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Reconstruction of the Indigenous Sources of Gold of the Glu-Kharinsky Placer (Kolyma River Basin, Magadan Region, Russia)

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Abstract

A comparative analysis of typomorphic features of gold placers and indigenous sources of gold was carried out for the Glukharinsky ore-placer node (the Nadezhda deposit and Glukharinskoye, Tyomnoye, and Tyi-Jurye ore occurrences). A correlation between fineness of placer native gold and composition of relic minerals preserved inside gold particles was obtained for the first time. This made it possible to establish mineral parageneses of native gold from potential indigenous sources. The study of placer gold fineness in combination with com-position of mineral inclusions allowed us to identify seven types of gold paragenesis: petzite-hessite with a fineness of 855‰, pyrite-polybasite-galena (a fineness of 670‰), bismuth telluride (900‰), cosalite-vikingite (790‰), galena (870‰), glaucodot (950‰), and hydrohematite (840‰). It was also shown that the placer contains the material from ore occurrences of different formation: gold-quartz-porphyry occurrences in granitoids (Au-Te-Bi type) and gold-silver occurrences. The method developed by us allows one to estimate the percentage of each ore source in placer formation.

Keywords

Ore-Placer Node, Native Gold, Mineral Associations, Placer, Indigenous Sources

1. Introduction

The study of the typomorphic properties of native gold, its morphology, structure and composition is an integral component of the study of gold ore and placer objects during prospecting and exploration. They are carried out using a complex of mineralogical data and allow us to obtain a number of additional information for judging the conditions of ore formation and formation of placers, the patterns of their placement. The first methodological guidelines for the use of genetic features of native gold during prospecting and exploration work were given by Lidia Aleksandrovna Nikolaeva in 1978, later the work was republished with additions [1].

Native gold is a mineral that preserves genetic information well. This is due to the fact that gold is chemically stable, does not break down for a long time, due to its malleability, and mineral inclusions in it are preserved without undergoing oxidation. Nina Vasilyevna Petrovskaya wrote about this in detail and convincingly in her book [2]. She described native gold in detail as a mineral, and showed that in the search and exploration by the typomorphic features of placer gold (probity, size, size, roundness, internal structure), it is possible to judge the types of ore deposits involved in the formation of placer, as well as to solve the inverse problem—to search for these deposits in the areas of the demolition of placer gold.

The fundamental work of N.V. Petrovskaya [2] was accepted by the world community. This was followed by the study of native gold in many regions of the world [3]-[22] Next, we give a list of regions where the study of typomorphic features of native gold was successfully conducted in the search and exploration: (in Russia) The Siberian Platform [3] [4], the Middle course of the Lena River [5], the Lower-Amur placer region [6], Kazakhstan [7], the Northeast of Russia [8], as well as in a number of regions of the world—Alaska (Klondike and Yukon) [9]-[14], Witwatersrand [15], Australia [16], USA, Alberto Province [17], Colorado [18], China [19], Mali [20], Macedonia [21] [22], etc. All the authors solved various geological exploration tasks using the indicator properties of native gold.

The authors solved various geological exploration tasks using indicator properties of native gold. Modern methods of regional microspectroscopy analysis (RCMA) allow one to determine not only gold fineness but also the composition of mineral microinclusions in gold particles when studying native gold placers. It is the composition of mineral inclusions in combination with native gold fineness that is highly informative for deciphering the type of ore sources of placer gold.

A correlation analysis between fineness of placer native gold and composition of mineral inclusions was performed for the first time. This made it possible to identify seven parageneses for potential indigenous sources.

The aim of the study was to show that, at the Glukharinsky placer, numerous mineral inclusions in native gold particles combined with information about its fineness indicate the mineral composition of ores from various gold deposit formations involved in the placer formation. The tasks were as follows: 1) diagnosis of minerals in placer gold particles; 2) determination of typomorphic signs of native gold: fineness, particle morphology, and structure; 3) comparative analysis of typomorphism of ore and placer gold, as well as ore mineral parageneses.

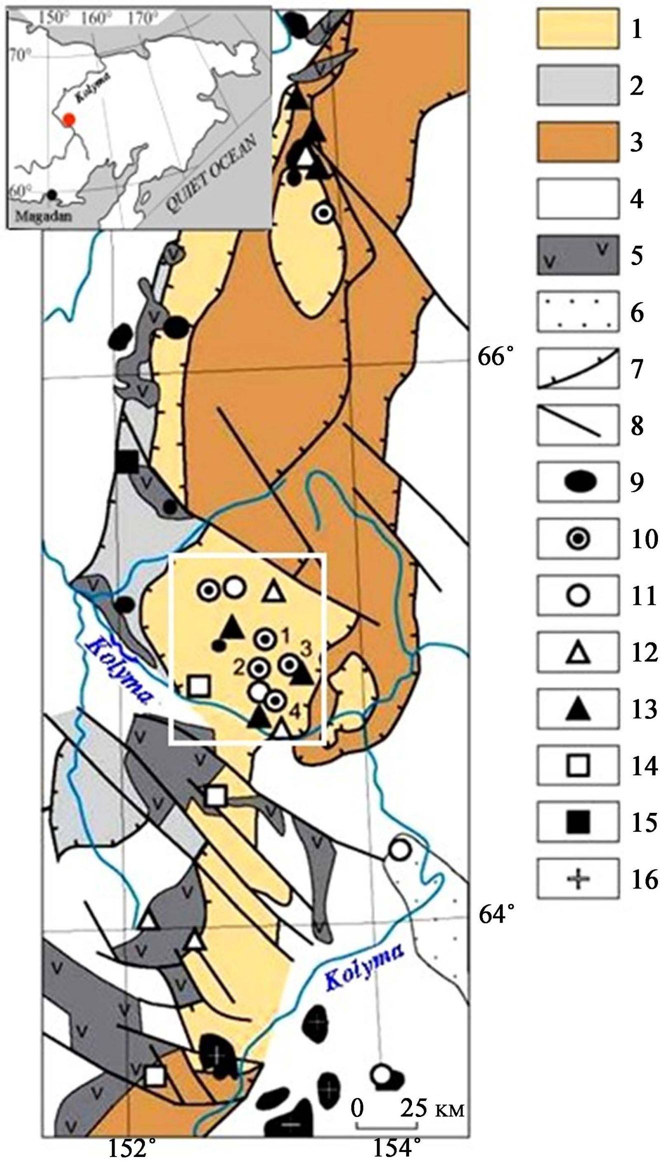
2. Regional Geological and Structural Position of the Glukharinsky Ore-Placer District

The Glukharinsky placer is located in Srednekansky District of Magadan Oblast, 250 km north of Seimchan village; it is an integral part of the Shamanikh-Stolbovsky ore-placer cluster located in the middle reaches of the Kolyma River (**Figure 1**) at the interfluve of its right tributaries. Geotectonically, the Shamanikho-Stolbovsky District belongs to the Prikolymsky terrane of the passive continental margin (**Figure 2**).

The terrane structure is a set of thrust sheets complicated by late high-angle faults. Folds forming a single structural ensemble with thrusts also play a significant role. Met-amorphosed Proterozoic sandstones, metapelites, carbonate and metavolcanic rocks, as well as hyperbasites nonconformably overlain by terrigenous, volcanogenic-sedimentary, and carbonate Paleozoic and Mesozoic rocks determine the terrane structure. Intrusive complexes are represented by small Devonian and Cretaceous granitoid bodies, as well as Late Cretaceous basite dikes. The scaly thrust structure of the terrane is crossed by rare granite porphyry dikes and a granite stock with an area of 1.6 km^2. The morphology, composition, and conditions of granite formation are similar to the Early Cretaceous alaskite-granite complex of Edekal River of the Prikolymsky terrane. Ore occurrences and deposits near the placer compose the Glukharinsky ore-placer node, which is controlled by sub-latitudinal faults. The node includes the Nadezhda gold deposit, Glukharinskoye, Tyom-noye, and Tyi-Jurye ore occurrences, and the industrial gold placer Glukhariny Creek (**Figure 3**).

Other researchers have previously studied the native gold of the Glukharinsky ore-placer node (mainly placer and a small percentage of ore gold) (1970-2007) [24] [25] [26]. They established the correlation between the composition of native gold placers and indigenous sources as well as the presence of two gold generations (500‰-750‰) and (800‰-950‰), in placers: moderately high-grade and relatively low-grade generations. The first generation had bismuth-telluride geochemical orientation, while the second generation had antimony-lead geochemical orientation, which was confirmed by single tetradymite finds and widespread gold-galena associations. Nevertheless, a complex geological structure, a long history of geological development, and a complex metallogeny of the

Figure 1. Kolyma River Valley (a photograph by G.H. Bulyakov).



The legend contains: Prikolymsky terrane, subterranes: 1—Spiridonovsky, 2—Shamanihinsky, 3—Yarhodonsky; 4—other terranes of the Yana-Kolyma orogenic belt; 5—Uyandino-Yasachnensky volcanogenic belt; 6—Balygychano-Sugoysky rift deflection; 7—thrusts; 8—high-angle faults; 9—granitoids, PZ2 and MZ; deposits and ore occurrences of various geological and genetic types: 10—mesothermal vein and stockwork Au, 11—epithermal vein and stockwork Au-Ag, 12—stockwork and vein Cu-Pb-Zn, 13—stratiform Pb-Zn, 14—strati-form Cu, 15—stratiform Fe, 16—vein and stockwork Sn; ore occurrences: 1—Glukharinskoye, 2—Tyomnoye; deposits: 3—Nadezhda, 4—Tyi-Jurye; inset: 1—Okhotsk-Chukotsky, 2—U-yan-dino-Yasachnensky volcanic belts. The rectangular outline shows the Glukharinsky ore-placer node area.

Figure 2. Tectonic and mineragenic scheme of the Prikolymsky terrane according to A.N. Glukhov *et al.* [23].

Prikolymsky terrane made it possible to identify significantly greater diversity in the composition of native gold and mineral parageneses formed by it at the next stage of research.

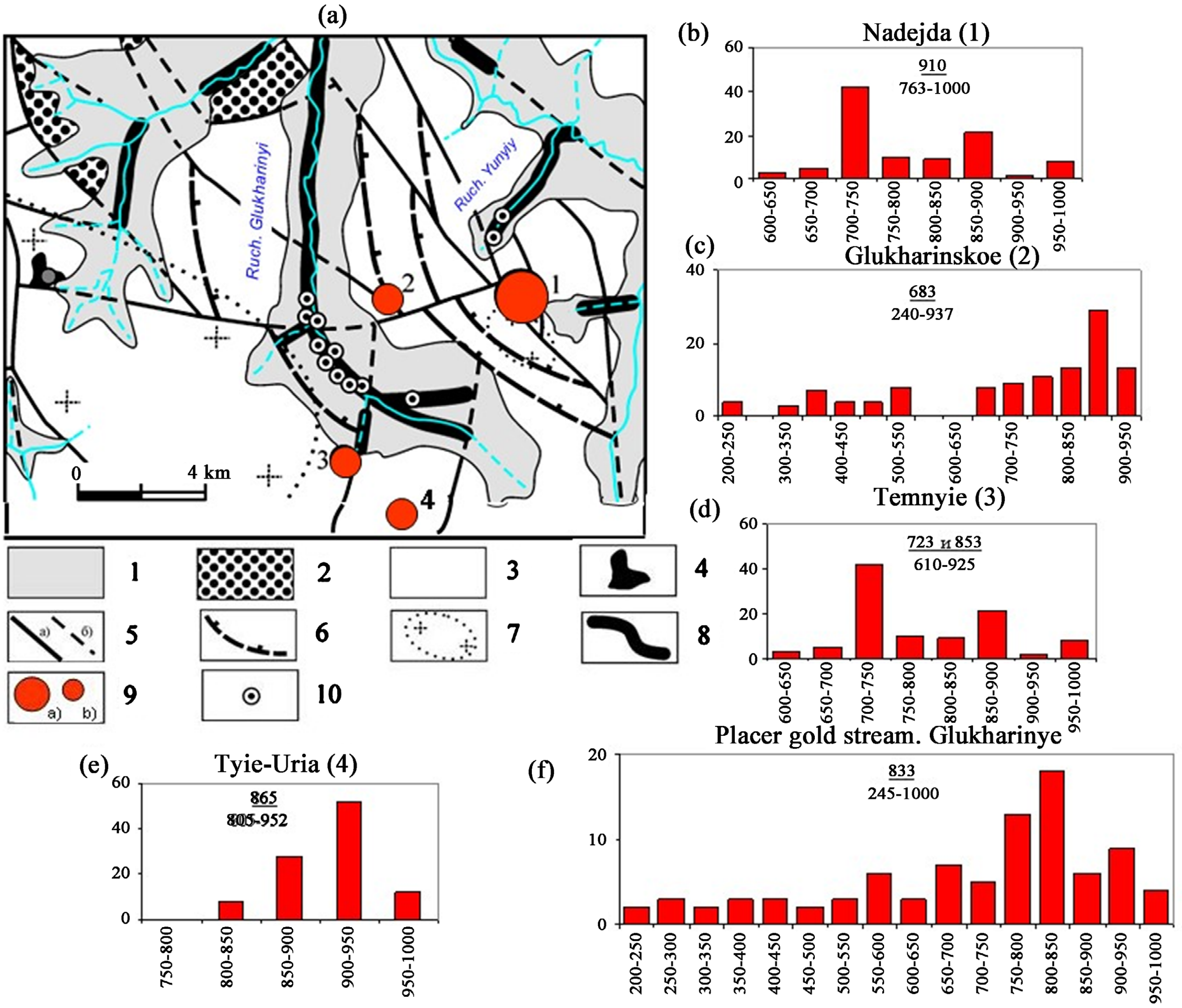


Figure 3. Geological structure of the Glukharinsky ore-placer node and the sampling location (a): 1—quaternary alluvial deposits; 2—Jurassic conglomerates; 3—metapelites, metabasites, carbonate and quartz-feldspar Proterozoic rocks; 4—granites; 5—established faults (a), putative faults (b); 6—thrusts; 7—undiscovered granitoid intrusions (according to geophysical data); 8—gold placers; 9—deposits; a): 1—Nadezhda, 2—Glukharinskoye, 3—Tyomnoye, 4—Tyi-Jurye and gold mineralization sites (b) [27] [28]; 10—placer samples; fineness histograms fir ore gold deposits of the Glukharinsky ore-placer node (b)-(e): (b)—Nadezhda; (c)—Glukharinskoye; (d)—Tyomnoye; (e)—Tyi-Jurye (f)—fineness histogram for gold from the entire Glukharinsky placer area (the abscissa axis: fineness intervals, ‰ ; the ordinate axis: frequency of occurrence, %); the nu-merator shows the average fineness, the denominator indicates the spread of values.

3. Research Methods and Objects

3.1. Research Objects

A total of 12 placer samples from the technogenic complex of the Glukharinsky and Yunyiy placer deposits were selected for the study. Each sample contained 15 - 25 particles of native gold: 200 grains in total. Sampling locations are shown in Figure 3.

We performed a comparative analysis of the data on ore gold and its mineral associations in the ores of Nadezhda, Glukharinskoye, Tyomnoye, and Tyi-Jurye deposits (**Figures 3(b)-(e)**) studied and published in [27] [28].

3.2. Research Methods

Placer Gold particles were placed in the compound and, after it was solidified, au-topsy was performed to obtain a preparation and polished sections, which made it possible to see inclusions of ore minerals in them.

The mineralogy of polished sections was studied by optical microscopy (OM) using a Carl Zeiss AXIOPLAN Imaging reflected light microscope (Oberkochen, Germany). Minerals intergrown with native gold in these samples were photographed and analyzed using the MC-LCD Data Visualizer and MMC software (LOMO, Russia).

The internal structure of native gold was revealed by etching polished grain surfaces with standard reagents: different concentrations of HCl + CrO_3 for high-grade gold and HCl + $4HNO_3$ for medium- and low-grade gold. The nature of internal structures was defined according to the recommendations presented in [1]. Mineral intergrowths and internal structures of native gold were photographed using a photomicrographic attachment to a reflected light microscope.

The fineness of native gold and the composition of ore mineral microinclusions were determined using a QEMSCAN device and the QUANTAX system by operator T.V. Sub-botnikova at the North-East Common Use Center of the SVKNII FEB RAS, Magadan. Around 60 microinclusions were analyzed in total, and gold fineness was determined in the same grains. The method of comparing placer gold fineness with ore mineral parageneses preserved inside gold particles was used for data analysis.

Data on ore gold and its mineral associations in the ore of the Nadezhda, Glukha-rinskoye, Tyomnoye, and Tyi-Jurye deposits published in [27] [28] were used for the comparative analysis.

4. Results

4.1. The Morphology of Placer Gold Particles

A total of 12 placer samples from the technogenic complex of the Glukharinsky and Yunyiy placer deposits were selected for the study. Each sample contained 15 - 25 particles of native gold: 200 grains in total. Sampling locations are shown in **Figure 3**.

According to the M. Powers scale [29] [30], the roundness coefficient Cr ranges from 12 to 21, less than 5% of grains have the Cr of 30, single crystals and crystal aggregates are rarely observed (**Figures 4(a)-(c)**). The described morphology indicates the proximity of ore sources and insignificant spread range of most placer gold.

4.2. The Fineness of Native Gold

Modern research methods allowed us to significantly expand the data on gold fineness range and its mineral paragenesis both in ores and placers. The ranges

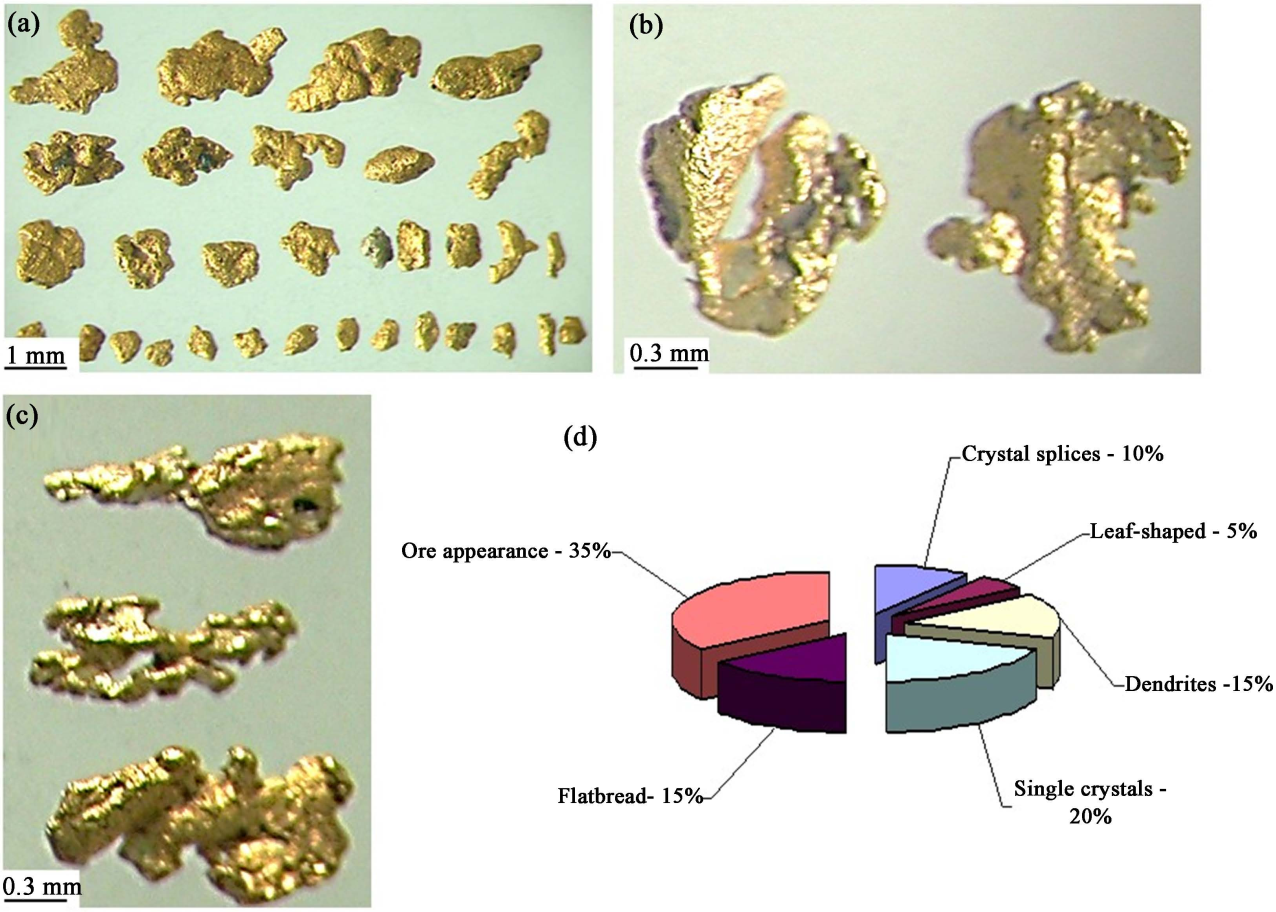


Figure 4. Morphology of placer gold particles. A) Morphology of native gold particles: (a)—angular and poorly rounded; (b)—a crystal aggregate; (c)—ore-like gold particle with numerous protrusions; (d)—the summary diagram (for 200 grains) of the prevalence of various morphological types of native gold particles at the Glukharinskoye placer.

for native gold fineness in both ores and placers gold are shown in **Figure 3**. A histogram of placer gold fineness distribution for Glukharinskoye and Yunyiy deposits (**Figure 3(f)**) shows a lognormal distribution ranging from 250 to 1000‰ with a pronounced maximum at 850‰ - 900‰ and a less clearly manifested small maximum at 650‰ - 700‰ (**Figure 3(b)**).

4.3. Mineral Inclusions in Native Gold Particles

Autopsy of gold grains revealed numerous mineral inclusions (**Figure 5**). The RSMA method revealed the following inclusions: galena PbS, gustavite $AgPbBi_3S_6$, bismuth telluride Bi_2Te_3, petzite $AuAg_3Te_2$, hessite Ag_2Te, cosalitelillianit? $(Pb,Cu)_3Bi_3S_6$, volynskite $AgBiTe_2$, glaucodote (Co,Fe)AsS, polybasite $Ag_{16}Sb_2S_{11}$, and pyrite FeS_2. The composition of identified mineral phases is presented in **Table 1**.

4.4. Internal Structures of Native Gold

Based on measured fineness of placer gold containing inclusions, five associations were identified with different gold structure: 1) gold-galena-bismuth telluride

Table 1. Composition of mineral inclusions in placer gold of various fineness (RSMA wt.%).

Element concentration, мас.%							Formula coefficients							The fineness of gold, ‰
Au	Ag	Cu	Pb	Te	Bi	S	Au	Ag	Cu	Pb	Te	Bi	S	
Galena PbS														
			92.64			7.36				1.32			0.68	670 - 870
			91.75			8.25				1.27			0.74	
			93.2			6.8				1.36			0.64	
			91.97			8.03				1.28			0.72	
			91.77			8.23				1.27			0.73	
			90.64			9.36				1.2			0.8	
			92.33			7.67				1.3			0.7	
Gustavite $AgPbBi_3S_6$														
11.0	6.53	4.51	19.63		44.5	13.83	0.75	0.72	0.84	1.12		2.53	5.12	785 - 790
	7.3	5.31	21.31		52.81	13.27		0.81	1	1.23		3.02	4.95	
	6.76	2.64	26.41		49.84	14.34		0.75	0.5	1.53		2.86	5.36	
	11.94		25.39		54.44	8.22		1.62		1.8		3.82	3.76	
Petzite $AuAg_3Te_2$														
30.68	38.97			30.35			1.14	2.87			1.89			855 - 900
55.37	30.44			14.19			2.05	2.51			0.99			
30.21	39.82			29.97			1.12	2.92			1.86			
24.16	42.56			33.27			0.9	3.04			2.01			
28.69	39.94			31.36			1.06	2.92			1.94			
Kozalite-lilianite? $(Pb.Cu)_3Bi_3S_6$														
		1.52	39.02		44.07	11.62			0.37	2.88		3.22	5.54	790
		1.05	38.11		42.1	12.17			0.25	2.82		3.09	5.83	
Tellurovismuthite Bi_2Te_3														
				44.17	55.83						2.82	2.18		900
				44.12	55.88						2.82	2.18		
				44.8	55.2						2.85	2.15		
Volynskite $AgBiTe_2$														900
	28.66			39.73	31.61			1.46			1.71	0.83		
Hessiite Ag_2Te														
5.87	61			33.13			0.11	1.98			0.91			855 - 900
5.49	61.44			33.06			0.1	1.99			0.91			
5.87	61			33.13			0.11	1.98			0.91			

Continued

Glaucodote (Co.Fe)AsS														950
Au	Ag	Cu	Fe	As	Co	S	Au	Ag	Cu	Fe	As	Co	S	
			5.72	43.11	29.17	22				0.17	0.93	0.8	1.11	
			5.77	43.54	29.13	21.56				0.17	0.94	0.8	1.09	
Pyrite FeS_2														670
			46.56			53.44				1			2	
Polybasite $Ag_{16}Sb_2S_{11}$														670
5.24	67.57	2.47		19.94		4.79	0.94	16.4	1.02		6.97		3.91	
A fine mineral mixture (hessian + petzite + gold)?														850
Au	Ag	Cu	Pb	Te	Bi	S								
6.91	66.4	2.08		19.61		5								

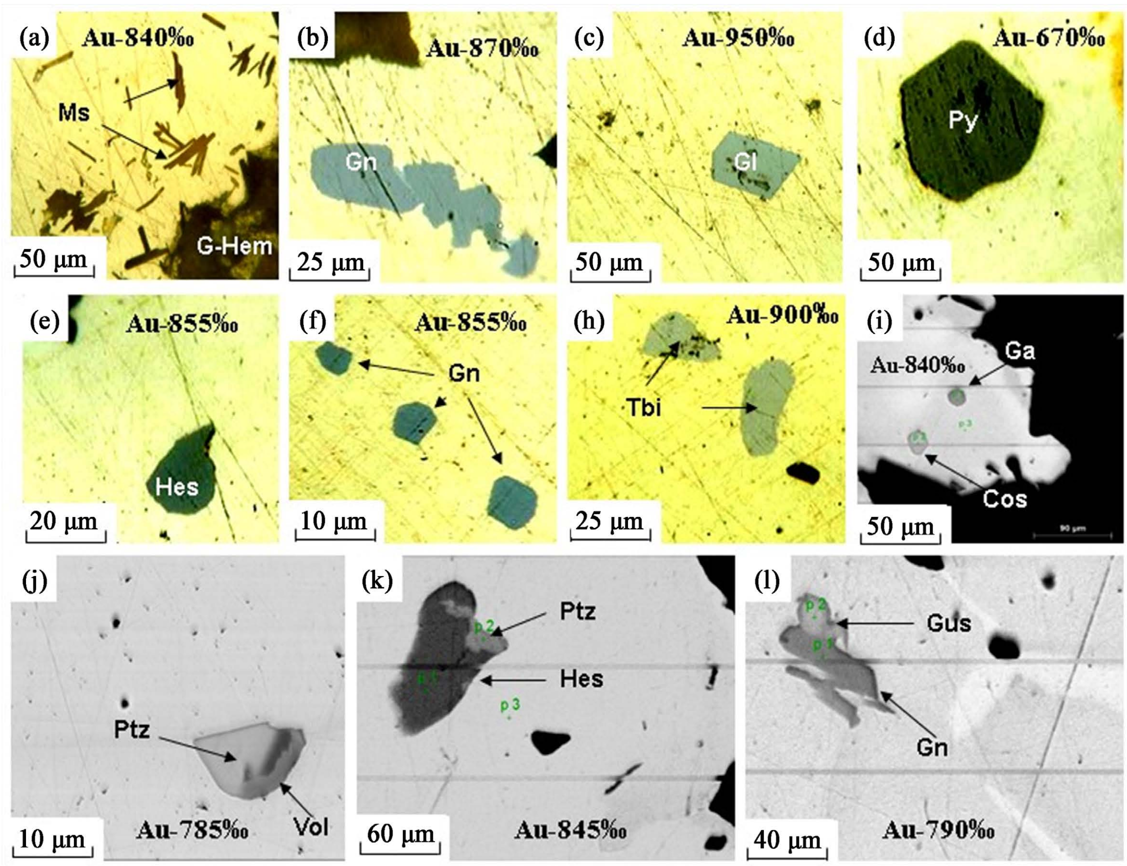


Figure 5. Mineral inclusions in gold of different fineness from the Glukharinsky placer: in re-flected light: (a) muscovite, (b) galena, (c) glaucodote, (d) pyrite, (e) hessite, (f) galena, (h) bis-muth telluride; in reflected electrons: (i) galena and cosalite, (j) petzite and volynskite, (k) petzite and hessite, (l) gustavite and galena.

is most commonly found together with medium and coarse-grained 850‰ - 900‰ gold with simple twins (Figure 6(a), Figure 6(b)); 2) gold-cosalite-gustavite-galena-bismutoplagionite-hessite-petzite with native gold fineness of 790‰ - 920‰, signs of granulation and sometimes tourmaline inclusions (Figure 6(d), Figure 6(e)); 3) gold-pyrite-polybasite-galena is characterized by low fineness of native gold (670‰ on average) and the presence of kustelite (Au < 500‰) it usually has a clear zonal structure, sometimes contains traces of plastic deformations (Figures 6(f)-(i)), it is also characterized by supergene margins indicating its presence in the oxidation zone, and possibly also in the weathered layer prior to entering the placer; 4) gold-glaucodote is char-acterized by high-purity gold (950‰ - 980‰), it is found in high-grade and copper gold (Figure 6(c)); 5) gold-hy- drohematite mineral paragenesis is characterized by single crystals of

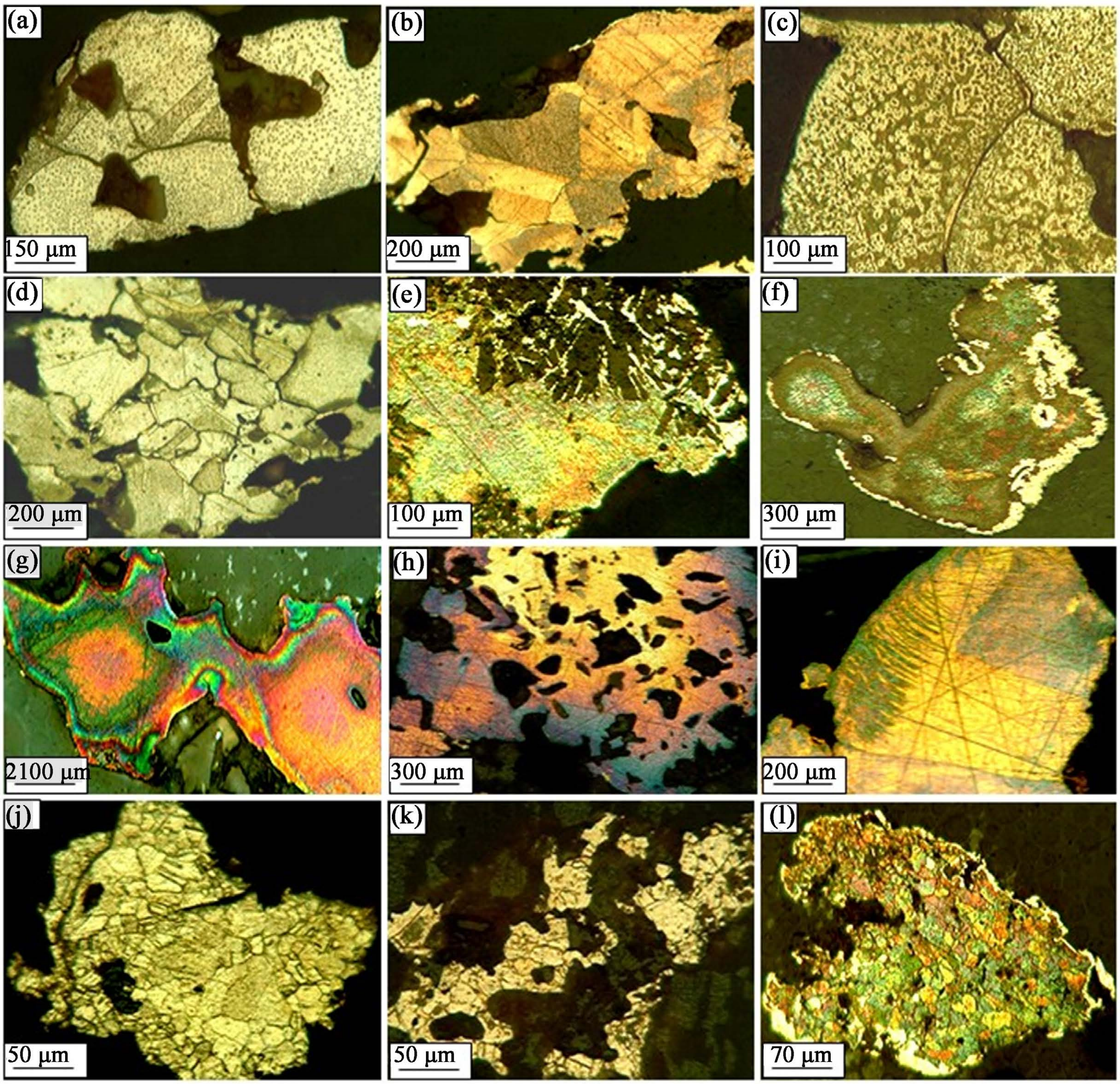


Figure 6. Various internal structures of native gold placers of the Glukharinskoye and Yunyiy deposits revealed by structure etching (CrO3+:HCl): ((a), (b)) polygonal-granular structure with simple twins; (c) copper gold with the structure of decomposed solid Au-Cu solution; (d) granu-lated structure; (e) tourmaline inclusions in medium-grade gold; f—high-grade sheath on low-grade gold; ((g), (h))—zonal structure of low-grade gold and the absence of roundness signs; (i) traces of plastic deformations (translation lines); j—l-completely recrystallized native gold (presuma-bly clastogenic gold from conglomerates).

gold with a fineness of 750‰ - 950‰ with rare inclusions of hydrohematite, quartz, carbonate, light mica, and andalusite. The occurrence of the selected associations of the association is shown in the histogram (**Figure 7**).

Approximately 10% of the studied gold turned out to be mercurous gold with Hg concentrations of 28 wt% - 33.1 wt% (RSMA data). We assumed it to be an industrial contamination, because Glukharinsky District placers have been exploited since the 60s of the last century when amalgamation was used.

Rare small-grained (0.1 - 0.3 mm) high-grade (900‰ - 950‰) gold with completely re-crystallized structure without ore inclusions occupies a separate position (**Figures 6(j)-(l)**). We assume that it may be clastogenic gold from gold-bearing conglomerates D2-3 with fragmentary formation either at the Glukharinsky ore-placer node (**Figure 3**). According to L.A. Nikolaeva *et al.* [1], such a structure is interpreted as complete recrystallization dur-ing gold redeposition. We can also assume that this gold may originate from the oxidation zone of the Glukhariny ore at the Glukharinsky ore-placer node (**Figure 3**). According to L.A. Nikolaeva *et al.* [1], such a occurrence, where small-size and fine-grained gold is localized in oxidized hematite (hydrohematite).entering the placer; 4) gold-glaucodote is characterized by high-purity gold (950‰ - 980‰), it is found in high-grade and copper gold (**Figure 6(c)**); 5) gold-hydrohematite mineral paragenesis is characterized by single crystals of gold with a fineness of 750‰ - 950‰ with rare inclusions of hydrohematite, quartz, car-bonate, light mica, and andalusite.

Rare small-grained (0.1 - 0.3 mm) high-grade (900‰ - 950‰) gold with completely re-crystallized structure without ore inclusions occupies a separate position (**Figures 6(j)-(l)**). We assume that it may be clastogenic gold from gold-bearing conglomerates D_{2-3} with fragmentary formation either at the Glukharinsky ore-placer node (**Figure 3**). According to L.A. Nikolaeva *et al.* [1], such a structure is interpreted as complete recrystallization during gold redeposition. We can also assume that this gold may originate from the oxidation zone of the Glukhariny ore occurrence, where small-size and fine-grained gold is localized in oxidized hematite (hydrohematite).

5. Discussion

The mineralogy of ore gold and its associations at the Glukharinsky ore-placer node was studied before [27] [28], which made it possible to compare the typomorphic features of native gold placers and indigenous sources. Types of mineral associations identified based on mineral inclusions and placer gold fineness (**Figure 7**) are quite consistent with those of indigenous sources (**Table 2**). However, as comparison has shown, two, and sometimes three types of gold paragenesis and two fineness intervals can be characteristic of individual indigenous sources.

The maximum amount of material in the central part of the upper layer of the Glu-kharinsky placer was supplied by the Tyomnoye ore occurrence, which is spatially close to the location of placer sampling (see **Figure 3(d)**): downstream

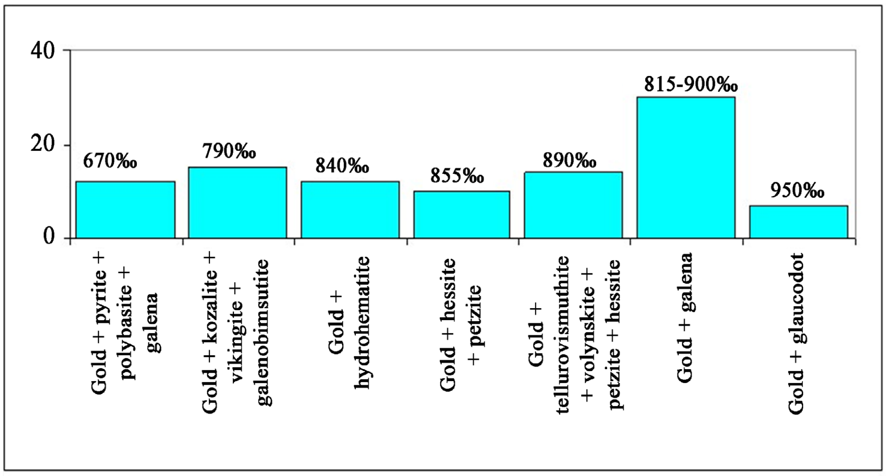


Figure 7. The frequency of occurrence of native gold of different fineness from the Glukharinsky placer in combination with mineral parageneses identified based on mineral fragments pre-served in placer gold particles: mineral parageneses (the abscissa axis—frequency of occurrence, % the ordinate axis—the fineness of native gold, ‰ is indicated above the frequency values for each paragenesis).

Table 2. Gold parageneses from ore sources and ore minerals accompanying gold mineralization (based on [27] [28]).

Deposit, ore occurrence	Ore minerals	Established mineral inclusions in gold	Native gold fineness, ‰
Nadezhda Au–Te–Bi mineral type	Pyrite, pyrrhotite, galena, sphalerite, chalcopyrite, tetradymite/bismuth telluride (?), petzite, hessite, and Pb-Bi sulfosalt	Galena, petzite, hessite, tetradymite, and Pb-Bi sulfosalt	910 763 - 1.000
Tyomnoye Au–Te–Bi mineral type	Galena, pyrite, sphalerite, chalcopyrite, hessite, petzite, Ag tetrahedrite, tetradymite, bismuth telluride, and uytenbogaardtite	Galena, bismuth telluride, hessite, and petzite	853 783 - 925 723 645 - 771
Tyi-Jurye	Pyrite, chalcopyrite, galena, hematite, and tetradymite	Hydrohematite, pyrite, and galena	855 813 - 977
Glukharinskoye Au–Ag mineral type	Hydrohematite, pyrite, pyrrhotite, arsenopyrite chalcopyrite, sphalerite, electrum, galena, fahlore, bornite, acanthite, aguilarite, uytenbogaardtite?, native Bi?, kustelite, and cinnabar	Hydrohematite, acanthite, and Ag sulfosalt	895 802 - 953 472 245 - 550

from the upper reaches of the Glukhariny Creek. It has two peaks of placer gold fineness, which may correspond to three parageneses and their quantitative content in the placer (Figure 7): gold-bismuth tel-luride-volynskite-petzite-hessite with a fineness of 900‰ (17%) and gold-cosalite-vikingite-bismutoplagionite with a fineness of 790‰ (14%). The list can also include gold-galena with a fineness of 87‰ (30%), since galena is widespread in this ore occurrence [28], as well as half of gold-hessite-petzite parageneses with a fineness of 855‰ (5%). In general, the amount of gold in the placer from the Tyomnoye ore occurrence is about 65%.

The ingress of gold to this part of the placer from the Glukharinsky ore occurrence is quite unambiguous, since a high range of gold fineness (250‰ - 900‰)

was established for ore and placer gold there (**Figure 3(c)**). Pyrite, Ag sulfosalts, hematite, and hydrohematite are found in the ore. The percentage of gold from this ore occurrence includes gold-hydrohematite paragenesis with a fineness of 840‰ (11%) and partially gold-pyrite-polybasite-galenite with a fineness of 670‰ (12%), which comprises about 25% of the paragenesis.

Ore bodies of the Nadezhda deposit are at a greater distance (**Figure 3(a)**) on the opposite slope. Despite this, a small part of gold migrated to the Glukhariny Creek placer in the upper reaches and, to a lesser extent, to the central part. In addition to tellurides, glaucodote was also found in the deposit ores. Therefore, gold with gold-glaucodote paragenesis with a fineness of 950‰ (5%) and partially gold-petzitehessite with a fineness of 855‰ (5%) was transported form the placer. The percentage of gold in this placer part removed from the Nadezhda deposit is about 10%. For Yunyiy Creek and Nadezhda placers, the eponymous ore deposit is apparently the main source of migration. However, no sampling was conducted there.

Apparently, the reconstruction is approximate, since it was performed using 60 placer gold grains containing micromineral inclusions. It demonstrates the composition of placer gold at a specific area of the Glukharinsky placer, where placer samples were collected. The remaining grains did not contain ore inclusions. It is possible that small-size gold with completely recrystallized structure is clastogenic and originates from conglomerates, the outcrops of which are exposed on the node territory (**Figure 3(a)**).

Thus, the provided interpretation suggests that the material migrated from indigenous sources to the placer at this exact proportion. There is no doubt that the tails of low-grade gold in fineness histograms both for the ore and placer are comparable to those of the Glukharinskoye ore occurrence. Its formation is presumably associated with subvolcanic processes. However, it has not been studied sufficiently enough, and its geo-logical and structural position has not been deciphered yet.

The Tyomnoye ore occurrence and the Nadezhda deposit share certain similarities in their composition. At the same time, it is also possible that the difference in composition of ore-containing rocks affected the increased silveriness of the Tyomnoye ores. The carbonate rocks containing it, unlike aluminosilicate rocks, are more prone to secondary changes and low-temperature solid-phase transformations (skarnification, marmorization). In addition, the carbonate environment favors silver deposition, while geochemical barriers for its massive deposition may occur at the boundary of carbonate and alumino-silicate rocks. The predominant forms of silver minerals in these ores are silver-containing galena and fahlores in early parageneses and sulfosalts, silver sulfide, and low-grade gold in late parageneses. The proximity of the roof of intrusive rocks allows us to expect the existence of gold- and silver-bearing skarns at deeper levels of the Tyomnoye deposit.

Placer sampling and subsequent study of gold typomorphism can serve as an effective technique to search for certain types of deposits. According to L.A. Nikolaeva *et al.* [1], the general knowledge about potential types of gold mineralization, indigenous sources and their placer-subvolcanic processes. However, it has not been studied sufficiently enough, and its geo-logical and structural position has not been deciphered yet.

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Placer sampling and subsequent study of gold typomorphism can serve as an effective technique to search for certain types of deposits. According to L.A. Nikolaeva *et al.* [1], the general knowledge about potential types of gold mineralization, indigenous sources and their placer-forming potentials, as well as gold transformations in placers can be obtained at a scale of 1:500,000-1:200,000, while more representative gold characteristics can be determined during prospecting and exploration.

For the Glukharinsky node, the constant presence of Bi and Te minerals in ore and placer gold characterizes not only the telluride-bismuth type of mineralization but also the correlation between gold deposits and granitoid magmatism, which was established for Yukon deposits in Alaska [31] [32]. Our research confirms that gold-quartz mineralization localized in ancient Proterozoic rocks is intrusion-related and associated with Mesozoic granitoid magmatism [33] [34] [35] [36]. This allows us to talk about the successive stages of gold mineralization in gold deposits of the Glukharinsky ore-placer node: early stage, meta-morphogenic-hydrothermal (gold-bismuth telluride) with superintrusive mineralization; late, volcanogenic (gold-polybasite-black ore); as well as a possible clastogenic stage, which is associated with conglomeration. This is confirmed by the placer gold structure: granulation of early-stage gold, which was affected by later volcanic magmatic intrusions, late-stage low-grade gold, which was not affected by metamorphism. We can assume the existence of other types of gold deposits on the territory of the Prikolymsky terrane, in weathered layers and skarns, as well as gold-bearing Carlin-type jasperoids (not forming placers): there are geological prerequisites for this.

6. Conclusions

The study of placer gold fineness in combination with com-position of mineral inclusions allowed us to identify seven types of gold paragenesis: petzite-hessite with a fineness of 855‰, pyrite-polybasite-galena (a fineness of 670‰), bismuth telluride (900‰), cosalite-vikingite (790‰), galena (870‰), glaucodot (950‰), and hydrohematite (840‰).

The performed study has shown that a large number and diversity of mineral inclusions in native gold in the Glukharinsky placer have an important indicator value. The study of the composition of these inclusions in combination with gold fineness (‰) made it possible to identify seven mineral parageneses and estimate the frequency of their occurrence (%). Comparison of these parageneses with those of ore sources located near the placer allowed us to reconstruct the primary sources of the placers, as well as to estimate the approximate contribution of each ore source to placer formation. This methodology can be applied to similar placers.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Nikolaeva, L.A., Gavrilov, A.M., Nekrasova, A.N., Yablokova, S.V., Pozdnyakova, N.N. and Shatilova, L.V. (2021) Typomorphism of Native Gold. Guidelines for Exploration Work. TsNIGRI, Moscow, 85 p.

[2] Petrovskaya, N.V. (1973) Native Gold. Nauka, Moscow, 345 p.

[3] Nikiforova, Z.S., Gerasimov, B.B., Glushkova, E.G. and Kazenkina, A.G. (2013) Gold Content of the East of the Siberian Platform (Placers—Root Sources). *Geology of Ore Deposits*, **55**, 305-319. https://doi.org/10.1134/S1075701513040065

[4] Nikiforova, Z.S., Gerasimov, B.B. and Tulaeva, E.G. (2008) Genesis of Gold-Bearing Placers in the Eastern Siberian Platform. In: *Fluvial Palaeo-Systems*: *Evolution and Mineral Deposits*, Project IGCP-514, Moscow, 73-83.

[5] Nikiforova, Z.S. and Surnin, A.A. (2001) To the Problem of Placer Gold Content of the Middle Lena. Domestic. Geology. No. 5, 70-72.

[6] Savva, N.E., Shilyaeva, N.A. and Alevskaya, N.L. (2004) Topomineralogy of Constitutional Features of Native Gold of the Nizhny Amur Placer Region. NEISRI FEB RAS, Magadan, 173 p.

[7] Kalinin, Y.A., Palyanova, G.A., Naumov, E.A., Kovalev, K.R. and Pirajno, F. (2019) Supergene Remobilization of Au in Au-Bearing Regolith Related to Orogenic Deposits: A Case Study from Kazakhstan. *Ore Geology Reviews*, **109**, 358-369. https://doi.org/10.1016/j.oregeorev.2019.04.019

[8] Savva, N.E. and Preis, V.K. (1990) Atlas of Native Gold. Nauka, Moscow, 292 p. (In Russian)

[9] Knight, J.B., Mortensen, J.K. and Morison, S.R. (1994) Shape and Composition of

Lode and Placer Gold from Klondike District, Yukon, Canada. Exploration and Geological Services Division, Yukon Region: Bull. 3. Canada. 142.

[10] Mustart, D.A. (1965) A Spectrographic and Mineralographic Investigation of Alluvial Gold from the Central Yukon. Unpublished B.Sc. Thesis, University of British Columbia, Vancouver, 46 p.

[11] Knight, J.B., Mortensen, J.K. and Morison, S.R. (1999) Lode and Placer Gold Composition in the Klondike District Yukon Territory, Canada, Implications for the Nature and Genesis of Klondike Placer and Lode Gold. *Economic Geology*, **94**, 649-664. https://doi.org/10.2113/gsecongeo.94.5.649

[12] LeBarge, W. and Naumov, V.A. (2008) New Results on the Stratigraphy and Placer Gold Potential of Central Yukon. Yukon Exploration and Geolgy. 1-13.

[13] Mc Coy, D., Newberry, R.J. and Layer, P. (1997) Plutonic-Related Gold Deposits of Interior Alaska. In: Goldfarb, R.J. and Miller, L.D., Eds., *Mineral Deposits of Alaska*, Economic Geology Monograph 9, Economic Geology Publishing Company, Littleton, 191-241. https://doi.org/10.5382/Mono.09.08

[14] Hart, C.J.R., McCoy, D.T. and Goldfarb, R.J. (2002) Geology, Exploration and Discovery in the Tintina Gold Province Alaska and Yukon. In: Goldfarb, R.J. and Nielsen, R.L., Eds., *Integrated Methods for Discovery: Global Exploration in the Twenty-First Century*, Society of Economic Geologists Spec. Publ. No. 9, Littleton, 241-274. https://doi.org/10.5382/SP.09.12

[15] Minter, W.E.L., Goedhart, M., Knight, J. and Frimmel, H.E. (1993) Morphology of Witwatersrand Gold Grains from the Basal Reef: Evidence for Their Detrital Origin. *Economic Geology*, **88**, 237-248. https://doi.org/10.2113/gsecongeo.88.2.237

[16] Wilson, A.F. (1983) The Economic Significance of Non-Hydrothermal Transport of Gold, and of the Accretion of Large Gold Nuggets in Laterite and Other Weathering Profiles in Australia. Geol. Soc. South Africa Spec. Pub. No. 7, 229-234.

[17] Giusti, L. (1986) The Morphology, Mineralogy and Behaviour of Fine-Grained Gold from Placer Deposits of Alberta: Sampling and Implications for Mineral Exploration. *Canadian Journal of Earth Sciences*, **23**, 1662-1672. https://doi.org/10.1139/e86-154

[18] Jensen, E.P. and Barton, M.D. (2007) Geology, Petrochemistry, and Time-Space Evolution of the Cripple Creek District, Colorado. The Geological Society of America Field Guide, No. 10, 63-78. https://doi.org/10.1130/2007.fld010(04)

[19] Qiu, Z.X. (1986) Gold Spherjids form Oxidation Zone of Yinnan Gold Deposit in Ningxia, China. *Chinese Science Bulletin*, **32**, 576.

[20] Freyssinet, Ph., Zeegers, H. and Tardy, Y. (1988) Morphology and Geochemistry of Gold Grains in Lateritic Profles of Gold Southern Mali. *Journal of Geochemical Exploration*, **32**, 17-31. https://doi.org/10.1016/0375-6742(89)90041-1

[21] Stefanova, V., Volkov, A.V., Serafimovsky, T. and Sidorov, A.A. (2013) Native Gold of the Epithermal Plavitsa Deposit (Republic of Macedonia). *Doklady Earth Sciences*, **451**, 541-546. https://doi.org/10.1134/S1028334X1308014X

[22] Stefanova, V., Volkov, A.V., Serafimovsky, T. and Sidorov, A.A. (2015) Native Gold of the Borovik Ore Field (Republic of Macedonia). *Geology of Ore Deposits*, **57**, 148-153. https://doi.org/10.1134/S1075701515020063

[23] Glukhov, A.N. (2019) Tectonic Factors of Ore Genesis of Precambrian Terranes on the Example of the Prikolymsky Uplift and the Omolon Massif (Northeast Asia). *Bulletin of St. Petersburg University. Earth Sciences*, **64**, 219-248. https://doi.org/10.21638/spbu07.2019.204

[24] Flerov, I.B. (1970) Relics of the Peneplenized Relief and Weathering Crust in the

Basin of the Middle Course of the Kolyma River. *Kolyma*, No. 12, 43-45.

[25] Preis, V.K. and Palymsky, B.F. (1988) Mineralogy of Native Gold from One of the Placers of the Prikolymsky Mountain-Anticlinory. *Kolyma*, No. 4, 11-13. (In Russian)

[26] Litvinenko, I.S. (2009) Gold Me If the Prikolyma Uplift. Intern. *Large Igneous Provinces of Asia*, *Mantle Plumes and Metallogeny*, Novosibirsk, 6-9 August 2009, 194-196.

[27] Glukhov, A.N., Savva, N.E. and Kolova, E.E. (2016) The Material Composition and Genesis of Gold Ores of the Nadezhda Deposit (Magadan Region). *Ores and Metals*, No. 4. 1-17.

[28] Biryukov, A.A. (2018) Genetic Significance of Teluride-Bismuth Mineralization at Gold Ore Objects of the Glukharinsky Ore Node (Magadan Region). *Bulletin of the NEISRI FEB RAS*, No. 4, 34-39.

[29] Powers, M.C. (1953) A New Roundness Scale for Sedimentary Particles. *Journal of Sedimentary Petrology*, **23**, 117-120. https://doi.org/10.1306/D4269567-2B26-11D7-8648000102C1865D

[30] Powers, M.C. (1982) Comparison Chart for Estimating and Sphericity. American Geological Institute, Alexandria, Data Sheet 18, 1-2.

[31] Lang, J.R., Baker, T., Hart, C.J.R. and Mortensen, J.K. (2000) An Exploration Model for Intrusion-Related Gold Systems. SEG Newsletter, No. 40, 15 p. https://doi.org/10.5382/SEGnews.2000-40.fea

[32] Savva, N.E. (2019) Silver-Arsenide Formation of the Omolon Middle Massif (New Data). *Bulletin of the North-Eastern Scientific Center FEB RAS*, pp. 9-17. https://doi.org/10.34078/1814-0998-2019-4-9-17

[33] Sillitoe, R.H. (1991) Intrusion-Related Gold Deposits. In: Foster, R.P., Ed., *Metallogeny and Exploration of Gold*, Blackie, Glasgow, 165-209. https://doi.org/10.1007/978-1-4613-0497-5_6

[34] Cox, D.P. and Singer, D.A. (1986) Mineral Deposits Models. United States Geological Survey. Bulletin 1693. 379 p.

[35] Vikent'eva, O.V., Prokofiev, V.Yu., Gamyanin, G.N., Goryachev, N.A. and Bortnikov, N.S. (2018) Intrusion-Related Gold-Bismuth Deposits of North-East Russia: PTX Parameters and Sources of Hydrothermal Fluids. *Ore Geology Reviews*, **102**, 240-259. https://doi.org/10.1016/j.oregeorev.2018.09.004

[36] Stimac, J., Goff, F., Goff Cathy, J. and Chapter, R. (2015) Intrusion-Related Geothermal Systems. In: Sigurdsson, H., *et al.*, Eds., *The Encyclopedia of Volcanoes*, Elsevier, Amsterdam, 799-822. https://doi.org/10.1016/B978-0-12-385938-9.00046-8