Mineralogical and Geochemical Features of Native Gold From Placers of the Evota Gold-Bearing Region (Russia, Aldan Shield)

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Abstract. Evota gold-bearing region is located in south of Republic Sakha (Yakutia) within the Nimnyr terrane of Aldan shield. A large numbers of gold-bearing placers are known on studied territory, but the primary sources for them have not been established. In this work, based on the study of the mineralogical and geochemical features of gold from alluvial deposits of the Evota gold-bearing region, possible genetic types of primary sources are considered. Obtained data showed that native gold in the studied objects has a very high, high and medium fineness. The roundness of gold is different. Almost ore crystals with sharp edges and well-rounded individuals with polished faces were found. The fineness of the studied gold grains was determined by microprobe analyzer Cameca Camebax-micro and varies in the range from 812 to 1000 ‰. A thin (up to 20 µm) high-grade rim was found in two grains (cr. Zolotoy). The central part of one of them has a fineness of 865 ‰, and in the edge part it reaches 1000 ‰, which indicates that this gold was in the hypergenesis zone. Admixture elements determined as traces and are presented Cu, Pd, Fe, Ni. Minerals-microinclusions - quartz, potassium feldspar, pyroxene, staurolite, maldonite, bismuthite revealed in gold grains. In some watercourses, for example, in the creek Sukhoi, only very high fineness gold (993-1000 ‰) was found. The presence of high-grade gold (cr. Sukhoi), intergrowths of gold with bismuthite (cr. Zolotoy), as well as inclusions of maldonite (cr. Yagodny) gives opportunity for assuming that primary sources could be basic ores such presented in the P. Pinigin deposit. At the sites (cr. Elovyi, r. Evota), both medium-grade and very high-grade gold were found, the fineness range varied from 827 to 998 ‰. The presence of gold with medium fineness and good roundness in studied watercourses probably indicates an additional supply of gold from primary sources formed as a result of the alkaline magmatism development of the Mesozoic age. Thus, for gold with high and very high fineness by admixture-elements, chemical composition and microinclusions, a genetic relationship with primary sources similar to the P. Pinigin deposit was found; for gold grains with medium fineness, formation in gold-ore mineralization characterized for the Mesozoic stage ore development such in deposits of Central-Aldan ore region is assumed.

1. Introduction
The Evota gold-bearing region is located in the south of the Republic of Sakha (Yakutia) within the Nimnyr terrane of the Aldan-Stanovoy shield. The territory is characterized by a large number of gold placers that have been worked intermittently since the 1930s [1]. Within the studied area, mapping and exploration works were conducted repeatedly [1–6], with the primary focus on finding gold mineral occurrences, phlogopite, and iron. As a result of the studies, individual ore occurrences were identified.
in the form of eluvial and deluvial oxidized quartz-sulfide ore boulders near the exocontact zones of syenite intrusions. In the southern part of the region, a horizon of quartz-K-feldspar metasomatites (2-4 g/t) was found at the contact zone of the Vendian-Lower Cambrian dolomites and Lower Jurassic sandstones. The presence of gold was also established in the magnetite ores of the Sivagli deposit (up to 0.12 g/t) and at the Desovsky deposit (up to 0.04 g/t) [4]. The P. Pinigin gold deposit, with gold mineralization in the Precambrian mafic rocks, was discovered on an adjacent area within the Leglier ore cluster [7]. Although extensive studies have been carried out on the territory, but the primary sources for most of the gold placers remain undetermined. This paper, based on the study of the mineralogical and geochemical features of gold from the alluvial deposits of the Evota gold-bearing region, predicts potential genetic types of the primary sources.

2. Another section of your paper
The studied region is located within the Nimnyr terrane of the Aldan-Stanovoy shield (figure 1). The terrain borders with the Amga tectonic melange zone in the west and the Tyrkanda tectonic melange zone in the east. In the southern part, the Nimnyr terrane borders the Sutam terrane through the Seim thrust. Structural plan of the Nimnyr terrane is defined by an extensive development of the gneiss-domes, the largest being the Timpton dome (175x200 km.) in the north [8]. The cores of the domes are composed of orthogneisses, represented by granite-gneisses, charnockite- and enderbite-gneisses with amphibolite bodies, which occupy more than 50% of the terrane. The shoulders of the domes are composed of a paragneiss complex. The metamorphism of the terrane rocks corresponds with three subfacies of the granulite facies: cordierite-hypersthene-orthoclase, biotite-hypersthene-orthoclase, and biotite-sillimanite-orthoclase subfacies of the moderate pressure zone [9].

![Figure 1. Map of the Aldan-Stanovoy shield terranes [9] with additions. Terranes: 1 – granite-greenstone terranes (WA – West-Aldan, EBT – Batomga), 2 – tonalite-trondhjemite-gneiss (TN – Tynda), 3 – granulite-orthogneisses (ANM – Nimnyr, CG - Chogar), 4 – granulite-paragneiss (AST – Sutam, EUC – Uchur), 5 – tectonic melange zones (am – Amga, kl – Kalar, tr – Tyrkanda); 6 – large rivers; 7 – Evota gold-bearing region.](image-url)
rocks, diopside schists, diopside and sphene-bearing salite plagioclase, magnetite ores, serpentine, forsterite- and clinohumite-serpentine rocks, hornblende, biotite-hornblende and diopside-hornblende plagioclase, biotite plagioclases and plagioclase [2].

3. Methods
Wide ranges of mineralogical and geochemical methods were used to study the typomorphic features of placer gold from the Malyj Nimnyr river basin. All analytical work was carried out in the Laboratory of Physical and Chemical Methods of Analysis, DPMGI SB RAS. The study of the gold grains morphology and surface, and their microphotography using Jeol JSM-6480LV scanning electron microscope, Micromed MS-2 Zoom stereoscopic microscope with Levenhuk C1400NG photographic attachment and Polam-P312 ore microscope were used. Fineness of gold and admixture elements in the central parts of the gold grains were analyzed on the Cameca Camebax-micro microanalyzer, analyst Khristoforova N. V. Standardized minerals, pure metals, and their alloys were used as standards. Detection limit (in %): Hg – 0.152; Bi – 0.132; Ag – 0.109; Au – 0.178; Cu – 0.11; Fe – 0.065; Pd – 0.062; Pt – 0.343; Ni – 0.089. Micro-inclusions in gold were analyzed using Jeol JSM-6480LV scanning electron microscope with Oxford instruments INCA Energy 350 energy dispersive spectrometer. The fineness of gold is presented according to the classification of N. V. Petrovskaya [10] (in ‰): very high-grade gold >950, high-grade gold 950-900, medium-grade gold 900-800, and low-grade gold 800-600

4. Mineralogical and geochemical features of native gold
The Yelovy creek. On the right tributary of the Malyj Nimnyr river, the creek flows through the metamorphic rocks of the pre cambrian Nimnyr formation and quaternary sediments (figure 2). The mesozoic multiphase syenite Medvedev massif is located in the headwaters of the creek. Single grains varying in size from 0.19 to 0.32 mm present native gold in the placer occurrences of the Yelovy creek. Their roundness and shape is varied, there are both medium and well-rounded elongated and
flattened individuals, as well as poorly processed crystals, and isometric, lumpy precipitates (figure 3 a, b). Rounded grains are characterized by flat, polished surface, smoothed edges and faces, and rounded shapes (figure 3 c, d, e).

**Figure 3.** A, b – microphotographs of native gold grains with medium and low roundness; c, d, e – with fine roundness, white and black scale lines in all microphotographs = 100 µm; f – histogram of the native gold fineness distribution.

The gold fineness varies from 827 to 965 ‰. The admixture elements Cu, Pd, and Ni are observed as traces. Quartz and Fe-aluminosilicates are frequently found as mineral inclusions. High-grade gold prevails in the watercourse, the average-grade gold content is about 30% (figure 3 f), and a single grain of very high-grade gold (965 ‰) was also detected. The mesozoic multiphase Medvedev massif is located at the headwaters of the Yelovy Creek. It has similar petrographic characteristics of the rocks that produce gold mineralization in the Lebedinsky deposit, in the Central Aldan ore region. The varying extent of the roundness and fineness of gold from this creek could be attributed with the input of gold from various sources. Poorly processed gold grains of the medium fineness are probably associated with mineralization formed during alkaline syenite magmatism. It is possible that well processed gold of high and very high fineness was formed from the other sources.

**The Yagodny site.** The site is located on the right tributary of the Medvedevka river. The creek basin is located within the Nimnyr formation, Lower Fyodor and Middle Fyodor subformations, and the zones of olivine-pyroxene hornblendites, poorly-defined granites and granite-gneisses, precambrian diabases, mesozoic augite-hornblende syenites, and quaternary deposits (figure 2). In the alluvial deposits of the creek, native gold is present in the form of grains ranging from 0.21 to 1.13 mm in size. The morphology of the studied grains is diverse. Rounded isometric, elongated (figure 4 a) and flattened grains are observed, as well as poorly rounded irregular individuals. The latter are characterized by isometric, less often lumpy and tabular shapes with uneven roughness and occasionally curved edges and indentations (figure 4 b). Microprobe analysis of native gold detected admixture elements - Cu (up to 0.19 %), Pd (up to 0.06%), and Ni (up to 0.06 %). The fineness of native gold varies from 812 to 997 ‰. The decrease of the fineness to 812 ‰ is due to the detection of a single grain with an Ag admixture up to 18.83%. The gold fineness distribution diagram clearly shows this, marking a single peak in the 980-1000 ‰ fineness zone (figure 4 f). Micro-inclusions are represented by quartz, pyroxene, Fe-aluminosilicates, and maldonite (figure 4 c).
The association of gold with maldonite in the P. Pinigin deposit was described in [7]. In the ores of the deposit, we discovered maldonite fringe on gold (figure 4 d). It is possible that the primary sources for native gold of very high fineness from Yagodny site are similar in geochemical features to the ore bodies of the P. Pinigin deposit. No mineral inclusions or admixture elements have been identified in a single gold grain of medium fineness (812 ‰), it is characterized by medium grade of roundness and is probably associated with the primary sources formed as a result of the extensive alkaline syenite magmatism of the Medvedev massif and swarm of dikes (figure 2).

![Figure 4](image)

**Figure 4.** Native gold, maldonite micro-inclusions and histograms of the native gold fineness distribution in the Yagodny site and the P. Pinigin deposit. A, b – morphological features of gold; c – maldonite in gold grain from the Yagodny site; d – maldonite fringe on gold from the P. Pinigin deposit; e, f – histograms of the native gold fineness distribution in the P. Pinigin deposit and the Yagodny site.

**The Zolotoy site.** The site is located on the left tributary of the Malyj Nimnyr river. The creek drains the rocks of the Nimnyr formation, Lower Fyodor subformation, olivine-pyroxene hornblendites, as well as the precambrian diabases (figure 2). It should be noted that earlier reports [1, 5] demonstrated the presence of the lower cretaceous dikes of alkaline syenite-porphyry and late cretaceous dikes of hornblende quartz syenite in the headwaters of the creek. In a later report [4], igneous rocks of similar composition and age are placed to the west and are not drained by this watercourse. Native gold is shown in the form of isometric, rounded, less often irregular elongated and flattened precipitates of 0.35 to 0.83 mm in size. Varying grades of roundness, from low and medium to fine, are characteristic of the gold grains. Grains with medium and low roundness frequently have angular shapes, indentations at the edges, and rough, uneven surface (figure 5 a). Grains of the fine degree processing have a relatively flat surface and rounded edges (figure 5 b). According to the data of the microprobe analysis, the fineness of gold varies from 805 to 1000 ‰, with admixture elements of Cu, Fe, Pd, and Ni. Quartz, Fe-aluminosilicates, and bismuthite are the inclusions detected in gold. It was established that one of the grains of very high fineness consists of an intergrowth of bismuthite and native gold (figure 5 c). Earlier, during the study of native gold of the P. Pinigin deposit, similar intergrowths were found (figure 5 d). In addition, two gold particles with a distinct (up to 20 microns) high-grade shell were found in this site (figure 5 e). Central part of one of the particles demonstrates 865 ‰ fineness, whereas the fineness of the marginal part reaches 1000 ‰. It should be noted that different morphological features are characteristic of gold grains of different fineness. Very high-grade...
and high-grade gold are characterized by medium and low roundness, while medium-grade gold grains are characterized by fine roundness, which indicates the possible presence of various sources for the gold grains of these groups.

Figure 5. Gold grains morphology, internal structure, and histogram of the native gold distribution in the Zolotoy site. a, b – gold morphology; c, d – intergrowths of bismuthite from the Zolotoy site and P. Pinigin deposit; e – high-grade shell on medium-grade gold; e – histogram of the fineness distribution in Zolotoy cite.

The Sukhoy site. The creek flows through the rocks of the Nimnyr formation, the Lower Fyodor subformation, granites, and poorly-defined precambrian granite-gneisses (figure 2). In alluvial deposits, native gold was detected in the form of single grains of 0.29 to 0.62 mm in size. The degree of gold grain processing varies, both fine- and medium-rounded (figure 6 a) precipitates have been identified. Most of the grains have isometric or slightly elongated shape; flattened and tabular individuals are rarely found (figure 6 b). According to the data of the microprobe analysis, all grains are classified as very high-grade gold, with fineness ranging from 993 to 1000 ‰. Admixture elements Cu (up to 0.18 %), Fe (up to 0.04%), Pd (up to 0.04 %), and Ni (up to 0.04%) were detected. Histogram of the native gold fineness distribution demonstrates the single peak in the 980-1000 ‰ fineness zone (figure 6 c). Mineral inclusions are represented by quartz, K-feldspar and poorly identified Fe-aluminosilicates. Native gold with fineness up to 1000 ‰ indicates possible presence of the P. Pinigin type ore occurrences on this territory.

Figure 6. Morphological features and histogram of the native gold distribution of the Sukhoy site. a, b – native gold morphology; c - histogram of the native gold fineness distribution.
The Evota river. The river drains the rocks of the Nimnyr formation, Lower Fyodor subformation, olivine-pyroxene hornblendites, as well as the precambrian diabases. A large mesozoic multiphase syenite Evota massif is located at the headwaters of this watercourse. The grains of native gold discovered at this site range from 0.28 to 0.38 mm in size. Most of the gold grains are well rounded, as indicated by the rounded shape, smoothed edges, and flat polished surface (figure 7 a, b). Grains are characterized by a predominance of flattened, elongated, and tabular shapes, and less frequently isometric. The gold fineness detected by microprobe analysis varies from 878 to 998 ‰. The admixture elements of Cu, Pd, and Ni were found.

Figure 7. Morphological features and histogram of the native gold distribution in the Evota river. a, b – native gold morphology; c - histogram of the native gold fineness distribution.

Mineral inclusions are represented by quartz and poorly identified Fe-aluminosilicates. Histogram of the gold fineness distribution demonstrates that deposits of this watercourse contain gold of the medium, high, and very high fineness (figure 7 c). Presumably, the presence of very high-grade gold grains (up to 998 ‰) in the watercourse is due to the fact that the previously discussed Sukhoy site, that is the source of this gold, flows into the area above the sampling point. It should be noted that gold grains of medium and high fineness were not detected in the Sukhoy site. The presence of medium and high fineness gold in the Evota river valley could possibly indicate the input of gold grains from mineralization formed during the occurrence of mesozoic alkaline magmatism in the upper reaches of the watercourse.

Table 1. Typomorphic features of placer gold from the Malyj Nimnyr river basin.

| Site   | Numbr. of grains | Shape          | Size (mm) | Roundness | Fineness (%) | Adm. elem. | Mineral inclusions         |
|--------|------------------|----------------|-----------|-----------|--------------|------------|---------------------------|
| Yelovy | 6                | Elongated      | 0.19 – 0.32| Fine      | 827 - 965 medium-grade - 33 % | Cu, Pd, Ni | Quartz Fe-Al-silicates    |
|        |                  | Flattened      |           | Medium    |              |            |                           |
|        |                  | Isometric      |           | Low       |              |            |                           |
| Yagodny| 9                | Elongated      | 0.21 – 1.13| Fine      | 812 - 997 medium-grade - 11 % | Cu, Pd, Ni | Quartz Pyroxene Fe-Al-silicates Maldonite |
|        |                  | Flattened      |           | Medium    |              |            |                           |
|        |                  | Isometric      |           | Low       |              |            |                           |
|        |                  | Irregular      |           |           |              |            |                           |
| Zolotoy| 9                | Isometric      | 0.35 – 0.83| Fine      | 805 - 1000 medium-grade - 55 % | Cu, Fe, Pd, Ni | Quartz Fe-Al-silicates Bismuthite |
|        |                  | Rounded        |           | Medium    |              |            |                           |
|        |                  | Flattened      |           | Low       |              |            |                           |
| Sukhoy | 6                | Isometric      | 0.29 – 0.62| Fine      | 993 - 1000 medium-grade - 0 % | Cu, Fe, Pd, Ni | Quartz K-feldspar Fe-Al-silicates |
|        |                  | Elongated      |           | Medium    |              |            |                           |
|        |                  | Flattened      |           | Low       |              |            |                           |
| Evota  | 6                | Flattened      | 0.28 – 0.38| Fine      | 878 - 998 medium-grade - 33 % | Cu, Pd, Ni | Quartz Fe-Al-silicates    |
|        |                  | Isometric      |           |           |              |            |                           |

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5. Discussion
This preliminary discussions were based on small amounts of material collected during field studies of the Nimnyr river basin, alluvial deposits of the Yelovy creek, Yagodny, Zolotoy, and Sukhoy sites, as well as the Evota river. The study of placer gold revealed that gold is comprised of single grains of predominantly lumpy, tabular shape, with a size of 0.19-1.13 mm, low and medium roundness, high and medium fineness, and similar admixture elements and mineral inclusions (table 1).

The obtained data showed that the studied sites are dominated by gold of high fineness and varying roundness. In some watercourses, such as the Sukhoy site, only very high-grade gold (993-1000 ‰) is found. The presence of high-grade gold (Sukhoy site), intergrowths of bismuthite and gold (Zolotoy site), and maldonite inclusions (Yagodny site) indicate that ores of the P. Pinigin type could have been the primary sources of native gold. At certain sites (Yelovy creek, Evota river), medium and very high-grade gold was found, with fineness ranging from 827 to 998 ‰. The presence of medium-grade well-processed gold in the studied watercourses (Yelovy creek, Yagodny site, Zolotoy site, Evota river) indicates an additional input of gold from primary sources, that may have been formed as a result of the Mesozoic alkaline magmatism.

6. Conclusions
Thus, it has been established that chemical compositions and microinclusions of the high-grade gold distinctly indicate a genetic relationship with primary sources similar to the P. Pinigin deposit. Presumably, gold of medium fineness and fine roundness was formed due to the formation of the gold mineralization typical for the deposits of the Central Aldan ore region.

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