The Internal Structure of Placer Gold of the North-East of the Siberian Platform as a Reliable Search Sign of Primary Sources

Boris Gerasimov 1

1 Diamond and Precious Metal Geology Institute, Siberian Branch, Russian Academy of Sciences, 39, prosp. Lenina, Yakutsk, Russia

Gerasimovbb@diamond.ysn.ru

Abstract. Typomorphic features of placer gold are carriers of the most important information necessary for the reconstruction of the history of the formation of placer and ore occurrences of gold and can be used as mineralogical criteria in the search for primary sources of placers. The study of these features is relevant for placer areas with unidentified gold sources, which include the territory of the north-east of the Siberian Platform. The internal structure of native gold is one of the most informative typomorphic features. We studied the internal gold structures of modern placers and conglomerates of the Early Permian age in the north-east of the Siberian Platform. The purpose of the work: to identify the features of the internal structure of placer gold, depending on the chemical composition and the degree of its transformations, as well as the possibility of their use as a prospecting indicator. Structural etching of native gold was performed using the reagent: HCl + HNO3 + FeCl3 × 6H2O + CrO3 + thiurea + water. As a result of the research, it was found that the well-rounded high-grade gold of modern placers has undergone repeated redeposition through intermediate sources. The discovery of slightly rounded gold with an internal structure without signs of exogenous transformation indicates that it entered the modern alluvium from a nearby primary source. This was a prerequisite for setting up ore gold exploration, resulting in identification of apocarbonate hydrothermal-metasomatic formations with disseminated gold-sulfide mineralization were identified. Thus, the features of the internal structures of placer gold in combination with other typomorphic features are additional indications of determining the sources of formation of gold-bearing placers.

1. Introduction

It is known that morphology, chemical composition, as well as the internal structure of native gold are transformed in the placers [1, 2, 3, 4, 5]. At the same time, the typomorphic features of placer gold carry the most important genetic information, necessary for use as additional features to the geological criteria at different stages of the study of potentially gold-bearing areas, as well as obtaining new knowledge to restore the history of the formation of placer and ore occurrences [1, 2, 6, 7].

One of the most informative typomorphic features showing post-ore endogenous changes and the duration of gold stay in an exogenous environment is its internal structure [1, 2]. One of the most informative typomorphic features showing post-mineral endogenous changes and the duration of gold's stay in an exogenous environment is its internal structure. One of these regions is the north-
eastern part of the Siberian Platform, since numerous placers of gold with unidentified primary sources are known here [8].

The classification of the internal structures of native gold was developed by N. V. Petrovskaya [1], later supplemented by L. A. Nikolaeva [2, 6]. We studied the features of the internal structure of placer gold (more than 500 gold particles) from exploration samples selected from modern alluvial deposits, as well as the Permian conglomerates in the north-east of the Siberian Platform.

The purpose of the research was identification of the features of the internal structure of placer gold, depending on the chemical composition, the nature and degree of its transformations, as well as the possibility of their use as a prospecting indicator on specific natural objects.

2. Materials and Methods

The research is based on the author's materials that were sampled during field work in the north-east of the Siberian Platform for 15 years. Field work included prospecting geological-geomorphological traverses, heavy mineral concentrate and small-volume sampling of producing facies of modern stream bed alluvium, as well as conglomerates of the Permian age. In addition, gold from the exploration samples of JSC "Almazy Anabara" was studied.

To achieve this goal, the following mineralogical studies were performed: gold is divided into size classes; morphological varieties of gold are identified, taking into account the color shades, the degree of roundness, and the presence of inclusions; these morphological varieties of gold are described; the fineness of the most typical gold par-ticles is determined.

To study the chemical composition and features of the internal structure of the gold particles were mounted on epoxy plug, followed by their grinding on corundum powders and polishing on diamond pastes to a mirror shine.

The chemical composition of the minerals was determined with «JEOL» «OXFORD» INCA-sight energy spectrometer equipped with Oxford Instruments analytical devices (wave and energy-dispersive spectrometers). The survey was carried out under the fol-low ing conditions: accelerating voltage 20 kV; measure current 1.09 nA; measurement time 7 s; analytical lines: Au – Mα, Ag – α, other elements – Kα. Limits of element detec-tion (wt.%): Au – 1.81, Ag – 1.11,Cu – 1.22,Hg–1.73. Analytical work was carried out in the Department of Physical and Chemical Methods of Analysis DPMGI SB RAS (analyst Khristoforova N.V.).

The internal structure of native gold was studied by etching it in mounted sections according to the developed method [9], using a reagent: HCl + HNO3 + FeCl3 × 6H2O + CrO3 + thiourea + water. The reagent was applied to the surface of polished gold mounted into an artificial polished section. Goldenrods were etched from 10 to 30 seconds, in several approaches. After each etching procedure, the polished section was washed under a strong stream of water, then dried. After that, the developed internal structures were studied in detail with NEOPHOT 32 ore microscope and JEOLJSM-6480LV scanning electron microscope. The interpretation of the features of internal structures was carried out in accordance with the recommendations of N. V. Petrovskaya [1, 9], L. A. Nikolaeva [2, 6], N. E. Savva and V. K. Preis [7].

3. Geological-structural position of the region

The geological structure of the studied territory includes the Precambrian, Paleozoic, Mesozoic and Cenozoic metamorphic, sedimentary and volcanogenic sedimentary rocks. The igneous formations are represented by rocks of granitoid, ultrabasic, al-kaline-ultrabasic, and trap formations belonging to the Proterozoic, Middle Paleozoic, and Mesozoic magmatic stages [10, 11, 12]. The tectonic position of the region is determined by the location in the area of development of two large structures of the Siberian Platform – the Anabar anticlise and the Lena-Anabar trough. On the Anabar anticlise, the Anabar massif, the Olenek uplift with the Sololiysky, Daldynsky and Kuysky block inliers the Udzhinskoe block uplift, the Sukhanskaia depression and a number of smaller structures of the second (Ebelakhsky uplift, etc.) and third order (size) are distinguished. The Lena-Anabar trough is a large linear depression area bounding the Anabar anticlise in the north. According to their predecessors the
modern structural plan of the basement and platform cover of the studied area was formed as a result of repeated activations of ancient faults [11, 12]. For example, during the Mesozoic tectonic-magmatic activation, the ancient systems of deep faults (Molodo-Popigai, Anabar-Eyekit, etc.) were rejuvenated, which led to the formation of a series of new faults.

4. Results and discussion

4.1. Internal structure of well-rounded placer gold of modern alluvial deposits

Placer gold is widely distributed in the modern alluvial deposits of almost all watercourses of the north-eastern part of the Siberian Platform. It is mainly represented by well-rounded flake and lamellar forms, the size of 0.1 – 0.5 mm with a coarse-shagreen and micropitted surface, sometimes with casts of pressing of minerals in the host sediments.

Gold particles have high fineness (900—999 ‰). Ag (up to 10%), Cu, and Hg (at the level of the detection limit) were detected as trace elements. The internal structure of this type of gold is significantly transformed and is characterized by thick high-grade rims, structures of recrystallization (Figures 1) and lines of plastic deformations (Figure 2).

![Figure 1](image1.png)

**Figure 1.** Complete recrystallization of high-grade (995‰) deformed gold, basin of river Malaya Kuonamka: (a) general view; (b) detail: magnification 150. Etched with a reagent based on Aqua regia. Image have been taken in BSE mode.

![Figure 2](image2.png)

**Figure 2.** Lines of ductile deformations of high-grade (975‰) gold, basin of river Bolshaya Kuonamka: (a) general view; (b) detail: recrystallization structures along with the lines of deformation are observed peripherally, magnification 400; (c) detail: magnification 200. Etched with a reagent based on Aqua regia. Image have been taken in BSE mode.
4.2. The internal structure of slightly rounded placer gold and gold of ore appearance of modern alluvial deposits

Along with the typical lamellar gold described above, slightly rounded gold and gold of ore appearance are found in some placers of the studied territory. Its content can range from 5 to 15% in the total mass of placer gold. This type of gold is distributed locally and is usually found near zones of deep faults and outcrops of the Precambrian basement rocks.

This gold is characterized mainly by the size from 0.1 to 2 mm, angular lumpy and dendritic forms. Its fineness varies in a very wide range of 350—999 ‰, medium- and low-grade varieties predominate. The content of Ag is registered at the level of 12-55 %, Hg - up to 4 %, Cu - up to 1.5 %. The internal structure of gold is almost unchanged, it is characterized by whole grains and coarse-medium-grained structures, as well as simple twins, sometimes fragments of very thin, high-grade rims are recorded.

High-silver (electrum, kustelite) slightly rounded gold from the placer of the Bolshaya Kuonamka River is characterized mainly by zonal structures that are not affected by endogenous and hypergene transformations (Figure 3). Low-grade inter-granular veinlets were found in the relatively low-grade gold of the appearance. According to N. E. Savva and V. K. Preis [7], the described structures are endogenous. In their opinion, the good preservation of endogenous structures in gold indicates its supply from nearby primary sources.

![Figure 3. Internal structure of low-grade slightly rounded gold form the placer of the Bolshaya Kuonamka river: (a) zonal structure of slightly rounded kustelite (350‰); (b) concentrically zonal structure of semi-rounded relatively low-grade gold (720‰); (c) clearly zonal structure of slightly rounded electrum (505‰). Etched with a reagent based on Aqua regia. Image have been taken in BSE mode.](image)

In the placer occurrence of the Billyakh river of the Anabar river basin, along with well-rounded lamellar gold, small (-0.25 mm) gold particles of ore appearance of lamellar, angular-lumpy and dendritic forms were found. Their surface is almost uredoned, spongy and porous. The fineness varies in very wide intervals – from low (535‰) to very high (999‰). The analysis of gold fineness and its morphological features has shown that only gold particles of ore appearance have relatively low (799-
700‰) and low (699-500‰) fineness. Heterogeneous multiphase internal structure is a characteristic feature of this gold is. In central part of the gold particles, a low-grade (500-600‰) phase is identified, represented by oval-shaped grains ranging in size from 10 to 50 microns (Figure 4). The intergranular gaps are filled with high-grade gold.

**Figure 4.** Internal structure of gold of ore habit from the Billyakh river placer: (a) general view in polished section; (b) detail: multiphase gold, magnification 3000; (c) detail: high-grade gold, developed in intergranular space, magnification 2700; (d) detail: oval shapes of low-grade gold grains, magnification 1400. Etched with a reagent based on Aqua regia. Image have been taken in BSE mode.

Similar gold was found in placers the Nebaybyt and Machala rivers – right tributaries of the Bolshaya Kuonamka river. It is represented here by isometric crystals, an-gular-lumpy and lamellar forms, as well as peculiar hooked individuals. The internal structure also has a heterogenous multiphase character (Figure 5). As a rule, low-slightly rounded gold is recorded in the ~0.25 mm class. Its probity varies very widely – from low (535‰) to very high (more than 950‰). Gold
particles do not show signs of transformation under hydrodynamic conditions, which indicates the proximity of the primary source.

4.3. The internal structure of gold of the Early Permian conglomerates
Gold from the Permian conglomerates of the Sololi river basin (Sololi uplift of the Olenek arch) was studied. Conglomerates are closely cemented rocks of light gray color. They are composed mainly of pebbles and gravel of milky-white and smoky quartz. The size of the pebbles is 1-2 cm, rarely 10 cm. The cement is white kaolinized sandstone. The apparent thickness of the rocks is about 2.5 m.

Gold has mainly lamellar forms with casts of pressing of minerals (figure) and the following granulometric composition: 0.25-0.5 mm – 10%, 0.25 mm – 90%. Its fineness varies from 700 to 999 ‰, at the same time, high-grade gold prevails (900-999‰) 80%. The internal structure is represented by structures of granulation, recrystallization and high-grade intergranular veinlets (Figure 6, a, b), which is generally typical for the gold of ancient intermediate sources. It should be noted that the placer gold from the stream deposits of the Sololi river basin, selected downstream from the outcrop of the Permian conglomerates, has a similar internal structure (Figure 6, c, d). This circumstance, as well as the identical fineness of gold, allows us to state that the Permian quartz conglomerates are the main sources of metal in the channel sand of the studied area.

![Image](image.png)

**Figure 6.** Internal structure of gold from the Sololi uplift of the Olenek arch: (a) high-grade (950‰) gold from the Permian conglomerates with very high-grade (999‰) intergranular veinlets; (b) structure of recrystallization of high-grade (950‰) gold from the Permian conglomerates; (c) high-grade (945‰) gold from modern alluvium of the Sololi river basin with very high-grade (999‰) intergranular veinlets; (d) structure of recrystallization of high-grade (935‰) gold from modern alluvium of the Sololi river basin. Etched with a reagent based on Aqua regia. Image have been taken in BSE mode.

In general, the results of the study of the internal structure of well-rounded gold of modern placers indicate its repeated redeposition through intermediate sources. This is clearly confirmed by our study of the gold of the Permian conglomerates (Figure 6). At the same time, the identity of the internal
structure of the gold of the Permian source and the modern alluvium of the Sololi river basin allows us to state the leading role of conglomerates as an intermediate source in the studied area.

The discovery of gold with an internal structure without signs of exogenous transformation indicates that it entered the modern alluvium from nearby primary sources. As an example, we can cite a peculiar unaltered internal structure of very fine, slightly rounded particles of gold from the placer of the Billah river (Figure 4). The combination of typomorphic features of this gold allowed us to refer it to the autochthonous type. In this regard, it was suggested that in the upper course of the Billyakh river, in the field of development of the Cambrian carbonate rocks in the fault zone, a gold-ore occurrence may be localized – a potential primary source of very fine gold [13]. This assumption was confirmed by our field works. Near-fault apocarbonate hydrothermal-metasomatic formations were found in the sources of the Billyakh river. Disseminated gold-sulfide mineralization was identified in these formations. According to epigenetic mineral associations, quartz-potassium feldspar and siliceous-quartz hydrothermal-metasomatic formations are distinguished. Ore minerals in them are represented by very small crystals and phases of pyrite, arsenopyrite, sphalerite and galena. Also quite often there is a barite in the form of very small veinlets in the microcracks of dolomite. Gold is found mainly in free native form in quartz veinlets, less often in association with pyrite. Its size ranges from the first to 15 microns along the long axis [14].

Similar gold as mentioned above was found in the basin of the Bolshaya Kuonamka river in the eastern framing of the Anabar shield (Figure 5). It is noteworthy that, here we have studied cataclastic dolomitic limestones, in which hydrothermal-metasomatic formations with disseminated gold-sulfide mineralization have also been identified [14]. Mineralization is represented by the smallest particles of gold, silver, pyrite, arsenopyrite, antimonite, molybdenum and acanthite. Based on the above, it is assumed that the identified occurrences of disseminated ore mineralization, localized in altered carbonate rocks, could be the primary sources of very fine non-rounded autochthonous gold. Thus, the described internal structures (Figures 4, 5) are probably indicative signs for native gold of apocarbonate near-fault hydrothermal-metasomatic formations. Of course, this assumption requires additional detailed research, which will be undertaken in the future.

The identification of slightly rounded low-grade gold with zonal structures (Figures 3), not affected by hypergene transformations, in the placer of the Bolshaya Kuonamka river also indicates the proximity of primary sources. In this regard, there is a prerequisite for setting up prospecting operations for ore gold at this site.

5. Conclusions
In conclusion, it should be noted that our research has shown that the internal structure of gold is a sensitive indicator of the evolution of native gold in time and space. It is especially significantly transformed in the conditions of ancient intermediate sources.

In general, features of the internal structures of placer gold in combination with other typomorphic features can be additional and sufficiently reliable criteria for determining potential sources of formation of gold-bearing placers (ancient gold-bearing sources or gold-bearing primary sources).

Acknowledgment(s)
The work was carried out according to the state task DPMGI SB RAS and as part of grant No. 18-45-140018 of the Russian Foundation for Basic Research and contract-based works with Almazy Anabara JSC.

References
[1] Petrovskaya N.V. Native gold. Nauka: Moscow, USSR, 1973. P. 347 (In Russian)
[2] Nikolaeva L. A. Genetic features of native gold as a criterion in the search and evaluation of ores and placers. Nedra: Moscow, USSR, 1978. P. 100 (In Russian)
[3] Chapman, R.J., Leake, R.C., Moles, N.R., Earls, G., Cooper, C., Harrington, K., Berzins, R. The application of microchemical analysis of gold grains to the understanding of complex local
and regional gold mineralization: a case study in Ireland and Scotland. Econ. Geol. 2000, 95, 1753-1773.

[4] Dill, H.G. Geogene and anthropogenic controls on the mineralogy and geochemistry of modern alluvial-(fluvial) gold placer deposits in man-made landscapes in France, Switzerland and Germany. JGE 2008, 99,29-60, doi:10.1016/j.gexplo.2008.02.002.

[5] Alam, M.; Li, S.; Santosh, M.; Yuan, M. Morphology and chemistry of placer gold in the Bagrote and Dainterstreams, northern Pakistan: Implications for provenance and exploration. Geol. J. 2019, 54, 1672-1687, doi:10.1002/gj.3262.

[6] Nikolaeva, L.A.; Gavrilov, A.M.; Nekrasova, A.N.; Yablokova, S.V.; Shatilova, L.V. Atlas of Native Gold of Ore and Placer Deposits in Russia; Tsniigri: Moscow, Russia, 2003; pp. 184. (In Russian)

[7] Savva N.E., Preis K. V. Atlas of native gold of the North-East of the USSR. Nauka: Moscow, USSR, 1990. P. 292.

[8] Nikiforova, Z.S.; Gerasimov, B.B.; Glushkova, E.G.; Kazhenkina, A.G. Indicative features of placer gold for the prediction of the formation types of gold deposits (east of the Siberian Platform). Russ. Geol. Geophys. 2018, 59, 1318-1329, doi:10.1016/j.rgg.2018.09.009.

[9] Petrovskaya N.V., Novgorodova M.I., Frolova K.E., 1980. The nature of structures and substructures of endogenous native gold particles. Mineralogy of native elements. Editor: Petrovskaya, N., Editor: Fatyanov, I., FESC AC USSR: Vladivostok, USSR, 1980; P. 10 - 20.

[10] Smetannikova L. I., Grinenko V. S., Malanin Y. A., Prokopyev A.V., et al. State Geological Map of the Russian Federation. Scale 1:1,000,000 (third generation). Anabar-Viluy series. Sheet R-51 - Dzhardzhan. Explanatory note. - Map factory VSEGEI: Saint Petersburg, Russia, 2013. P. 397.

[11] Rubenchik Li. B., Borisheva N. A., Zaretsky L. M. Explanatory note to the geological map of scale 1: 200 000 (Sheet R-50-VII, VIII). Moscow, USSR, 1980. P. 72.

[12] Tectonics, geodynamics and metallogeny of the territory of the Republic of Sakha (Yakutia). Editor: Parfenov, L., Editor: Kuzmin, N., MAIK "Nauka/Interperiodica": Moscow, Russia, 2001. P. 571.

[13] Gerasimov B. B. Indicator typomorphic features and potential sources of fine alluvial gold of the Ebelyakh area (north-east of the Siberian platform) // Bulletin of the Saint Petersburg University. Earth Sciences. 2018. V. 63. Issue 3. P. 291-302. https://doi.org/10.21638/spbua07.2018.303

[14] Gerasimov, B. Typomorphism of fine placer gold and potential primary sources of the Anabar mineral subprovince (North-eastern Siberian Platform) // IOP Publishing: IOP Conf. Series: Earth and Environmental Science 362, 2019, 012039 https://doi.org/10.1088/1755-1315/362/1/012039. Web of Sciences. https://mess-earth.org/index.html.