addressing the deficiency in replenishing the world's uranium mineral resource base.

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GENETIC PRIMARY SOURCE–PLACER CONNECTION AS A CASE-STUDY OF THE GORNY PRIISK GOLD DEPOSIT, AVZYAN ORE PLACER FIELD, SOUTHERN URALS

The study of the Avzyan ore placer field shows that native gold of the Gorny Priisk deposit is predominantly small (up to 0...n mm) and has a high fineness (955–980). The main impurity is silver 3–5 wt.%, and insignificant amounts of Bi, As, Sb, Se, Te and Ni are observed. Morphologically, gold represents spongy and dendritic forms. Microparticles of very high-fineness secondary gold 0.1–0.5 µm in size are observed on the surface of grains.

Gold of the Kamenny Klyuch placer is larger and has a lumpy and irregular shape. This is a high-fineness gold (926–979) with a similar set of impurity elements. The morphology of gold grains from the Kamenny Klyuch creek deposits clearly indicates their short distance from the primary source.

The alluvial gold of the Avzyan placer has the largest sizes and belongs to the medium and large size categories with good roundness. The fineness of gold is 939–971. It is characterized by hypergene neoplasms on the grain surface in the form of a high-fineness rim. Grains covered with amalgam with mercury content up to 20 wt.% are revealed, which indicates the induced contamination of the area of mining.

A genesis and geology model of the bedrock–weathering crust–alluvial placer systems was built. It is shown that the valley of the Bolshoy Avzyan river is a valley of inherited development. The presence of gold of varying roundness (from poorly rounded to well-rounded grains with a high-fineness shell) is reflective of gold flow to the placer from the weathering crust (Gorny Priisk) through intermediate reservoir rocks (Kamenny Klyuch).

Keywords: *Southern Urals, Avzyan ore placer field, Gorny Priisk, native gold, placer, Zigaza–Komarovo formation, Riphean, weathering crusts, black shales*
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Introduction

According to mineragenic zoning, the largest ore cluster on the western shoulder of the Southern Urals is the Avzyan placer field. Its center holds placers in the valleys of the Bolshoy Avzyan river and the right hand feeder of the Belaya river. Northward, there are placers of Avzyan, Kamenny Klyuch, Shatak Bort, Ryzhova Polyana, Bogryashka, Bolshoi Klyuch, Nadezhda and Kurgashlya. From incomplete archival data, the Avzyan group of placers produced 1897 kg of gold between the late 19th century and 1949. On the right-hand side of the Big Avzyan river valley, there are primary gold deposits and gold ore mineralizations of Gorny Priisk and Ulyuk-Bar, Kalashnikov vein, Bogryashka, Rameev vein and Kurgashlya. All these placers form the Avzyan ore placer field. Formation of the field is associated with the intersection of the Karatash overthrust (multi-stage Riphean–Wendian process, with early Paleozoic activation of tectonic magmatism and with gold ore specialization) with the diagonal neotectonically active Big Kizil lineament zone of the Riphean origination [1, 2]. The most significant sites of the Avzyan ore placer field are the Avzyan and Kamenny Klyuch gold placers intersecting the northern and partly eastern wings of the Gorny Priisk gold deposit (**Fig. 1**). The present authors have acquired new information on the gold content of these sites, and tried to harmonize the whole present knowledge within a unified genesis and geology model.

Methods

In the course of investigation of carbonaceous shale and clayey crust of weathering at the Gorny Priisk deposit and adjacent placers, the authors took samples up to 30 l in volume. The samples were washed on site, in pans. All in all, 23 samples were taken, and a few hundreds of small gold grains were washed out.

Photographing of surface of the grains and the microprobe analysis of polished specimens was carried out on scanning electron microscope Tescan Vega 3 with energy dispersive spectrometer Oxford Instruments X-act at the Shared Use Center at the Southern Ural Federal Research Center for Mineralogy and Geoecology UB RAS (analyst M. A. Rassomakhin, carbonaceous coating, accelerating voltage 20 kV, action time 120 s, reference MAC—Micro-Analysis Consultants LTD, reg.no. 1362).

Gold fineness was calculated from the formula CAu/(CAu+CAg)×1000, and gold typification used the classification proposed by N. V. Petrovskaya (‰): 1000–950—very high purity; 950–900—high purity; 900–800—medium purity; 800–700—low purity; 700–300—electrum; 300–100—kustelite; < 100—silvery gold (Au-bearing silver) [4].

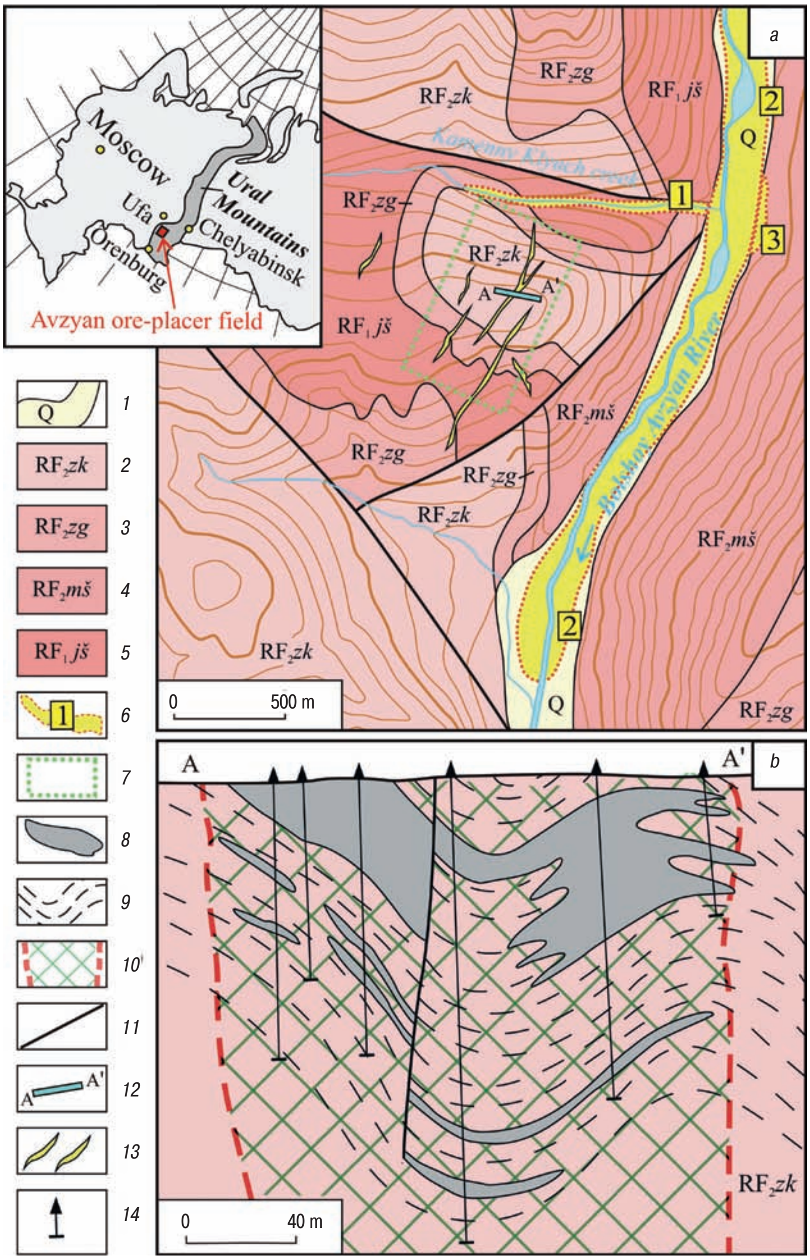

Fig. 1. Geological map (*a*) and sectional view (*b*) of the Gorny Priisk deposit (according to the data of Abzelilovo geological exploration party and [3])

Legend: *1* – Quaternary deposits; *2* – Zigaza–Komarovo suite (carbonaceous–argillaceous shale, sandstone); *3* – Zigalga suite (sandstone, quartzite-bearing sandstone, basalt lavas); *5* – Yusha suite (clayey siltstone, sandstone); *6* – outlines and numbers of placers (*1* – Kamenny Klyuch; *2* – Avzyan; *3* – Shatak Bort); *7* – outline of Gorny Priisk deposit; *8* – gold-bearing sand and shale; 9 – carbonaceous–argillaceous shale; *10* – oxidation and tectonic alteration zone; *11* – faulting; *12* – position of section A–A′ *13* – gold-bearing quartz veins; *14* – exploration holes

Gorny Priisk deposit

The deposit is located 6 km northwestward of the Verhnij Avzyan settlement and adjoins a tectonic block bounded on the east and west by the Karatash and Bolshoy Avzyan faults directed nearly in parallel to a meridian (see Fig. 1). The deposit is localized in the Zigaza–Komarovo terrigenous–carbonaceous suite (RF_2zk). Ore bodies are of three types: beds, veins and strings. The bedded bodies represent inclusion of sulfides in the zones of schistosity of carbonaceous shales and sandstone. The Au–carbonate–quartz strings occur in the zones of schistosity and fracturing. The quartz ore veins contain inclusions of pyrite and chalcopyrite. Gold content is usually not higher than 2–4 g/t but jumps (to a few tens grams per ton) in interbeds enriched with quartz and sulfides. At the deposit, there is a weathering crust of great linear and areal spread in the zone of crush and mineralization. According to the production research performed by the Unipromed Institute, the mineral composition of the clayey weathering crust contains quartz 58–60%, hydromica 20–70%, kaolinite and vermiculite 4–6%, pyrite 0.5% and iron hydroxides 0.1–0.5% [5]. Based on the integrated production test results, a mixed-type processing technology was developed, and the standard quality gold concentrate was obtained with the gold content of 56 g/t at the recovery of 63–65% [6]. In 2001 the sample of the gold-bearing weathering crust of the Gorny Priisk deposit was tested using

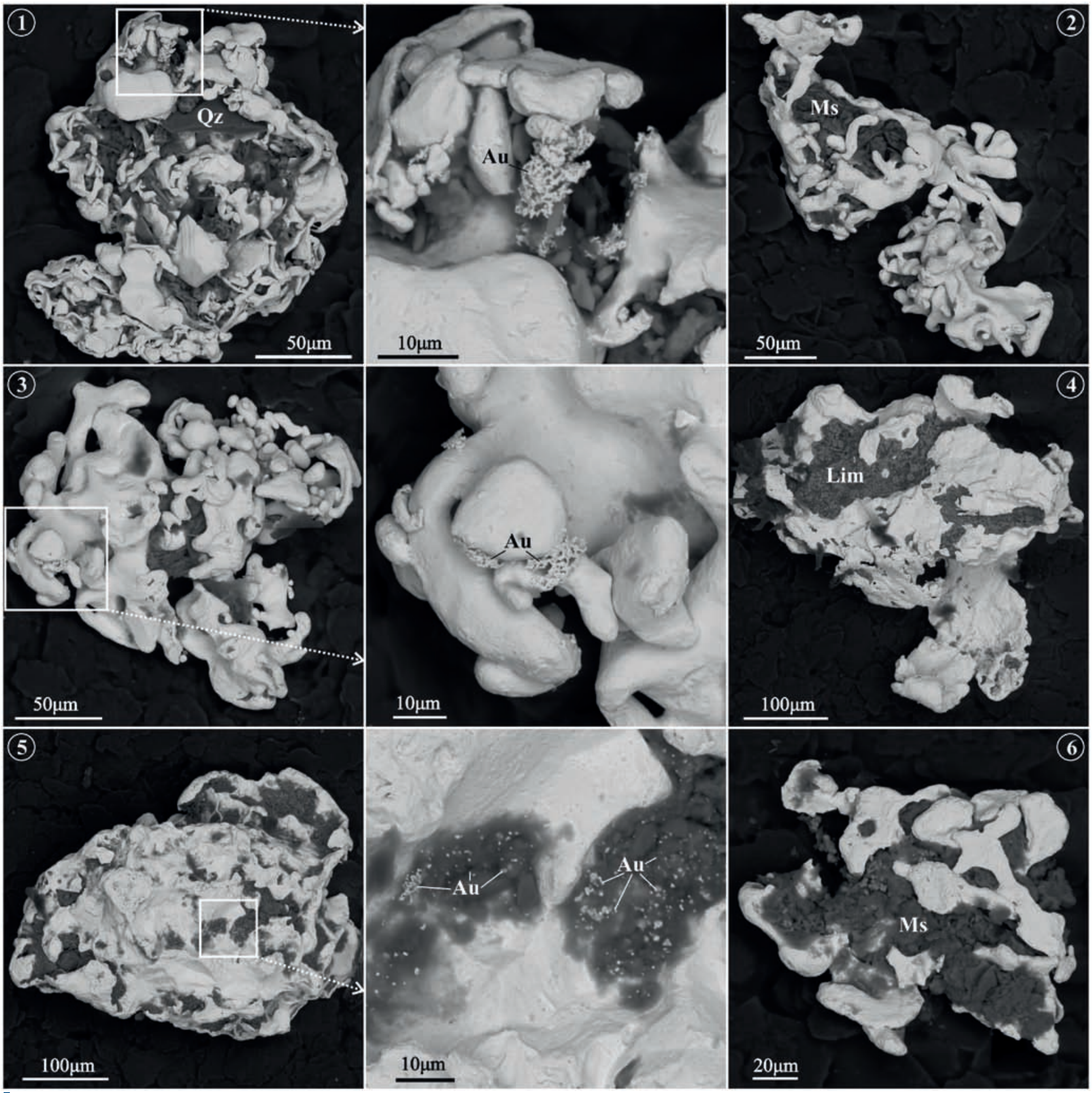

Fig. 2. Electron microscope images of native gold from weathering crust at the Gorny Priisk deposit:
Legend [8]: Au – Gold, Ms – Muscovite, Qz – Quartz, Lim – Limonite, Kfs – Feldspars, Au(Hg) – Gold Amalgam

the hypochlorite leaching technology, and the material was assumed to be suitable to treatment by that method [7].

Native gold of the Gorny Priisk deposit is mostly small, to 0…n mm in size, and has a high fineness (955–980). Morphologically, it represents spongy and dendritic forms, which is beneficial for gold dissolution in leaching (**Fig. 2**). The major impurity is silver with the content of 3–5 wt.% and seldom to 13 wt.%. There are insignificant amounts of Bi (to 1.2 wt.%), As (0.7 wt.%), Sb, Se, Te and Ni (0.2–0.3 wt.%). Such 'motley' of contents of elements is probably due to polygenesis of orogeny [7].

In the hollows on the surface of gold grains, there are numerous growths, films and accretions of iron oxides and hydroxides, and muscovite. The analysis of nanorelief of gold grains revealed that the formations contained a great number of microparticles of very high grade gold 0.1–0.5 μm in size and dendrites to 10 μm in size (see Fig. 2). Nanogold is preserved in the hollows and microcracks on gold surface and is reliably protected from the external impacts [9]. Much gold revealed on the surface of grains at the near-source placers and in weathering crust allows using it as an indicator of a gold sulfide or gold sulfide–quartz mineralization, and of progressing process of ore substance re-distribution [10].

The morphostructural features of gold ore are reflective of the fact that the deposit is a mineralized tectonically treated zone resembling a linear stockwork. The geological information about the Gorny Priisk deposit tells about a complex combination of different-type morphostructure mineralizations within the limits of the deposit: gold sulfide, gold–quartz

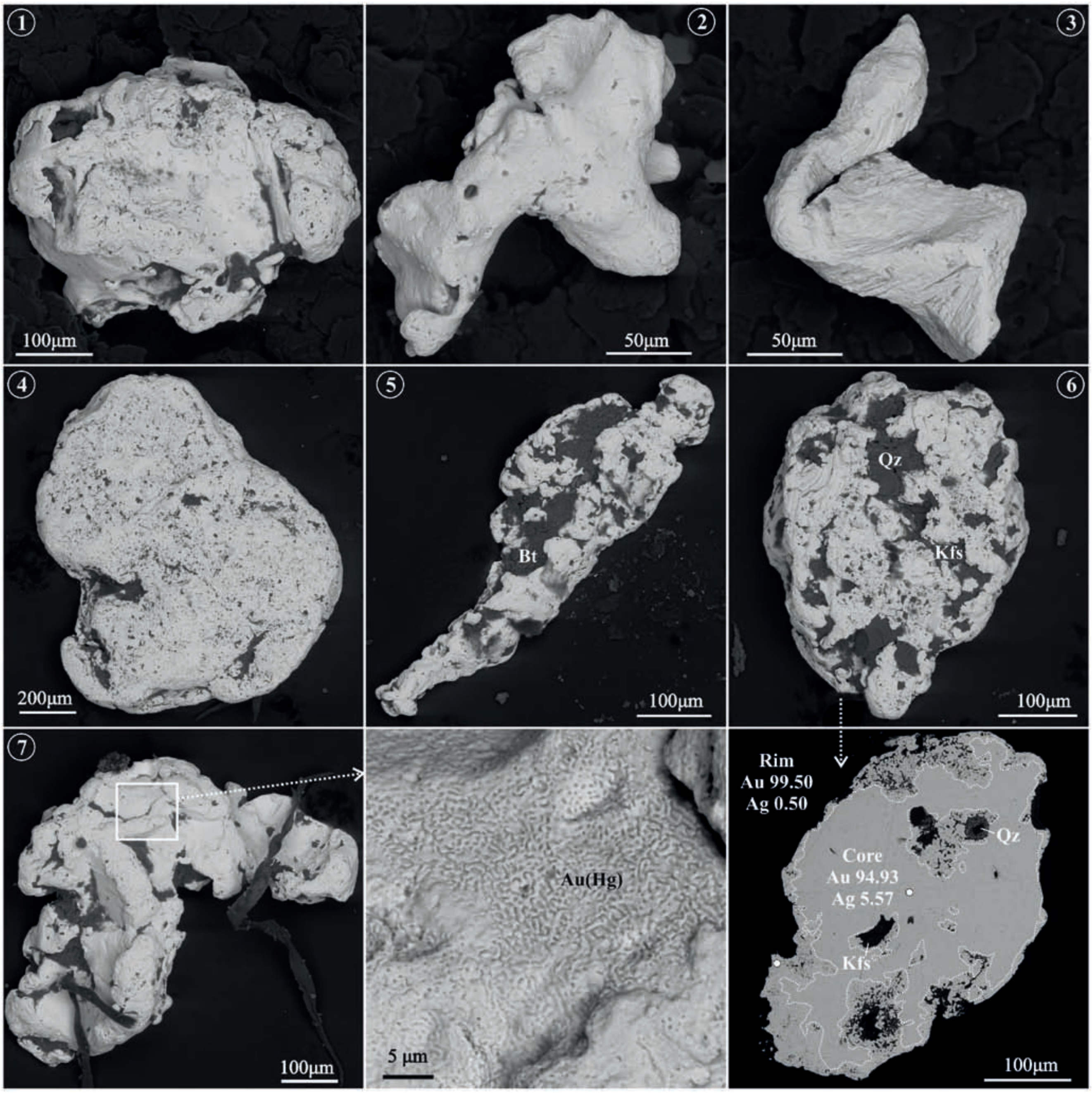

Fig. 3. Electron microscope images of native gold from alluvial beds at the Kamenny Klyuch creek (nos. 1–3) and Bolshoy Avzyan river (nos. 4–7).
Comment: the dashed line shows a high fineness rim, and the points give the results of the analysis of the rim and core in the polished cuts of gold grains

and gold sulfide–quartz, which is a common situation for the gold deposits localized in terrigenous rock mass of the Southern Ural [7, 11–14].

Kamenny Klyuch placer

The Kamenny Klyuch placer lies at the mouth of the valley of the similarly named creek, the right-hand inflow of the Bolshoy Avzyan river, 5 km northward of the Verhnij Avzyan settlement (see Fig. 1). This is a Neopleistocene alluvial placer. It was discovered in 1907 and was developed manually until 1914. Gold production reached 71.8 kg at the average gold content of 1–2.4 g/m^3 per bed. In 1999 the placer was mined by the Avzyan team using separately bulldozer and hydraulic excavation. Gold production totaled 8.7 kg at the average content of 215 mg/m^3 of rock mass. The operations were stopped because of complex geological conditions (narrow valley for waterworks to be constructed). The creek valley cuts the northern wing of the Gorny Priisk gold sulfide–quartz deposit. The placer is 0.6 km long and round 50 m wide. The placer section represents mostly boulder bed with clayey and sand aggregate to 10 m thick. The weathering products contain [15]: (1) a brown color clayey material, heavily rusty, with fragments of strongly sheeted sandstone and carbonic shale with nests of leached pyrite and (2) a white color argillaceous material with remnant disintegrated quartz veinlets and veins. The main minerals in black sand are goethite, ilmenite, rutile, epidote and barite. Monazite and xenotime are also common [16].

Gold is contained in clayey–sandy beds with pebble, to 1 m thick. The clay contains 10% of gold grains of a size suitable for separation by gravity

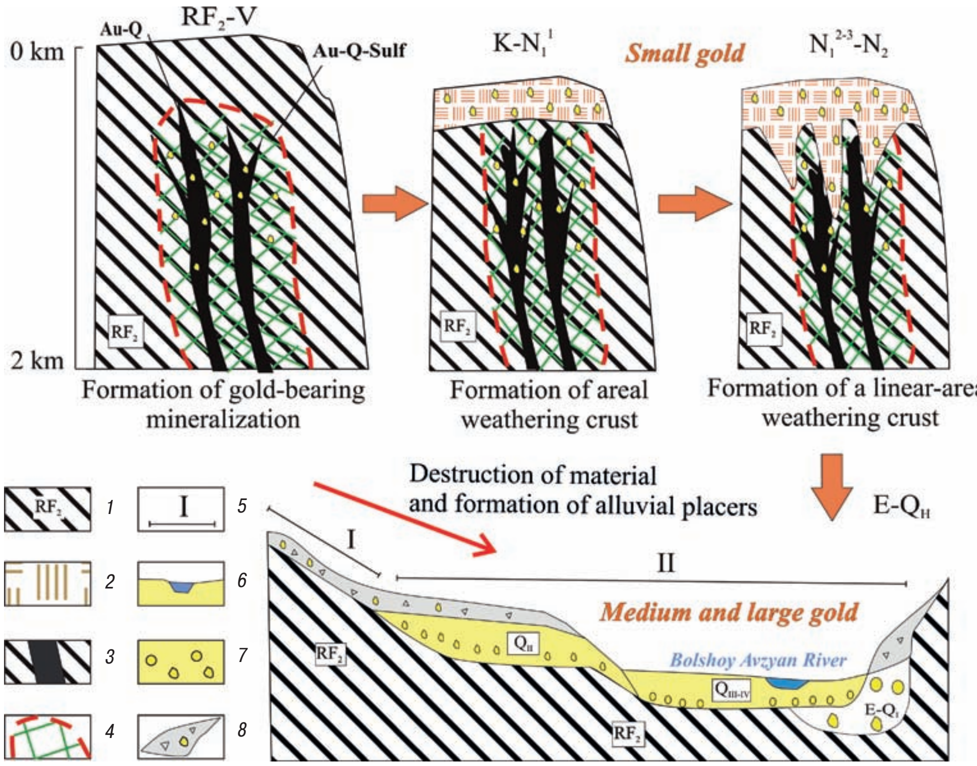

Fig. 4. Genesis and geology model of the primary source–placer gold in the river valley of inherited development

Legend: *1* – ore-bearing terrigenic–carbonic beds of the Zigaza–Komarovo suite (RF_2zk); *2* – linearly and areally spread weathering crust; *3* – quartz veins; *4* – wall rock alteration (beresitization); *5* – delluvial placers (I), alluvial placers (II); *6* – river valley; *7* – gold placers; *8* – slope detritus

(0.3×0.8 mm), and the rest of the gold grains are fine (0.25 mm). Gold may be intergrown with enclosing rocks and may be in nuggets a few grams in weight (**Fig. 3**, nos. 1–3). Gold grains have mostly a plate-like shape, and the coarser grains are lumpy and have an irregular shape. Gold has a high fineness (926–979) and is moderately impure with silver (2–4 wt.%). The following elements are observed at higher concentrations (wt.%): 0.4–1.2 bismuth; 0.7 arsenic; 0.26 antimony; 0.25–0.34 tellurium at nearly zero copper.

The morphology of gold grains from the Kamenny Klyuch placer points unambiguously at its closeness to the source. The presence of unoxidized sulfides in the panning samples is an indicator of a comparatively young age of the placer.

Avzyan placer

The placer is located 2.5 km northward of the Upper Avzyan settlement (see Fig. 1). This is an Eopleistocene–Holocene placer. The placer was developed manually using the opencast and underground methods, and between 1908 and 1948 580 kg of gold was produced at the average gold content of 2.5 g/m^3 per bed. From the detailed exploration in 1978–1984 (principal investigator A. V. Mokrinskiy, 1984), it is found that the placer adjoins the floodplain and the first bottom of the Big Avzyan river. The floodplain rises above the water level by 1.5 m, it has a width of 100–300 m, and the areas are even and waterlogged. The placer section represents Polymistic sand–pebble–boulder beds. Laterally, the placer has a belt shape, its length is 2.6 km and average width is 45 m, the average thickness of rock mass is 4.6 m, including 3.2 m of black dirt and 1.4 m of sand. Along the Avzyan placer, gold reserves have three peaks of richness, which points at a number of primary gold sources along the stream line. The Kurgashlya, Karasmayak and Bolshoi Klyuch placers located along the right-hand inflows of the Big Avzyan river to the north of the Gorny Priisk cluster contain small and coarse gold (up to nuggets of 0.5–1 g). The exploration results show the commercial gold content only along the first hundreds of meters beneath the outlets of the creeks. Then, the valley of the Big Avzyan river holds areas with uneconomic contents of fine gold. The richest sites of the Avzyan placers are found beneath the washing of the remains of the Pleistocene paleo-channel of the Shatak Bort placer, and there is also gold from the weathering crust of the Gorny Priisk deposit and the valleys of the Kamenny Klyuch and Bogryashka creeks. Average gold content of rock mass is from 74 to 568 mg/m^3 per roadways and 188 to 4825 mg/m^3 per beds [17]. Sands have an average washability, and gold belongs to categories III (average) and IV (coarse) of commercial classification (see Fig. 3). Gold fineness is 939–971, and 950 on the average.

Hypergenic formations on the surface of gold grains represent high-grade rims, and the difference in silver contents of the center and the rim may reach 5.2 wt.% (see Fig. 3, no. 6). Such rims are frequently observed on gold grains at some placers in the Urals and in the Russian Far East.

Development of the high-grade rims is associated primarily with the chemical removal of impurities from gold grains [23], and the rims are wider on grains which occur longer in the hypergenesis zone [24]. The depth of the high-grade rims on the gold grains from the Avzyan placer is small, 20–50 μm, which, together with other factors (moderate roundness, accretions with other minerals), points at the short time of the occurrence of the grains in the zone of hypergenesis [25].

The analysis of the internal structure of native gold from the Miass zone of placers by the method EBSD [26] reveals the low degree of deformation of the core and the fine-grained mosaic structure of the rim, which is explained by re-crystallization of the most deformed parts of gold during displacement. However, the proposed mechanisms offer no explanation for the formation of high-grade rims in hollows on the grain surface, and for re-deposition of spongy gold with a sharp change in the silver content at the phase boundaries.

For the most of placers in the Southern Ural, the presence of 'invisible' gold is typical. In some cases, percent of very fine (–0.25 + 0.1 mm), fine (–0.1 +0.05 mm) and powdery (–0.05 +0.01 mm) sizes of native gold may reach 75% of the total mass of the metal [17, 27]. Gold diggers recovered such gold using the method of amalgamation during refinement of black dirt and, also, mercury pouring of the first sluice carpets on washing machines. Because of the high velocity of the slurry flow, there was a high loss of mercury and amalgam, which resulted in contamination of the large placer fields with mercury (Avzyan, Urazovo, Miass, etc.). When investigating the Avzyan placer gold, the authors observed some tens of grains covered with loose coat of amalgam and differing from the most grains by the reflected light intensity (see Fig. 3, no. 7). The depth of the surface corrosion of such grains is on the average 20–25 μm, and their maximal mercury content can reach 20 wt.%. Although mercury is a regular impurity in gold of some deposits [21, 28–30], amalgam present only on the surface of gold grains washed in the zones of old mine openings allows suggesting the induced nature of amalgam.

Genesis and geology model

The final stage of this study was genesis and geology modeling of the placer formation in the test area, and identification of the main phases of geology and geomorphology situations of evolution (**Fig. 4**) [2]. Geochronologically, in the Avzyan placer field, gold ore formation is connected with the stages of tectono-thermal activation at the edge of the Middle and Later Riphean and in the Wendian periods [12, 31]. An additional source of noble metals could be Riphean carbonic shales of the Zagaza–Komarovo suite (RF_2zk) [11, 32].

The post-Hertzian period (after repeated tectono-magnetic activation in the Paleozoic and early Mesozoic ages) features destruction of the mountainous relief of the Southern Urals, which ends in the Cretaceous–early Miocene with the formation of a peneplain. Development of paleo-hydraulic network of the Central Ural zone in the Southern Urals, in the basin of the Belaya river upstream conforms with two main stages of the continuous–discontinuous neo-orogenic upheaval of the area and two large geological milestones of its structural layout reconstruction [33]. In the Neogene period (middle Miocene–Pliocene) of upheaval, the pediplainization of the relief takes place with exposure of ore strata at the Gorny Priisk deposit. The weathering crust spread linearly and areally on the valley pediments (see Fig. 4).

In the Eopleistocene–early Neopleistocene period, the regular phase of the neotectonic upheaval is connected with the sharp downcutting of the hydraulic network and the subsequent formation of the paleo-valley systems of gold-bearing depositions. In the Neopleistocene, as a result of continuous–discontinuous upheaval, bench and valley placers of gold get formed while the Eopleistocene paleo-cut-in placers remained after washing-out get buried. On the flattened tops of the ridges, as a result of active anti-planation processes, a series of alpine terraces form. In the modern period, the induced relief is being formed.

A similar evolution model of the Vagran gold cluster in the Northern Urals was developed [18, 34]. Both models, for the Northern and Southern Urals, have the common Uralian history [35]: (1) peneplanation of terrain with formation of MZ–KZ areal weathering crust; (2) intra-continental orogenic neo-tectonic activation in N_1 with formation of linear–areal weathering crusts and exposure of gold-bearing ore strata of primary deposits; (3) with the beginning of the N-Q (E-Q in the Southern Urals) stage of neo-orogenic upheaval activation, the uplift of the central part of the folded belt, the re-structuring of the structural layout of the hydraulic network and the formation of the main gold placers took place [12].

Conclusions

Thus, the findings of the analysis of native gold in the weathering crust at the Gorny Priisk deposit and clastic placer gold at the Avzyan placer field are set forth below.

1) The main source of placer gold are the development zones of gold–quartz (gold–low sulfide–quartz) formations at the Gorny Priisk deposit. The major proofs are the free gold, many accretions with quartz, grains size and the high gold fineness of 940–980.

2) The valley of the Big Avzyan river is the valley of inherited development and holds gold of different roundness, from weakly ore-like rounded to well-rounded grains with high-fineness rim. This is reflective of gold feeding from the weathering crust directly (Gorny Priisk deposit) and from intermediate reservoirs (valley of the Kamenny Klyuch creek), including deposits of the Eopleistocene paleo-cut-in (Shatak Bort placer). Fragments of the latter with a depth to 15 m below the modern-time water level of the Big Avzyan river avoided washing-out and were struck by exploration of the northern wing of the Avzyan placer.

The research findings, with the analysis of different placer formation situations as a case-study of the Avzyan placer field, and with the genesis and geology modeling of the primary source–weathering crust–alluvial placer system allows positive evaluation of the prospects for increasing gold resources from placers and primary deposits in the region.

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DETERMINATION OF GROUNDWATER REGIME IN A METAL MINERAL DEPOSIT BY DATA MINING AND SPATIAL INTERPOLATION IN THE CENTRAL REGION OF THE REPUBLIC OF CUBA

This study evaluates the groundwater regime in a metal mineral deposit in Cuba, combining statistical analysis, data mining and spatial interpolation of 15 504 historical records in 38 years. Kriging Regression was used (0.091 m prediction error) and bootstrap method to model the variability of the water table in an area of 4 174.55 kml between Ciego de Avila and Camagьey regions. The results reveal flow patterns and recharge/discharge areas, with significant influence of morphometric parameters such as elevation and drainage network. The variability of the groundwater level in the mineral site (10.12–18.49 m) highlights the need for careful water management, especially due to mining pollution.

Keywords: *groundwater level, data mining, bootstrap method, spatial interpolation, kriging region, mineral deposit, Cuba*
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Introduction

The exploration of mineral deposits is an essential part of the mining activity. In spite of this, mining exploitation significantly large extensions of land and the lower layers of the soil, including groundwater reserves [1–3]. Pollution by mining residuals, especially in metal mineral deposits, compromises water quality for general uses [4–6]. Previous studies deal with the problems of groundwater related to metal mineral activity, such as gold [7–9] and other minerals [10–12], also highlighting the urgency of sustainable water management in