogenic placers are favorable conditions for gold migration and formation of individual enrichment areas (Smirnov, 1955).

Newly formed lead, mercury, copper, iron, etc. (having geochemical affinity with Au), and primarily, of course, gold itself serve as geochemical barriers for gold precipitation (Craw, 2017; Shuster, Southam, 2015; Kirillov et al., 2018 , Sazonov et al., 2019; Kalinin et al., 2018; Khusainova et al., 2020; Tolstykh et al., 2019). The high fineness of authigenic gold can be explained both by purification as a result of electrochemical leaching (Roslyakov, 1981; Fon et al., 2021), and by the later formation of chemically pure Au (Kalinin et al., 2009; 2022; Novgorodova et al., 1995; Osovetskiy, 2012; Hough et al., 2008) .

The ubiquitous presence of carbon in matter creates reducing conditions that promote the deposition and concentration of native gold (Amosov et al., 1997; Safronov, Kuznetsova, 2021; Moiseenko, Kuznetsova, 2014, Xianhai et al., 2018; Dunn et al., 2019; Hastie et. al., 2021). The presence of characteristic nitrogen and phosphorus lines in the spectra, high gold fineness, and its morphological features may indicate the biogenic origin of authigenic gold (Amosov, Vasin, 1993; Kuimova, Moiseenko, 2006; Korobushkina, Korobushkin, 1986; Marakushev, 1997; Southam et al., 2009; Reith et al., 2010; Rea et al., 2016; Shuster et al., 2016, 2017; Zammit et al., 2015; Anand et al., 2017; Fairbrother et al., 2012; Shuster et al., 2016; Southam et al., 2009; Xianhai et al., 2018; Petrella et al., 2022).

It is necessary to especially note the fact of establishing a rare morphological form of new gold – filamentous (Fig. 9). The tendency of native gold to form filamentous shapes has long been noted by researchers (Mayorova et al., 2011; Fairbrother et al., 2012). Successful experiments have been conducted on the experimental growth of gold filaments (Nadgorny et al., 1959) . Apparently, under certain physicochemical conditions and favorable geological environment, it is energetically advantageous to build a rounded-elongated (filamentous) structure from gold atoms entering from solution due to directional growth.

CONCLUSION

Newly formed native gold of varying shapes, sizes, and composition has been established in the weathering crust and technogenic placers of the Nizhneselemdzhinsky gold-bearing node of the Amur region. Authigenic gold is present both in aggregates of aluminosilicate minerals directly associated with grains of primary gold and on their surface.

Despite the different chemical composition of authigenic gold in weathering crusts and technogenic placers, the mechanism of formation of newly formed Au is apparently similar. During the transformation process, there is decomposition of Au-concentrating minerals, such as tellurides, gold-containing sulfides and sulfoarsenides, followed by precipitation of Au at geochemical barriers and formation of new forms of the noble metal, from ultrafine to micro-sized.

Geochemical barriers for gold precipitation are carbon atoms present in aggregates of aluminosilicate minerals, as well as particles of newly formed ultrafine metal clusters – native gold, mercury, lead, copper, tin and their compounds.

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Table 1 . Composition of native gold (fig. 2 b, c, spectra 1 and 4) and film formations on it (fig. 2 c, spectra 2 and 3), wt. %

Spectrum	Cu	Ag	Au	Total
1	13.66	13.66	86.34	100.00
2	1.25	9.73	89.02	100.00
3	1.27	6.52	92.21	100.00
4	13.98	13.98	86.02	100.00

Note. – content below detection limit

Table 2. Composition of high-carbon aluminosilicate-ferruginous formations (fig. 3, spectrum 6 and 7), filling cavities between newly formed Au films on the surface of gold particle (fig. 3, spectrum 1-5), wt. %

Spectrum	Cu	Fe	Ti	Ca	K	Cl	Si	Al	Mg	Na	O	C
6	2.97	2.97	0.44	4.31	0.65	1.77	8.11	4.17	2.82	2.02	39.97	32.77
7	0.83	2.50	0.79	0.79	1.45	1.19	5.93	4.32	0.72	2.04	35.48	44.75

Note. – composition of spectra 1-5 is not provided, as it corresponds to 100% Au

Table 3 . Composition of lamellar (fig. 4 c, d spectrum 2-7) and spheroidal (fig. 4 c, d spectrum 1, 8) gold formations, wt. %

Spectrum	Cu	Ag	Au
1	1.50	–	98.50
2	1.45	4.87	93.69
3	1.66	1.48	96.87
4	1.89	5.19	92.92
5	1.69	3.04	95.27
6	2.04	3.87	94.09
7	1.08	2.04	96.88
8	0.81	–	99.19

Table 4 . Composition of native gold and aluminosilicate aggregate containing ultrafine gold (fig. 5 **c, e**), wt. %

Element	Spectrum										
	1	2	3	4	5	6	8	9	10	11	12
C	–	5.19	5.21	3.54	5.27	3.61	4.81	6.72	7.27	12.34	3.94
O	36.19	38.77	48.73	44.02	40.67	21.16	18.07	19.16	20.03	17.1	25.23
Na	–	0.3	0.37	–	–	–	–	–	–	–	–
Mg	–	0.63	0.31	–	0.31	–	–	–	–	–	–
Al	14.89	10.28	12.61	10.46	11.85	4.15	5.43	4.58	6.71	4.34	10.7
Si	14.33	10.83	13.31	10.44	11.22	5.35	5	4.61	6.7	5.08	10.57
P	–	0.22	0.24	0.39	0.29	–	–	–	–	–	–
S	–	–	0.21	0.33	0.02	–	–	–	–	–	–
Cl	0.56	0.44	0.64	0.55	0.36	0.78	0.77	0.98	0.88	0.89	0.65
K	0.95	2.29	1.12	0.63	1.09	0.9	0.53	0.36	0.81	1.41	1.12
Ca	0.37	0.81	0.42	0.73	0.65	0.1	0.19	0.41	0.12	0.3	0.42
Ti	1.36	0.45	0.23	0.44	0.5	0.72	0.64	0.4	0.37	1.11	0.82
Mn	3.49	3.5	3.82	2.61	3.06	1.93	2.25	1.85	2.13	3.3	4.35
Fe	5.44	18.1	5.19	11.39	19.03	2.86	3.61	3.94	6.72	5.86	15.79
As	–	–	–	–	–	–	–	–	–	–	0.25
Sn	0.86	–	–	–	–	10.45	2.66	5.14	2.41	5.09	1.11
Au	13.72	4.79	5.57	11.47	3.43	17.5	16.99	18.33	18.36	14.02	16.11
Hg	2.41	2.15	0.96	1.05	0.93	3.01	4.9	3.89	5.67	4.47	2.45
Pb	5.43	1.25	1.06	1.95	1.32	27.48	34.15	29.63	21.82	24.69	6.49

Table 5 . Composition of native gold and mineral inclusions in it (fig. 6-8, 10-11), wt. %

№ of figure	Spectrum	Element																
		C	N	O	S	Mg	Al	Si	Cl	K	Ti	Mn	Fe	As	Ag	Au	Hg	Pb
6	1	–	–	–	–	–	–	–	–	–	–	–	–	–	0.86	65.09	13.55	20.5
	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	92.04	6.07	1.89
	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	91.18	2.55	6.27
7	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	88.62	9	2.38
	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	84.35	12.21	3.44
	3	7.87	–	39.7	–	–	15.46	16.5	–	–	0.64	0.46	7.98	0.17	–	1.1	1.37	8.75
	4	–	–	26.68	–	0.51	10.11	14.69	0.96	0.85	–	0.91	16.74	–	–	2.51	–	26.04
	5	–	–	54.63	–	–	20.17	21.66	–	0.42	1.03	–	2.09	–	–	–	–	–
8	1	11.62	–	7.02	–	–	–	–	–	–	–	–	–	–	–	71.33	10.03	–
	2	4.55	–	1.3	–	–	–	–	–	–	–	–	–	–	–	85.32	8.83	–
	3	5.25	3.25	0.49	–	–	–	–	–	–	–	–	–	–	–	83.79	7.22	–
	4	15.68	–	6.63	–	–	–	–	–	–	–	–	–	–	–	77.69	–	–
	5	13.62	–	–	–	–	–	–	–	–	–	–	–	–	–	77.64	8.74	–
	6	17.28	–	9.96	–	–	–	–	–	–	–	–	1.51	–	2.36	56.34	12.55	–
	7	11.35	–	0.95	–	–	–	–	–	–	–	–	–	–	–	79.9	7.8	–
10	1	4.32	3.38	4.66	–	–	–	–	–	–	–	–	–	–	–	87.64	–	–
	2	4.72	3.29	8.1	–	–	–	–	–	–	–	–	–	–	–	83.89	–	–
	3	5.28		47.3	–		14.79	17.23			6.34		7.11	–	–	–	–	1.95
	4	3.66	3.13	10.2	–	–	–	–	–	–	–	–	–	–	–	77.97	5.04	–
	5	4.83		11.8	–	–	–	–	–	–	–	–	–	–	–	80.04	–	3.33
11	1	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	–	–
	2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	–	–
	3	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	–	–
	4	–	–	18.05	8.67	–	–	–	–	–	–	–	–	–	–	12.46	–	60.82
	5	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	–	–
	6	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	–	–
	7	–	–	–	–	–	–	–	–	–	–	–	–	–	–	100	–	–

Figure captions

Fig. 1. Schematic map: geographical location (marked on the inset), geological structure of the research object, using (Geological map..., 2001). Legend: *Holocene* : 1 – pebbles, sands, clays, sandy loams; *Neopleistocene* : 2 – loams, clays, sands, pebbles, silts; 3 – clays, sands, pebbles; *Neogene-Quaternary* : 4 – silts, clays, sands, pebbles (Belogorsk Formation); *Neogene* : 5 – sands with gravel, pebbles, kaolinite clays (Sazanka Formation); *Paleogene* : 6 – clays, silts with interlayers of brown coal, pebbles and tuffs (Kivda Formation); *Cretaceous system* : *Carboniferous system* : 7 – sandstones, siltstones, phyllites, volcanics, limestones, tuff conglomerates (Gramatukha Formation); *Devonian system* : 8 – sandstones, siltstones, clay shales, tuff siltstones, tuffites (Orlovka strata); 9 – siltstones, limestones, clay shales, sandstones, conglomerates, gravelites (Polunochka strata); *Silurian system* : 10 – sandstones, tuff sandstones, siltstones, tuff siltstones, tuffites, gravelites, breccias, crushed rocks (Mamyn Formation); *Ordovician system* : 11 – rhyodacites, dacites, rhyolites, andesites, their tuffs, lava breccias of dacites and rhyolites (October strata); *Cambrian system* : 12 – siltstones, limestones, marls, dolomites (Kosmatka strata); *Riphean (?)* : 13 – marbleized limestones, metagravelites, metaconglomerates (undifferentiated strata); 14 – calcareous metasandstones, sericite-quartz and actinolite-chlorite schists, lenses of marbleized limestones (Dagmar strata); 15 – biotite-quartz schists, quartz-sericite schists with interlayers of schistose, calcareous metasandstones (Nekla strata). Intrusive formations *:* *Cretaceous* : 16 – granites, granite-porphyries, granodiorites, quartz monzonites, diorites (Burinda complex); 17 – andesites, diorite-porphyrites, dacites (Taldan complex); *Late Permian or Early Triassic* : 18 – syenites, granosyenites, quartz monzonites (Khara complex); 19 – rhyolites (Manegr complex); *Paleozoic* : 20 – granites, leucogranites, granodiorites, quartz diorites (Tyrmo-Bureya complex); 21 – a) leucogranites, granites, granodiorites; b) granosyenites, quartz diorites; c) trachyrhyolites, trachyrhyodacites, rhyodacites (October complex); *Proterozoic* : 22 – granites, subalkaline granites, granodiorites; 23 – quartz and gneissoid diorites, granites, plagiogranites and granodiorites (Gara complex); 24 – metagabbro, gabbro, gabbro-diabases; 25 – modern gold placers; 26 – location of the research object; 27 – sampling points.

Fig. 2 . Grain of native gold from the WZ of LGD (a, b), with high-fineness authigenic thin-lamellar aggregates (c). Photos (a) and (c) in SE; (b) in BSE.

Fig. 3. Chemically pure (1000 ‰) authigenic thin-lamellar formations (spectra 1-5), on the surface of native gold from the WZ of LGD, with caverns filled with high-carbon alumosilicate-ferruginous formations (spectra 6-7). Captured in BSE.

Fig. 4. Grain of native gold (a, b), consisting (c, d) of authigenic thin-lamellar formations (Au_{pl}), on the surface of which spheroidal gold segregations (Au_{sp}) are found. Photos (a, b) in SE; (c, d) in BSE.

Fig. 5 . Native gold (a) with inclusions of clay material aggregates containing fine and ultrafine gold particles (b-d). Points of EDA analysis are shown. EDA spectrum with the composition of one of the chemically pure Au particles is provided (d, e, Spectrum 7) (*here the electron beam partially captures the mineral matrix*). Photo in BSE.

Fig. 6 . Lead-mercury newly formed gold: a - low-fineness films with high lead content; b - spongy authigenic gold with low lead content. Composition is shown in Table 5. Photo in BSE.

Fig. 7. Globular authigenic gold (composition shown in Table 5). Photo in BSE.

Fig. 8. Spongy mercuric gold consisting of individual rod-like and lamellar individuals covering the surface of native gold: a - general view; b-e - different areas at different magnifications. Composition is shown in Table 5. Photos a-d in BSE, e - in SE.

Fig. 9. Authigenic gold on the surface of one of the samples (a, b); sample areas at different magnifications (c-g); f - newly formed high-fineness (1000 ‰) gold (spectrum 1), g - filamentous mercuric gold (spectrum 2). Below are the corresponding EDA spectra. Photos a - in SE, b-g in BSE

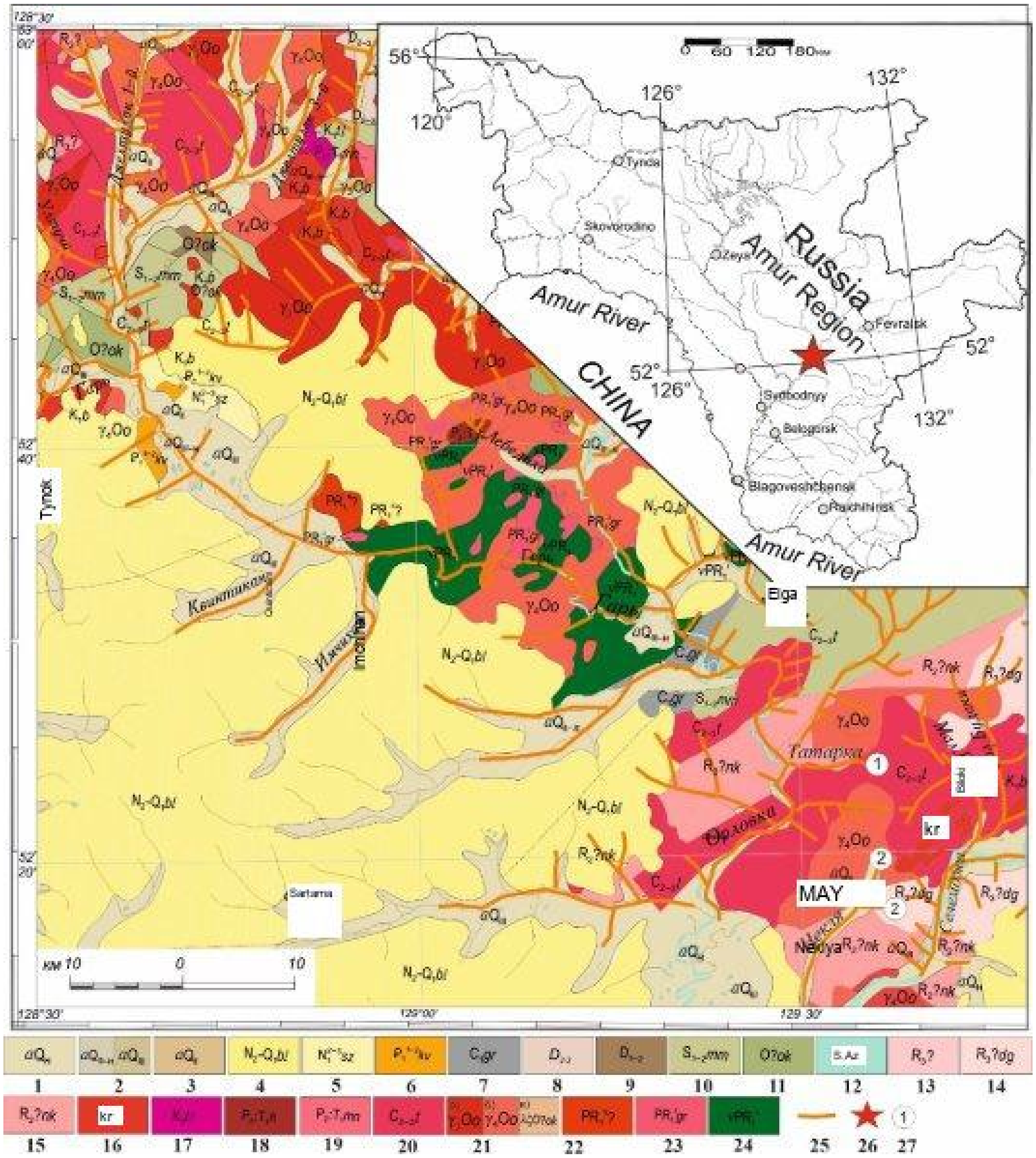
Fig. 10 . Newly formed high-fineness spongy native gold: a - general view of the sample: b, c - areas at different magnifications. Composition is shown in Table 5. Photo in BSE.

Fig. 11 . Newly formed high-fineness spongy, thin-lamellar and globular native gold (sp. 1–3, 5–7), with authigenic anglesite deposited on the surface (sp. 4). The composition is shown in Table 5. Photo in BSE.

Fig. 12. Truncated ternary diagram of Au-Ag-Cu compositions of native gold from weathering crust. EDA of different samples are plotted in descending order of gold fineness.

Fig. 13. Diagram of compositions of fine and ultrafine native gold from technogenic placers of NZU (Fig. 5, Table 4) of the Au-Hg-Pb* system (where Pb* = Pb+Sn). Approximate formulas of intermetallic compound compositions are provided.

Fig. 14. Diagram of compositions of authigenic gold from technogenic placers of the Au-Hg-Pb* system (where Pb* = Pb+Sn) (Fig. 6–11, Table 5). Approximate formulas of intermetallic compound compositions are provided.



Russia
Amur Region
CHINA
Amur River
Amur River
Tynda
Skovorodino
Zeya
Fevralsk
Svobodnyy
Belogorsk
Blagoveshchensk
Raichikhinsk
56°
52°
52°
120°
126°
126°
132°
132°
Elga
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kr
км 10 0 10
1 2 3 4 5 6 7 8 9 10 11 12 13 14
15 16 17 18 19 20 21 22 23 24 25 26 27

Fig. 1

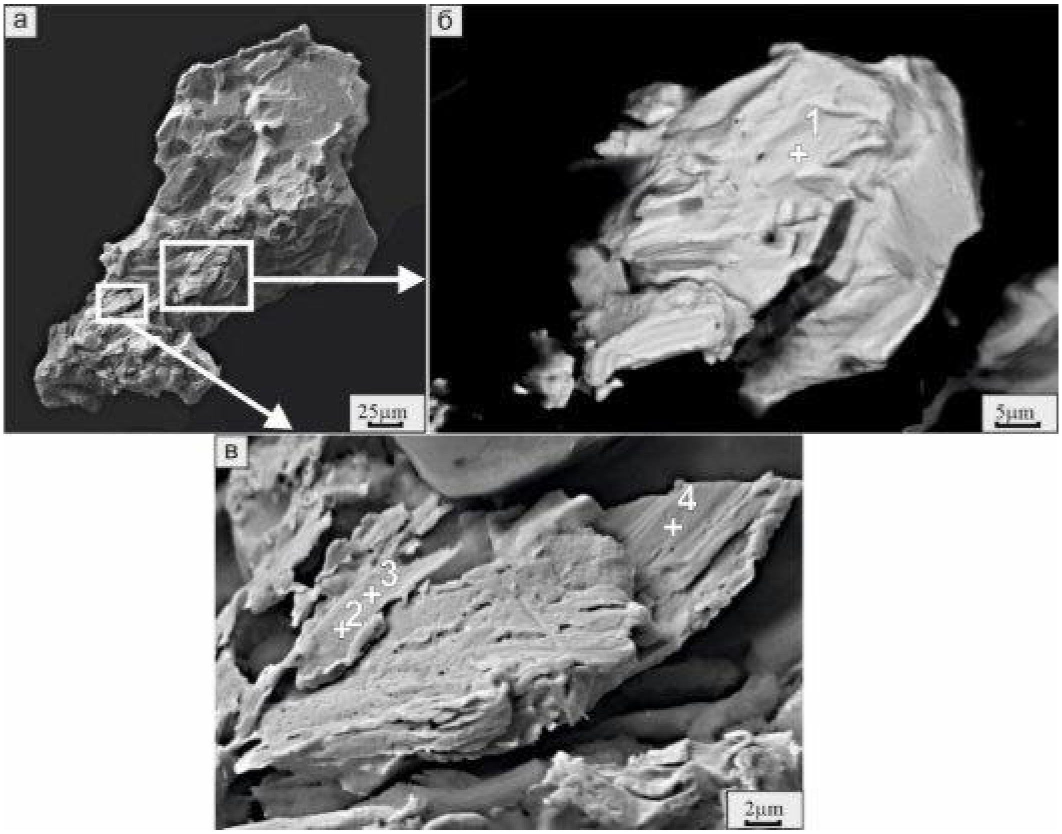

Fig. 2

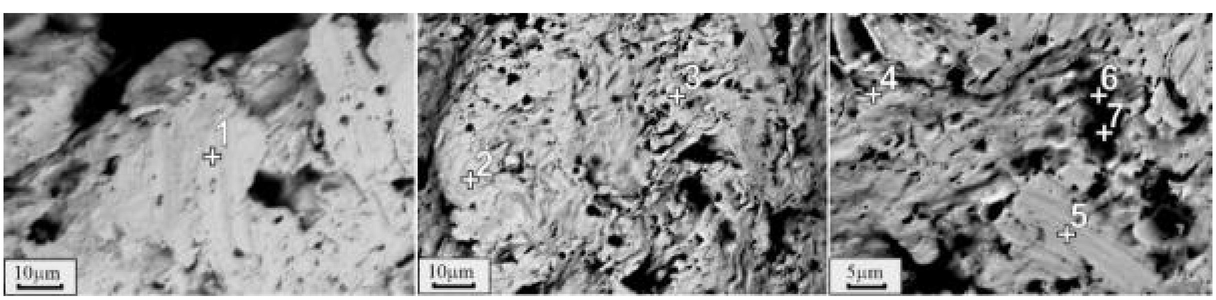

Fig. 3

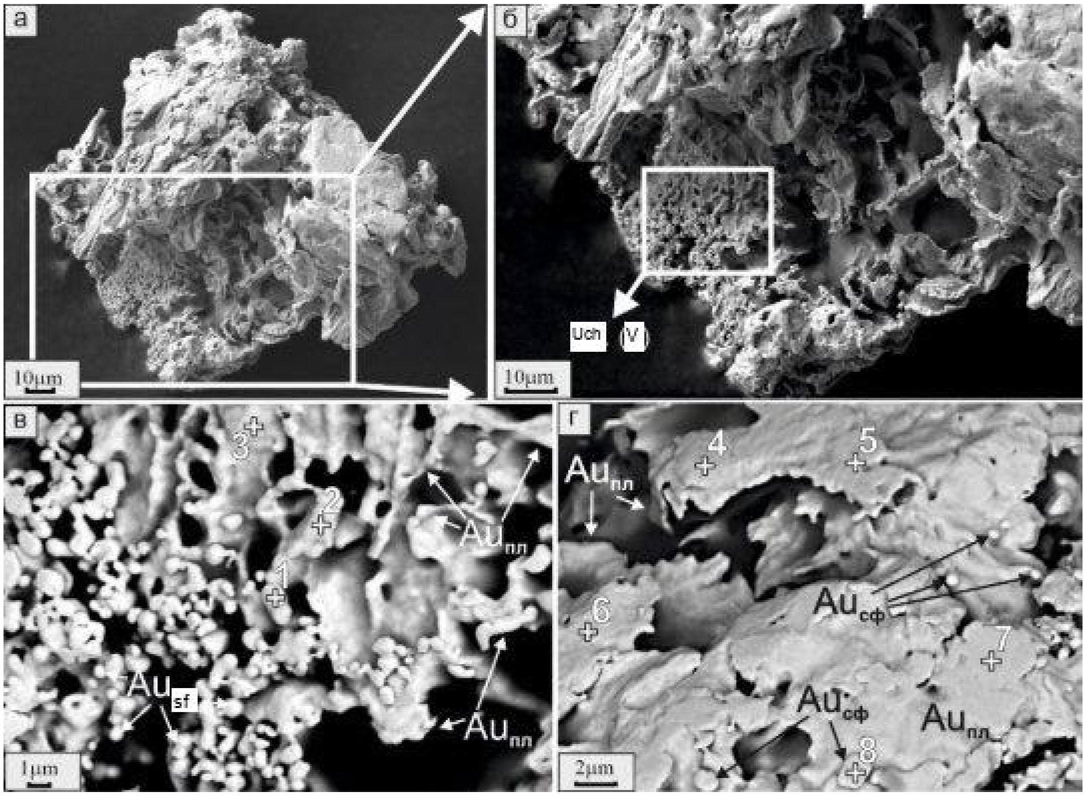
а
10μm
б
Uch
(V)
10μm
в
3
2
1
Auпл
Ausf
Auпл
1μm
г
4
5
Auпл
Auсф
6
7
Auсф
8
Auпл
2μm

Fig. 4

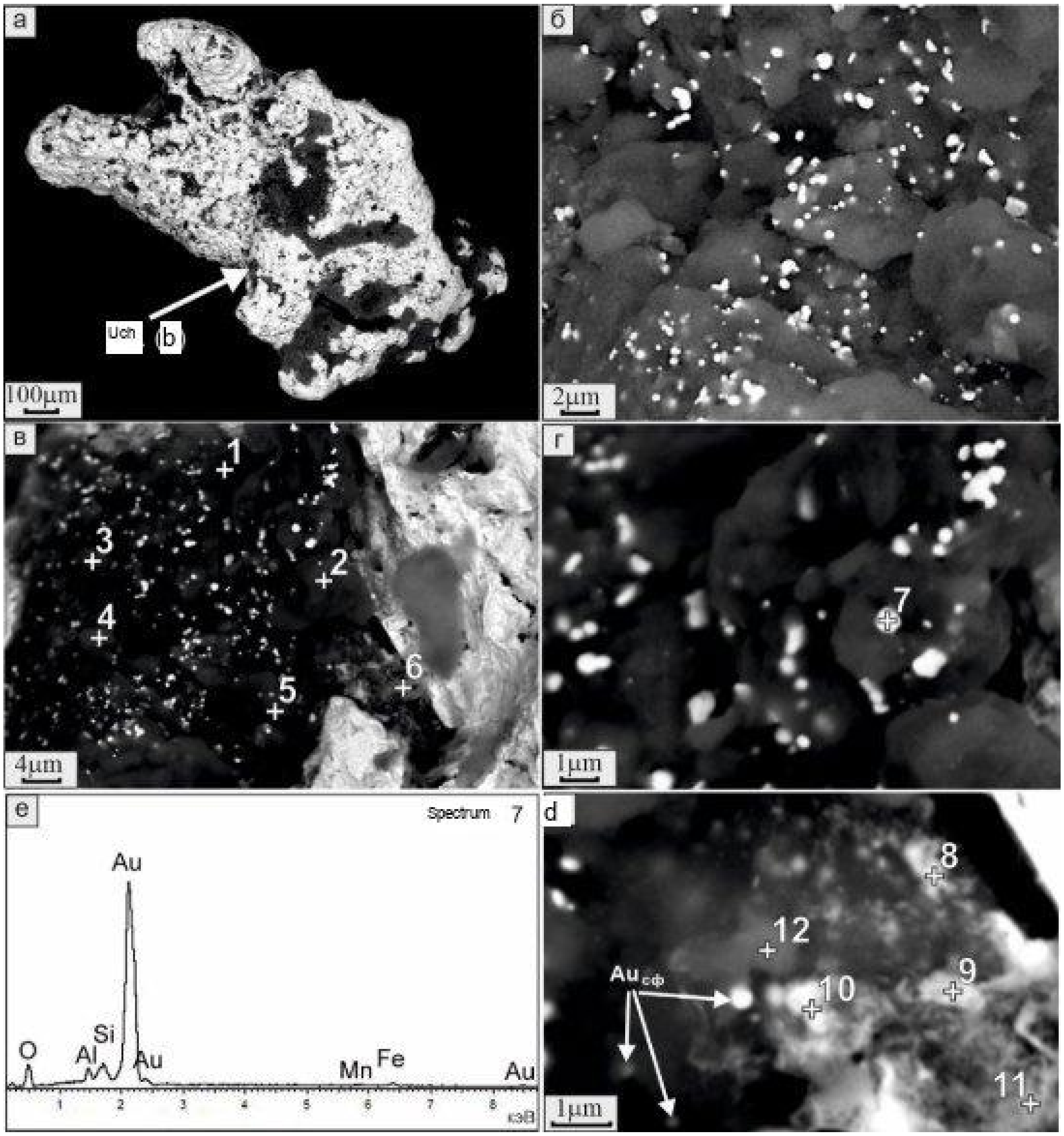
а
Uch. (b)
100µm
б
2µm
в
1
3
2
4
6
5
4µm
г
7
1µm
e
Spectrum 7
Au
O
Al
Si
Au
Mn
Fe
Au
кэВ
d
8
12
Au сф
10
9
11
1µm

Fig. 5

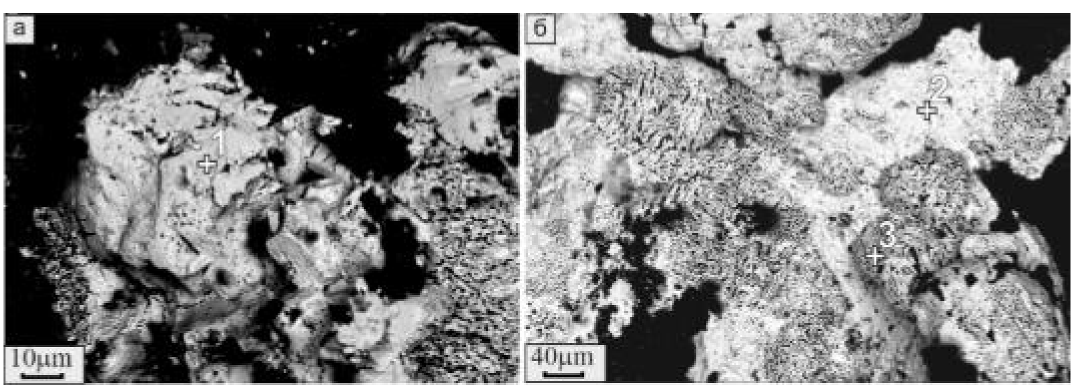
а
1
10µm
б
2
3
40µm

Fig. 6

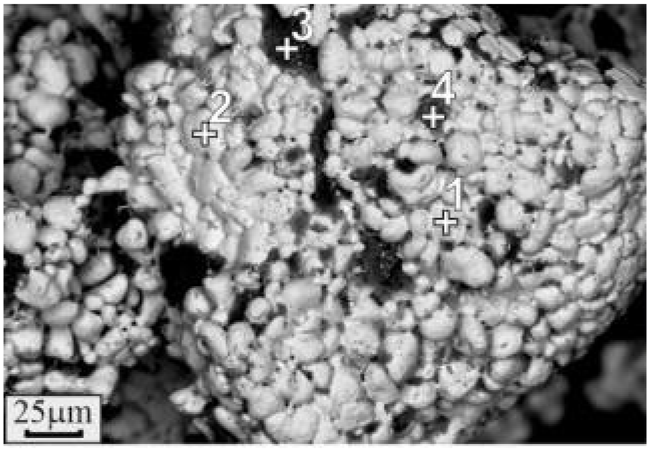

Fig. 7

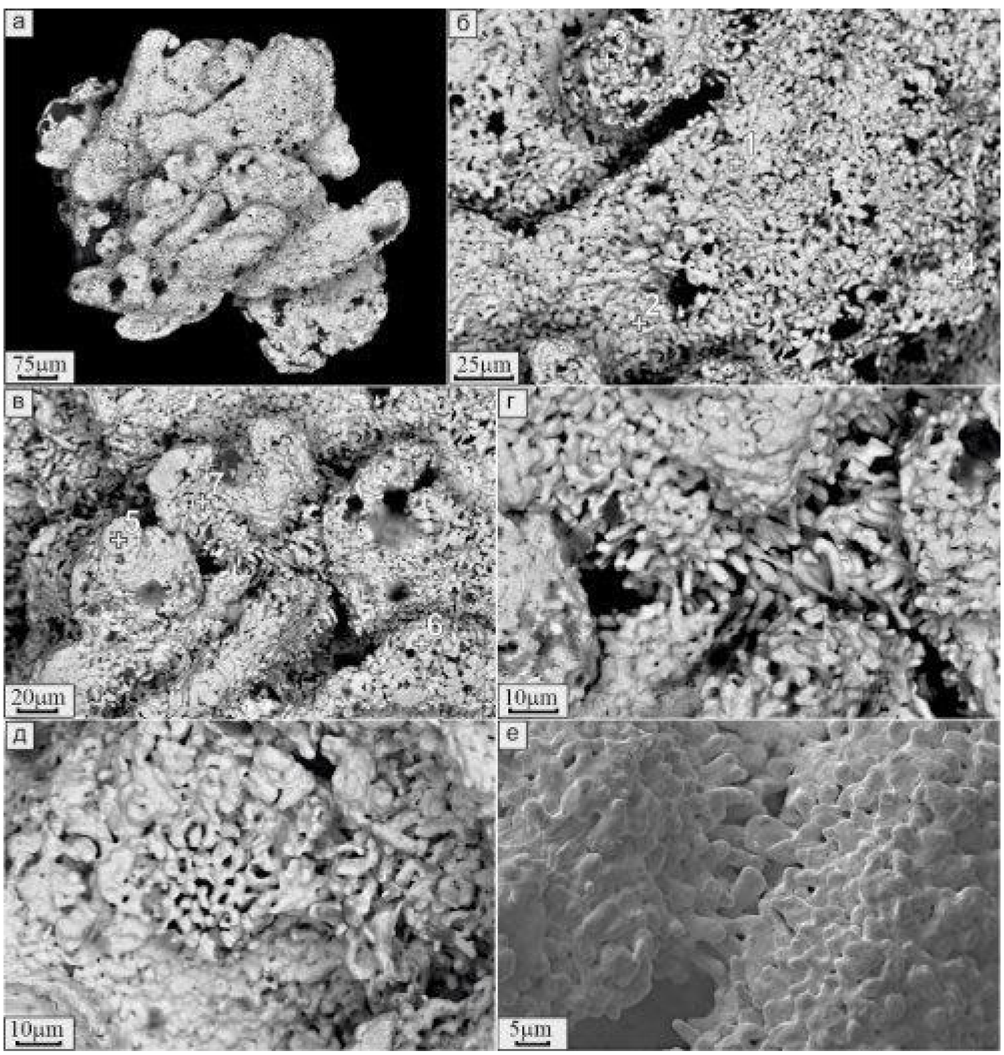

Fig. 8

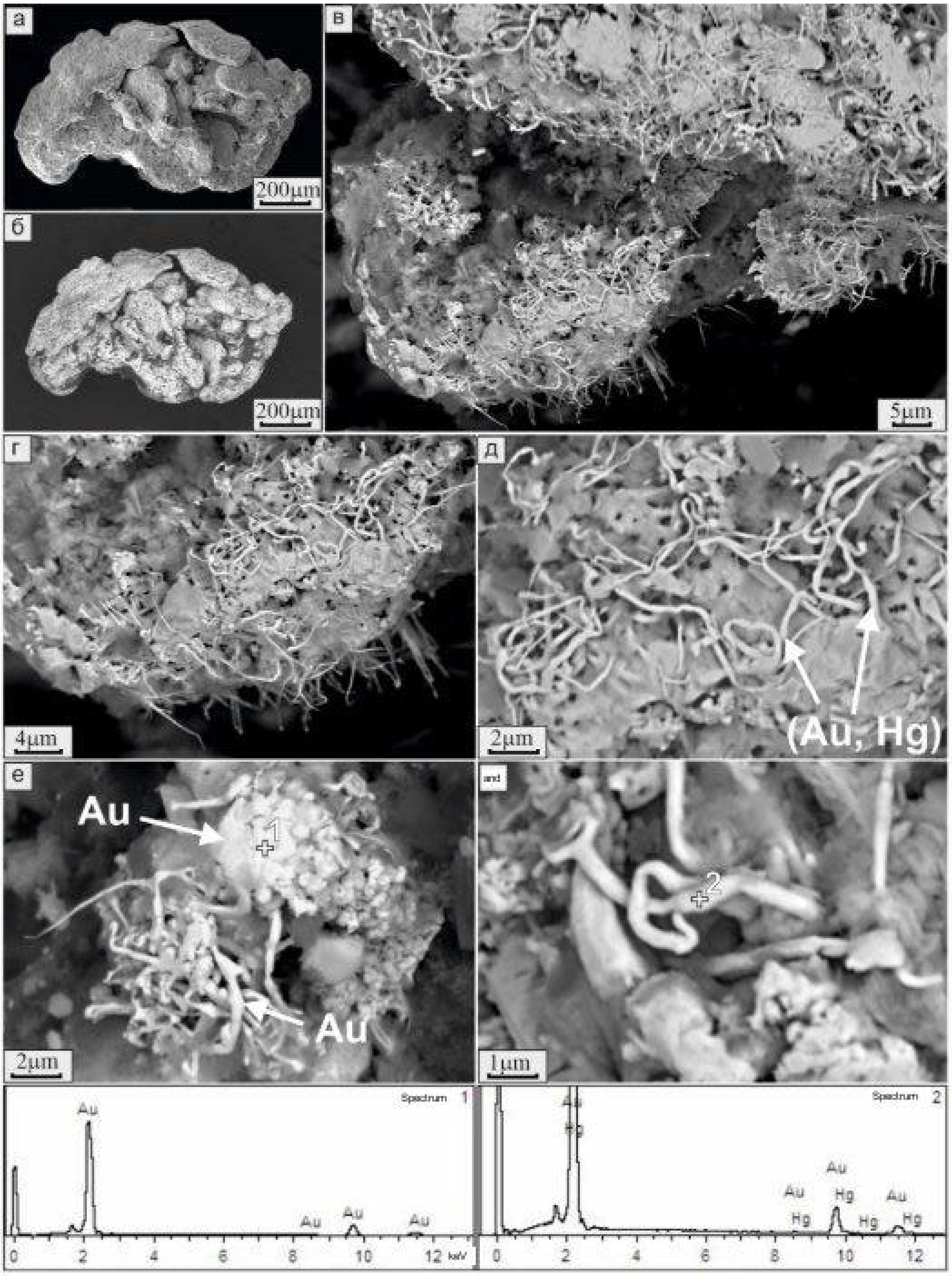
а
200µm
б
200µm
в
5µm
г
4µm
д
2µm
(Au, Hg)
е
Au
1
Au
2µm
2
1µm
Spectrum 1
Au
Au
Au
Au
0
2
4
6
8
10
12 keV
Spectrum 2
Au
Hg
Au
Hg
Au
Hg
Hg
Au
Hg
0
2
4
6
8
10
12

Fig. 9

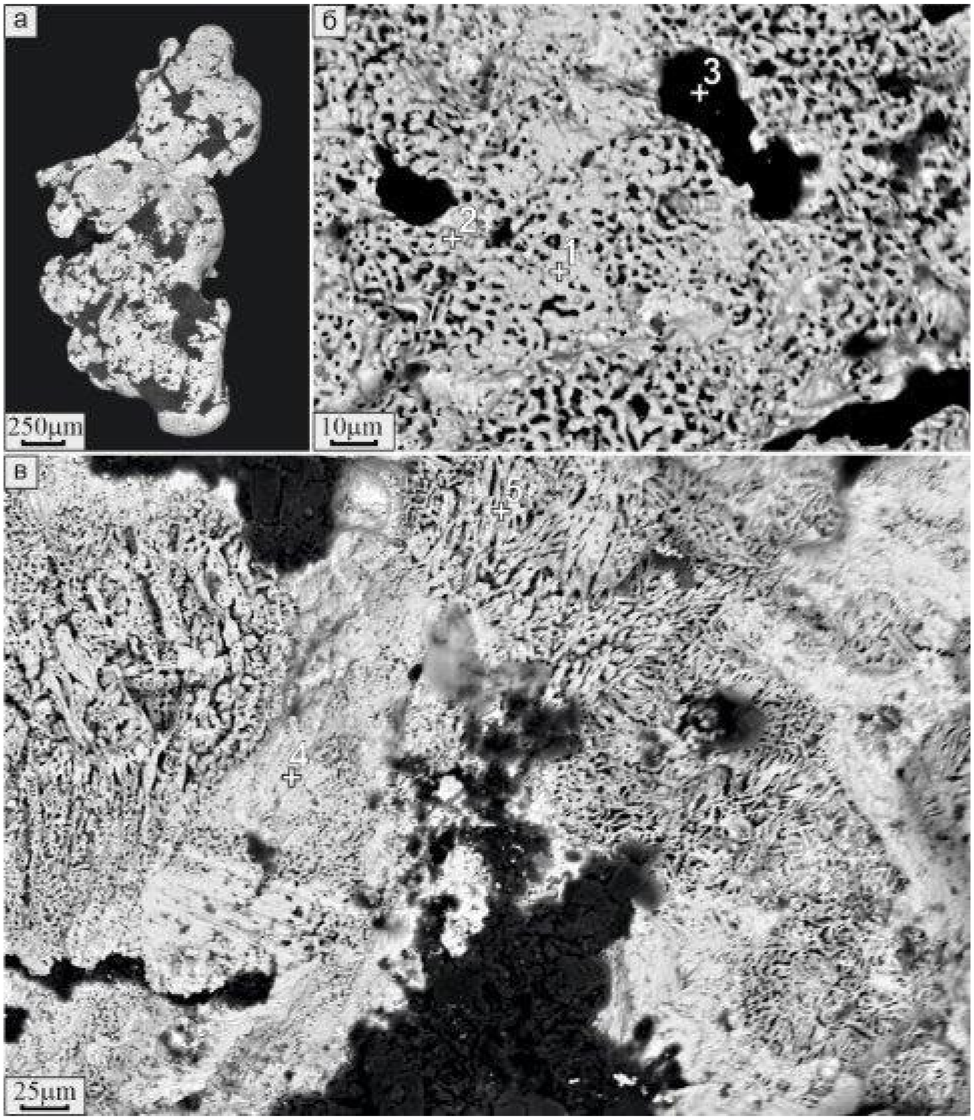

Fig. 10

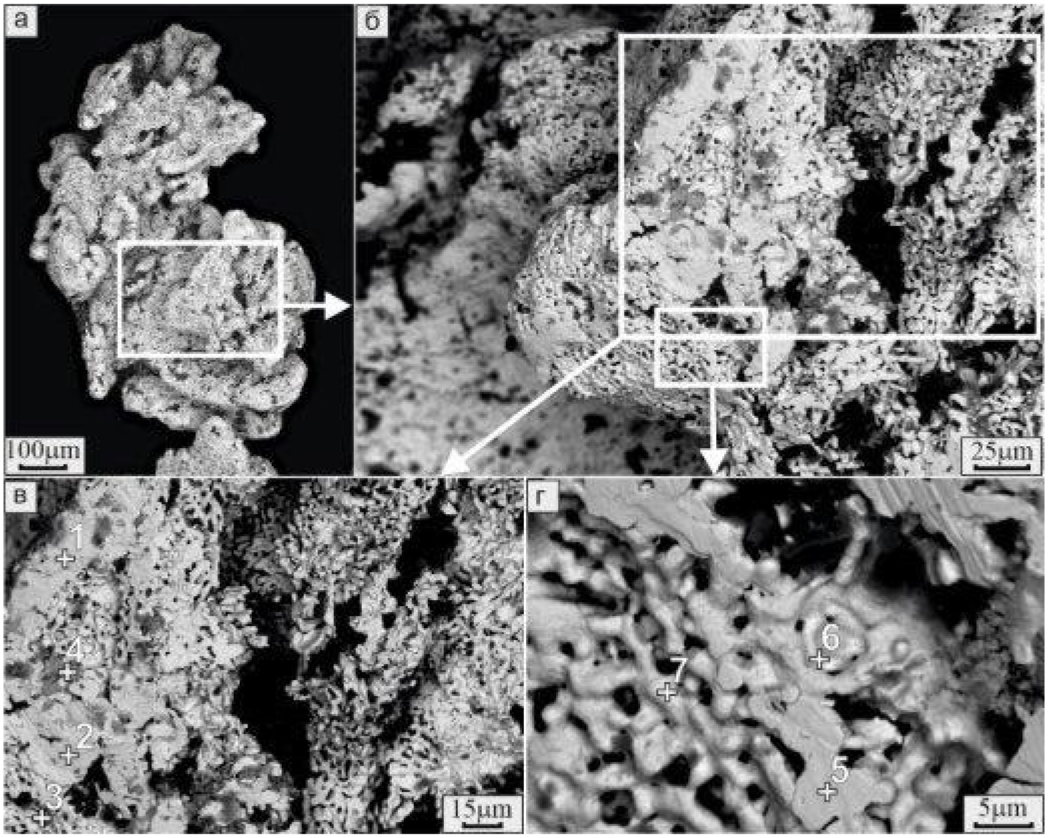

Fig. 11

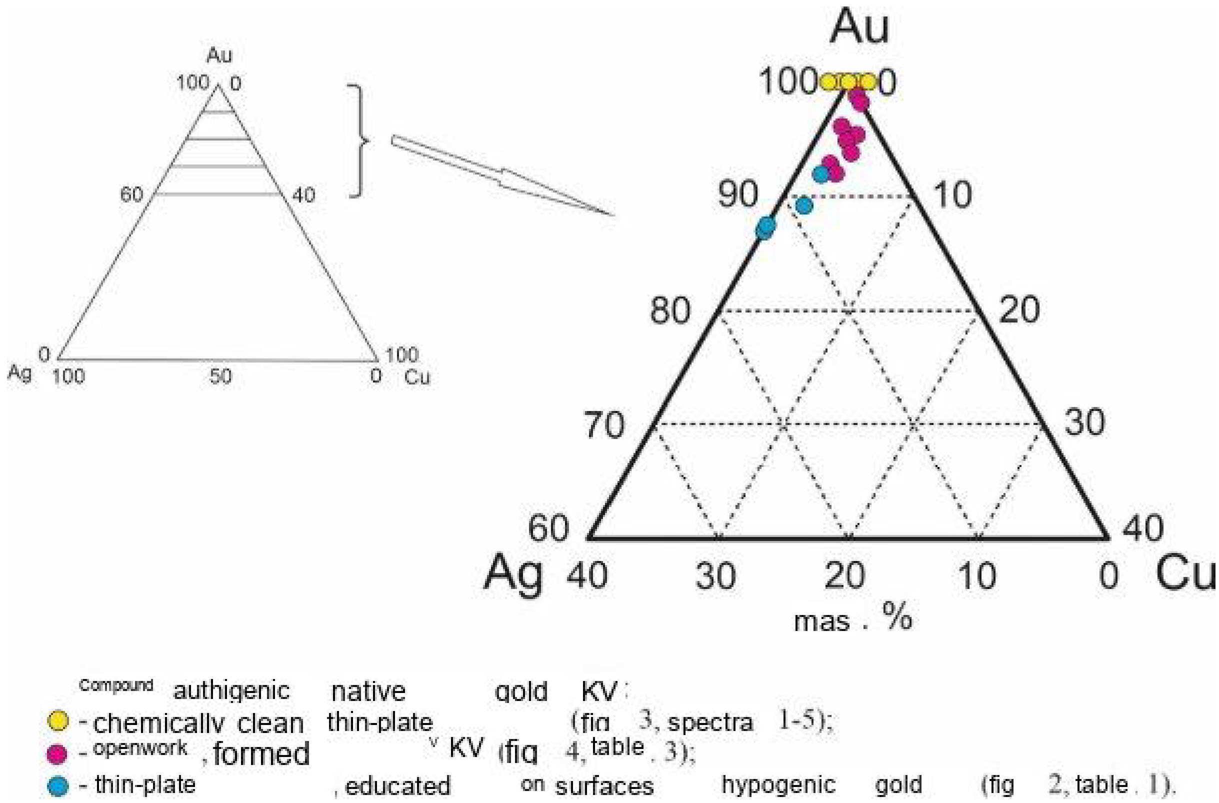
Au
100
0
60
40
0
100
Ag
100
50
0
Cu
Au
100
0
90
10
80
20
70
30
60
40
Ag
40
30
20
10
0
Cu
mas . %
Compound authigenic native gold KV:
- chemically clean thin-plate (fig 3, spectra 1-5);
- openwork, formed v KV (fig 4, table 3);
- thin-plate, educated on surfaces hypogenic gold (fig 2, table 1).

Fig. 12

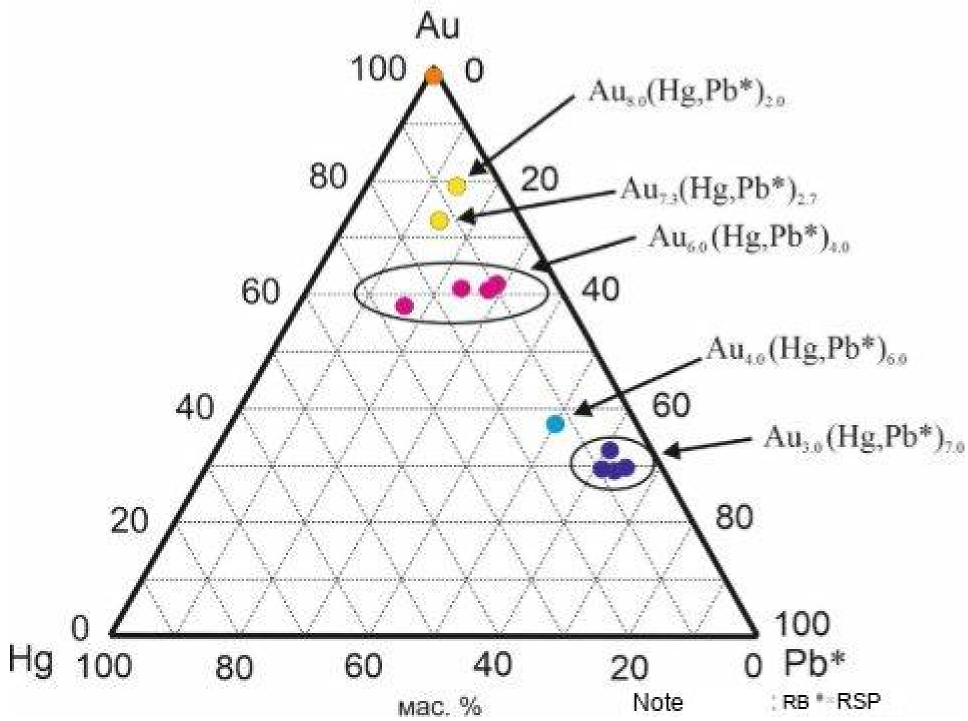
Au
Hg
Pb*
100
0
80
20
60
40
40
60
20
80
0
100
100
80
60
40
20
0
$Au_{8.0}(Hg,Pb^*)_{2.0}$
$Au_{7.3}(Hg,Pb^*)_{2.7}$
$Au_{6.0}(Hg,Pb^*)_{4.0}$
$Au_{4.0}(Hg,Pb^*)_{6.0}$
$Au_{3.0}(Hg,Pb^*)_{7.0}$
мас. %
Note
: RB *=RSP

Fig. 13

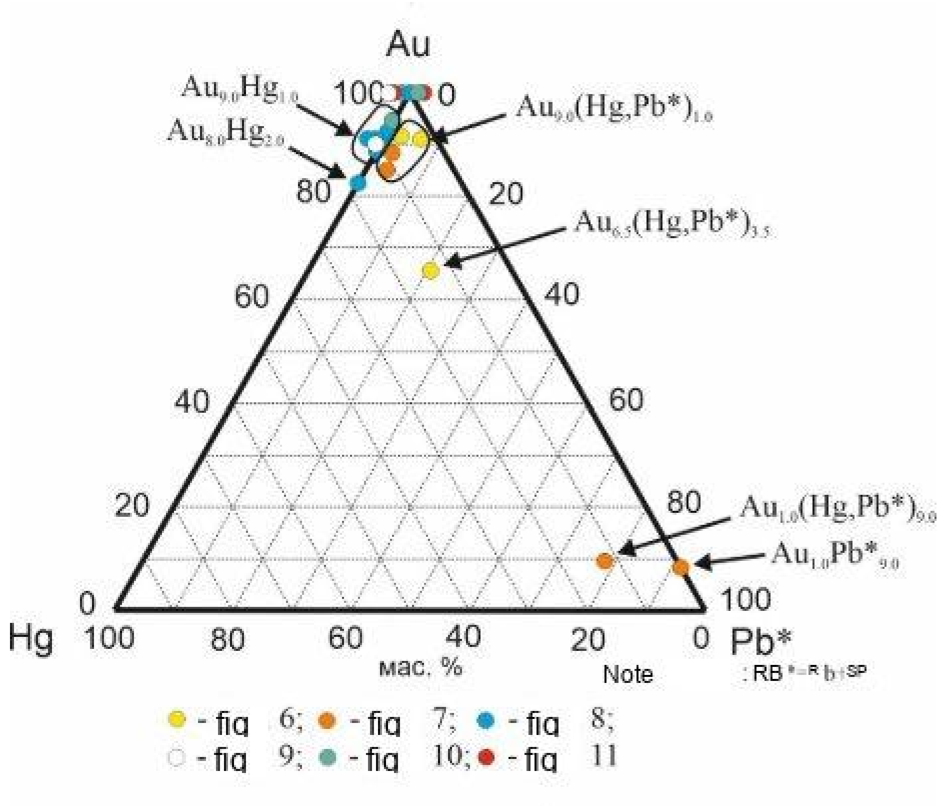
Au
Hg
Pb*
$Au_{9.0}Hg_{1.0}$
$Au_{8.0}Hg_{2.0}$
$Au_{9.0}(Hg,Pb^*)_{1.0}$
$Au_{6.5}(Hg,Pb^*)_{3.5}$
$Au_{1.0}(Hg,Pb^*)_{9.0}$
$Au_{1.0}Pb^*_{9.0}$
мас. %
Note
- fig 6; - fig 7; - fig 8;
- fig 9; - fig 10; - fig 11

Fig. 14