Mineralogical Method as an Effective Way to Predict Gold Ore Types of Deposits in Platform Areas (East of the Siberian Platform)

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Abstract: The study of the mineralogical and geochemical features of placer gold and the mechanisms of its distribution in the territory east of the Siberian platform, overlain by a thick cover of Mesozoic–Cenozoic deposits, where traditional methods of searching for gold fields are not effective, allowed researchers, for the first time, to establish the stages of ore formation and to predict the types of gold deposits and their location. The identified indicators of placer gold (morphology, granulometry, chemical composition, micro-inclusions, and internal structures) indicate that ore occurrences in both the Precambrian and Mesozoic stages of ore formation were primary sources of placer gold. The identification of characteristic indicators in placer gold for certain types of gold deposits allowed researchers to prove the formation of gold ore sources east of the Siberian platform for the first time: low-sulfide quartz gold, gold–ferruginous quartzite, gold–copper–porphyry, and gold–platinoid formations are found in the Precambrian stage of ore formation and gold–silver, gold–sulfide–quartz, and gold–rare metal formations are found in the Mesozoic stages of ore formation. Thus, for the first time, based on a huge amount of factual material, it is proved that the mineralogical and geochemical features of placer gold carry enormous information about both the endogenous origin of gold (stages of ore formation—Precambrian and Mesozoic) and the expected type of formation of the predicted deposits. It is established that the predicted type of ore sources corresponds to a certain geological and structural position; this contributes to a more correct selection of methods for searching for ore and placer gold deposits in closed territories and assessing their prospects. In general, the application of the mineralogical method for the first time makes it possible to develop criteria for predicting resources and types of gold deposits, and to assess the prospects of gold mining potential in platform areas at a new level of knowledge.

Keywords: placer gold; mineralogical and geochemical features; stages of ore formation; geological and structural positions; deposits; forecasting; east of the Siberian platform

1. Introduction

The placer gold content in the east of the Siberian platform was established at the end of the 19th century; however, gold deposits have not yet been identified in this area, since this area is covered by a thick cover of the Mesozoic–Cenozoic sediments. Currently, researchers’ points of view on the nature of ore gold content are acutely debatable, and it is unclear what types of gold deposits are formed in this area and with what geological and structural positions they are associated. The research area in the east of the Siberian Platform includes the Lena–Anabar in the northeast, the Lena–Vilyui interfluve in the southeast, and the basin of the middle course of the Lena River (Figure 1).
The studied area covers the eastern part of the Siberian Platform. The basement of the platform is composed of crystalline rocks of the Archean and has a folded-block structure. The Archean metamorphic basement rocks, represented by crystalline shales, crystalline gneisses, quartzites, and terrigenous-carbonate rocks, are widely developed on the Aldan and Anabar shields. The Proterozoic terrigenous formations can be traced in the areas of the basement outcrops. The platform cover is composed mainly of the Paleozoic–Mesozoic terrigenous–carbonate deposits, such as sandstones, limestones, and dolomites with interlayers of conglomerates.

Intrusive bodies of the sedimentary cover of the platform are represented by the Middle Paleozoic dikes and sills of basic and alkaline–basic composition. The Late Proterozoic gabbro-dolerites and leucocratic dolerites can be traced in the area of the Urinsky anticlinorium and the Udzhinsky uplift. Archean–Mesozoic magmatic complexes of different age from ultrabasic to acidic composition are widespread on the Aldan and Anabar shields and on the territory of the Olenek uplift. Hornfelsing and marbling of the host rocks, as well as skarnification, amphibolization, chloritization, serpentinitization, carbonatization, and pyritization are observed with varying degrees of intensity in the zones of exocontact intrusions. Confinedness of magmatic formations of different ages to the fault zones in-
icates the repeated occurrence of the Mesozoic tectonic–magmatic activation in the east of the Siberian Platform, creating potential grounds for the formation of gold ore sources. The poorly consolidated Cenozoic sediments of diverse genesis are widespread throughout the studied area—these are alluvial, aeolian, and deluvial deposits of the Lower, Middle, Upper Quaternary, and modern age.

There are a number of assumptions about the types of ore sources, of which we will consider only the main ones. Previously, researchers assumed that the gold ore bodies of the Baikal–Patom folded belt were the sources of placer gold content [2]. Later, many scientists came to the conclusion that placer formation occurred due to local sources—gold-bearing sulfidized metamorphic rocks and ferruginous quartzites of the Archean, as well as quartz–carbonate veins of the Early Proterozoic [3,4]. Some predecessors believed that the placer gold content was partially formed due to gold ore occurrences, related to trap bodies and intrusions of acid composition [5], and also due to gold-bearing metasomatic formations, which occurred in the terrigenous strata of the Paleozoic, spatially confined to zones of faults [6].

In the 1970s, the largest organizations of the USSR actively searched for ore sources, including the All-Russian Scientific Research Geological Institute (VSEGEI), Scientific Research Institute of Arctic Geology (NIIGA), and the Institute of Geology of the Siberian Branch of the Russian Academy of Sciences (IG SB RAS). Much attention was paid by researchers to the search for ancient gold-bearing conglomerates of the Witwatersrand type [3,4], as well as the identification of the gold ore potential of the widely occurring basitic magmatism [2,5]. Traditional methods of prospecting for gold deposits have not brought positive results, since this area is covered by a thick cover of the Mesozoic–Cenozoic sediments. In this regard, it became necessary to study the typomorphic features and mechanisms of distribution of placer gold, which carry enormous information about the primary types of ore sources.

2. Materials and Methods

In order to predict the type of ore source and to determine its location, a mineralogical method is proposed—the study of mineralogical–geochemical features of placer gold and the mechanisms of its location [7]. The article is based on the results of field work and mineralogical and geochemical studies of placer gold and the mechanisms of its distribution in the east of the Siberian platform.

It is proved that placer gold carries information about both the endogenous origin of gold and its change in exogenous conditions depending on the environment [8]. Based on the study of morphology (size, shape, surface) of placer gold, chemical composition (fineness, impurity elements), and micro-inclusions, it has become possible to predict the types of ore sources and the stages of ore formation [9–11]. This method has been successfully applied in the study of the ore-placer Khatyrkhai gold-bearing cluster in the south-east of the Siberian platform, where it was necessary to determine the type of ore source [12]. A comparison of the mineralogical and geochemical features of placer gold and the mineralogy of the gold-bearing ores of the Khatyrkhai ore-placer cluster allowed us to establish that the identified micro-inclusions in placer gold (sulfides, tellurides, oxides, etc.) fully correspond to the mineralogical composition of gold-bearing ore occurrences (Figure 2).

The results obtained convincingly prove that the type of ore source can be clearly determined by the identified indicators in placer gold. In this case, the primary source of placer gold in the Khatyrkhai ore placer field is the gold skarn (Lebedinsky) type of mineralization.
Furthermore, as a result of studying the mechanisms of distribution of placer gold with indicators characteristic of certain minerogenic types, it was found that in the east of the Siberian platform, the predicted types of gold deposits are located in various geological structures. It is proved that the identified minerogenic type of gold deposits corresponds to a certain geological and structural position [14].

Identified patterns made it possible to develop a method for predicting minerogenic types of gold deposits based on the indicators of placer gold and features of their distribution and to link them with various geological structures for the first time [15]. Similar studies on the mineralogy of placer gold, in order to identify the types of ore sources and the genesis of placers, have been successfully conducted and continue to be developed by Russian scientists [16–22] and also by foreign researchers [23–37] The study of the typomorphic features of placer gold (morphology, chemical composition, micro-inclusions, internal structure) in order to identify minerogenic types of ore sources was carried out using well-known mineralogical and geochemical methods. All analyses were performed in the

**Figure 2.** Minerals of gold-bearing ore (A) and micro-inclusions in placer gold (B) of the Khatyrkhai ore-placer field. Minerals: Tbi-tellurovismuthite; Ccp-chalcopyrite; Qz-quartz; Mnz-monazite; Sm-smyrite; Py-pyrite; Gn-galena; Sp-sphalerite; Tnt-tennantite; Hem-hematite; Brt-barite; Au-gold; Gth-goethite; Kfs-potassium feldspar. The abbreviations of mineral names are given according to the generally accepted international classification [13].
laboratory of physical–chemical methods of analysis of the Diamond and Precious Metal Geology Institute, SB RAS (DPMGI SB RAS), Yakutsk (Russia). Well-known sieves were used to obtain granulometric data (the size of the gold particles). Placer gold was poured through sieves of more than 1 mm, 1–0.5 mm, 0.5–0.25 mm, 0.25–0.16 mm, 0.16–0.1 mm, and less than 0.1 mm. The study of the morphology, surface structures, and internal structure of the gold particles was carried out using a scanning electron microscope “JEOL JSM-6480LV” (Japanese Electron Optics Laboratory, Tokyo, Japan), stereoscopic microscope “LEICA MZ6” (KaVo, Biberach an der Riss, Germany), and an ore microscope “JENAVERT SL 100” (Carl Zeiss AG, Oberkochen, Germany). The trace element composition of native gold was analyzed on an X-ray microanalyzer, “JXA-50A”, “JSM-6480LV” (Japanese Electron Optics Laboratory, Tokyo, Japan). The content of impurity elements in it was studied by the atomic emission spectrography (PGS-2, East Germany, Oberkochen). Micro-inclusions in native gold were identified using a scanning electron microscope “JEOL JSM-6480LV”, with an energy-dispersive spectrometer, namely the Energy 350 of Oxford Instruments (London, UK). Oxford Instruments INCA software, namely the microanalysis Suite Issue v.4.17, was used. Quantitative analysis and processing of the results were carried out using the XPP method in the software INCA Energy (Software Oxford Instruments INCA the microanalysis Suite Issue v.4.17). The shooting conditions were as follows: an accelerating voltage of 20 kV, probe current of 1.07 nA, and the time of spectrum acquisition during quantitative optimization on cobalt and samples was 20 s. For example, the lower limits of the 156 determined contents were 0.6% Au, 0.2% Ag, 0.8% Hg, 0.1% Fe, 0.1% Cu, … The following 157 X-ray lines were selected: Kα for Fe, Cu, S, and O; Lα for Pd, Ag, and Sb; and Mα for Au 158 and Hg. The following standards were used: pure metals (Fe, Cu, Pd, Ag, Au) and InAs for As and Hg. Standards were as follows: Au M, Ag L-Au 750, Hg M-HgTe, Cu K-Cu, Mg K-olivine, Ti Ka-ilmenite GF-55, Al K, Na K, Si Ka-albite, Cr K-chromite 531M-8, S K, Fe K-pyrite, Pt-Pt, Pd-Pd, K K-orthoclase, and As L-arsenopyrite.

The error in determining of main components is <1–2 rel.%, trace elements is <10 rel.%. Standards were as follows: Au M, Ag L-Au 750, Hg M-HgTe, Cu K-Cu, Mg K-olivine, Ti Ka-ilmenite GF-55, Al K, Na K, Si Ka-albite, Cr K-chromite 531M-8, S K, Fe K-pyrite, Pt-Pt, Pd-Pd, K K-orthoclase, and As L-arsenopyrite.

3. Results
For the first time, based on the results of studying the mineralogy of placer gold and the mechanisms of its distribution in the east of the Siberian Platform, two types of native gold with certain typomorphic features and corresponding to two stages of ore formation—Precambrian and Mesozoic—have been explained [9].

The first type of placer gold is represented by well-rounded scaly and lamellar shapes, 0.1–0.25 mm in size with a coarse–shagreen, coarse–pitted surface, sometimes with casts from the pressing of the minerals of the host deposits. It is characterized by pseudo-intergrowths of gold with rounded quartz, ilmenite, zircon, and other minerals, indicating its supply from ancient gold-bearing deposits. Gold particles have high fineness (900‰–999‰), a minor range of impurity elements, and single micro-inclusions of pyrite and arsenopyrite. The internal structure of gold has been significantly transformed and is represented by primary recrystallization and secondary recrystallization structures with lines of plastic deformations and thick high-grade shells (10–30 microns), indicating its prolonged stay in exogenous conditions.

The second type of placer gold is characterized mainly by a larger size (0.25–2.0 mm), lamellar and lumpy forms, and sometimes an ore habit. The gold fineness varies between 500‰–900‰, and medium- and low-grade varieties prevail. The content of Ag varies between 12%–40%, with Hg up to 6%, and Cu of 0.1–4 wt.%. A wide range of impurity elements is identified in gold, including Fe, Pb, As, Sb, Zn, Te, Bi, etc. The internal structure of gold is practically unchanged; it is characterized by mono-grains and coarse–medium-grained structures, and fragments of very thin high-grade shells are sometimes noted. In addition, it records unclear zonal and inter-block structures, granulation, and disintegration, as well as porosity typical for near-surface deposits [16–18].
3.1. Indicators of Placer Gold of Ore Formations of the Precambrian Stage of Ore Formation

The identification of characteristic indicators in placer gold of type I of the Precambrian stage of ore formation made it possible for the first time to prove the formation in the east of the Siberian platform of gold ore sources for low-sulfide gold–quartz, gold–ferruginous quartzite, gold–copper–porphyry, and gold–platinum formations (Table 1).

Table 1. Indicators of placer gold of ore formations of the Precambrian stage of ore formation.

<table>
<thead>
<tr>
<th>Types of Gold Ore Formations</th>
<th>Characteristics of Placer Gold</th>
<th>Granulometry (Mm)</th>
<th>Shape</th>
<th>Fineness (%)</th>
<th>Impurity Elements</th>
<th>Micro-Inclusions</th>
<th>Internal Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-sulfide gold–quartz</td>
<td></td>
<td>&lt;0.1–0.25, less often &gt;0.25</td>
<td>Scaly, lamellar</td>
<td>900–999</td>
<td>Ag &lt; 20 wt.%, Cu 0.1 wt.%</td>
<td>Pyrite, arsenopyrite, quartz, carbonate</td>
<td>Primarily recrystallized, secondarily recrystallized, strain lines, high-grade shells up to 20 microns or more</td>
</tr>
<tr>
<td>Gold–copper–porphyry</td>
<td></td>
<td>&lt;0.1–0.25; &gt;0.25</td>
<td>- -</td>
<td>950–999</td>
<td>Cu 0.5–1 wt.% to 4 wt.%</td>
<td>Not detected</td>
<td>- -</td>
</tr>
<tr>
<td>Gold–platinoid</td>
<td></td>
<td>&lt;0.1–0.5</td>
<td>- -</td>
<td>950–999</td>
<td>Pt 96 g/t, (sometimes up to 1130 g/t), Pd 5–570 g/t, (sometimes up to &gt;1015 g/t), Ni 5–100 g/t, Cu &lt; 1.5 wt.% (sometimes up to 27 wt.%), Hg 0.2–0.5 wt.%</td>
<td>Mineral phases of the Pt group, growths of gold (Au–95.95%, Pd–4.12%, Ag–1.36%) and platinum (Pt–87.95%, Fe–10.95%)</td>
<td>- -</td>
</tr>
<tr>
<td>Gold–ferruginous quartzite</td>
<td></td>
<td>&lt;0.1–0.25</td>
<td>- -</td>
<td>950–999</td>
<td>Fe—68 g/t and more</td>
<td>Hematite, magnetite, corundum</td>
<td>- -</td>
</tr>
</tbody>
</table>

Note: Impurity elements Ag, Cu, Hg—determined by microprobe analysis (wt.%), Fe, Pt, Pd, Ni, Bi—atomic emission spectral analysis (g/t). Department of physical–chemical methods of analysis of DPMGI SB RAS. Analysts: Korkina S.Y. and Naryshkina E.L.

Low-sulfide gold quartz formation. Characteristic indicators of placer gold have been established for ore sources of the low-sulfide gold–quartz formation of the Precambrian stage of ore formation, namely high fineness, micromineral inclusions of pyrite, arsenopyrite, quartz, and carbonates, the presence of recrystallization structures, and lines of plastic deformations.

Based on the identified indicators in placer gold, this type of mineralization is predicted in places with basement outcrops and their framings. Gold is represented mainly by scaly shapes, and less often by thin platy forms of a fine fraction (0.1–0.25 mm) and high fineness (900‰–999‰) (Figure 3a–c). Gold has a homogeneous Au-Ag composition.

Gold is characterized by completely primarily recrystallized internal structures, continuous high-grade shells up to 20–40 microns, and traces of plastic deformations in the form of numerous translation lines, sometimes leading to the complete or partial disappearance of the primary hypogenic granular structure; as a result, gold acquires a stratified structure (Figure 3d–f). The identified internal structures of placer gold indicate its prolonged stay in exogenous conditions and are characteristic of ancient repeatedly redeposited gold from the Precambrian levels to younger Quaternary deposits [9]. As a result of the analysis of the composition of the microminerals enclosed in the matrix of gold particles, micro (1–5 microns) inclusions of sulfides were found; considering the elemental composition, they correspond to pyrite and arsenopyrite (Figure 3g,h). These micro-inclusions are located directly in the matrix of gold particles, away from the marginal parts, which asserts their
syngenic endogenous origin. In gold, there is a predominance of micro-inclusions of rock, forming minerals; quartz dominates in percentage terms (Figure 3i), followed by feldspars and carbonates. In general, identified indicators of placer gold, namely, high fineness (950‰–999‰), micromineral inclusions of pyrite, arsenopyrite, quartz and carbonates, the presence of primary recrystallization structures, and lines of plastic deformations are characteristic of the primary sources of the low-sulfide gold–quartz formation.

Gold–copper–porphyry formation. One of the indicators for the predicted deposits of the gold–copper–porphyry formation is an increased Cu content (up to 4% or more) in high-grade scaly gold. Gold with such typomorphic features with a stable Cu content from 0.3%–0.5%, and in isolated cases from 1 to 4%, was found in the Bol. Kuonapka River basin of the Anabar Shield and its framing (Figure 4c). Earlier, A.V. Tolstov [38], based on the identification of an increased copper content in placer gold up to 4.5% or more, also suggested the formation of this type of mineralization in the Billyakh deep fault zone (Borosku site, Anabar River). Later, A.P. Smelov et al. [39] found that in the Billyakh zone, an increased Au content of up to 2.5 g/t in igneous rocks of the granitoid massif and its host metamorphic complexes (plagiogneisses, granite gneisses, crystalline schists) allowed them to predict the formation of gold–copper–porphyry deposits in this area. A.A. Kravchenko et al. [40] also confirmed the gold–copper–porphyry type of mineralization in the Billyakh

Figure 3. Indicators of placer gold characteristic of ore sources of the low-sulfide gold–quartz formation. (a–c) scaly shapes with casts of pressing of minerals of the host rocks; (d–f) internal structures of placer gold: (e) dense high-grade shell, (f) strain lines, (d) the primary recrystallization structure of high-grade gold; (g–i) micro-inclusions in the matrix of gold particles (Au): (g) pyrite (Py), (h) arsenopyrite (Apy), and (i) quartz (Qz).
and Kotukai zones of tectonic mélange, in schistose granitoids and host gneiss with sulfide mineralization, where they have identified a gold content of up to 2.7 g/t.

Figure 4. Indicators characteristic of ore sources of the gold–copper–porphyry formation. Diagrams: (a) granulometry, (b) fineness, and (c) content of micro-impurity Cu (wt.%) in placer gold.

**Gold–ferruginous quartzite formation.** The indicators of placer gold for the mineralization of the gold–ferruginous quartzite formation include scaly gold particles, sometimes angular forms of ore habit, a very fine fraction, high fineness, completely primarily recrystallized and secondarily recrystallized internal structure of gold particles, the constant presence of trace amounts of Fe, Bi, and micro-inclusions of hematite, ilmenite, and corundum (Figure 5). Such gold, along with gold of the low-sulfide gold–quartz formation, was found in the north-west of the Aldan Shield in placer occurrences of the middle course of the Tokko River and its tributary, the Torgo River. This gold is characterized by exceptionally high fineness (950‰–999‰) and a very small size (~0.1–0.25 mm) and it is represented mainly by scaly, thin platy (Figure 5a–c), and sometimes lumpy forms of ore habit with a completely primarily recrystallized and secondarily recrystallized internal structure.

Figure 5. Indicators of placer gold characteristic of ore sources of the gold–ferruginous quartzite formation: (a) scale; (b) granulometric composition (mm); (c) fineness (%); (d–f) micro-inclusions in gold: hematite (Hem), corundum (Crn), ilmenite (Ilm).

Spectral analysis in gold has determined the stable presence of elemental impurities, namely Fe (0.0068%) and Bi (0.0016%), and microprobe analysis determined the presence of Cu (>0.1%). Permanent micro-inclusions of hematite, ilmenite, and corundum are also revealed in it (Figure 5d–f). This gold is similar in typomorphic features to visible native gold from ferruginous quartzites of the Borchalinskaya formation of the Archean of the western part of the Aldan Shield [41], where, in addition to finely-dispersed gold, visible fine and very fine gold (0.04–0.25 mm) of a very high fineness was found (~950‰). It is represented by angular scaly, lamellar, isometric, and irregular shapes with a rough pitted surface. In ferruginous quartzites, this gold is associated with magnetite and hematite, impurity elements are represented by Fe, Bi and an increased amount of Cu. The identified
similarity of native gold indicates that the ore sources for placer occurrences of the middle reaches of the Tokko and Torgo rivers were probably ferruginous quartzites of Archean age, in which the content of 0.6 to 1 g/t of gold was previously determined by assay test. In addition, the presence of hematite and pebbles of quartzite composition is observed in the stream bed alluvium of these watercourses, which also indicates a gold–ferruginous quartzite type of source. The discovery of the following indicators in gold—a fine fraction of 0.1–0.25 mm, scaly, thin platy, and lumpy forms of ore habit, exceptionally high fineness (>950‰), the existence of permanent Fe, Bi, and Cu impurity elements, and the presence of micro-inclusions of hematite, ilmenite, and corundum, as well as structures of complete primary recrystallization and secondary recrystallization—are confirmed by the presence of well-known gold deposits of the gold–ferruginous quartzite formation in this region, which are widespread in the territory of South Yakutia (iron ore deposits at Tarynnakhskoye, Ymalakhskoye, etc.), where the gold content is set to 10 g/t [41]. Similar gold to the gold–ferruginous quartzite formation with a size of 0.1–0.25 mm was also found in the ferruginous sandstones of the Proterozoic age of the Udokan deposit, where the gold content is set to 2.5 g/t [42].

**Gold–platinoid formation.** The following indicator signs of placer gold have been established for ore sources of the gold–platinoid formation: scaly and lamellar shapes, high fineness with stable impurity elements of Pt, Pd, and Ni, and sometimes the presence of mineral phases Pt and intergrowths of Au and Pt in gold is noted. Ore sources of the gold–platinoid formation are predicted for the first time in the framing of the Suntar Arch (the basins of the Kempendiai, Buyaginskaya, Tenkinskaya Nurchuku rivers, etc.) and Anabar Shield (the Bol. Kuonapka River basin) based on the discovery of the stable impurity elements Pt, Pd, and Ni in high-grade scaly gold (Figure 6a), as well as mineral phases of Pt and intergrowths of Au-Pt (Figure 6b–e).

In the framing of the Suntar Arch in the right-bank tributaries of the Vilyui River according to the results of spectral analysis (more than 100 objects), in high-grade scaly gold with an increased Cu content of up to 2 wt.%, in fractions 0.1–0.25 mm, the constant presence of the trace impurity Pt was 96 g/t (in single samples up to 1130 g/t), for Pd it was 5–570 g/t (in single samples > 1015 g/t), and for Ni it was 5 g/t (in single samples up to 100 g/t) was revealed (Figure 6a). This gold is characterized by recrystallized internal structures, Luders’ lines, and a wide development of intergranular high-grade veinlets. Discovery of inclusions of an exotic mineral phase of the Pt group in a number of gold particles is also evidence of the presence of ore sources of the Au–Pt formation in the studied area (Figure 6b). In addition, as a result of spectral quantitative analysis of a large gold particle (>2 mm) from the channel deposits of the Chara River (south-east of the Siberian platform) similar impurity elements, namely Pt (16 g/t), Pd (from 6–52 g/t), and Ni (40 g/t), were found [43]. The set of indicators identified in placer gold—high fineness, Cu content (up to 2 wt.%), and the constant presence of the impurity elements Pt, Pd, and Ni, as well as inclusions of the exotic mineral phase of the Pt group—allows us to predict the mineralization of the gold-platinoid formation within the Suntar Arch uplift, probably related to the widespread basitic magmatism of the Early Proterozoic and later ages. The connection of gold ore sources with basitic magmatism is confirmed by previously obtained data by V.L. Masaitis et al. [5], who revealed gold ore occurrences in trap formations with a gold content of up to 1 g/t, provided the basis for their search for gold deposits in the fields of development of basitic magmatism. Later, V.M. Mishnin et al. [44], based on the analysis of geophysical studies, associated the prospects of the Precambrian ore content with widespread basitic magmatism.

Mineralization of the gold-platinoid formation is also predicted in the basin of the Bolshaya Kuonapka River (Anabar Shield) based on the detection of the trace impurities Pd (from 4 to 7 wt.%), Cu (up to 4 wt.%), and Hg (0.1–0.5 wt.%) by microprobe analysis in high-grade lamellar gold (Figure 6c); according to the results of spectral analysis, Pt is found up to 0.026% and Ni is found up to 0.011%, while ferruginous platinum inclusions have also been found in gold (Figure 6d). The discovery of palladium gold individuals in
growth with ferruginous platinum is evidence of a single source of gold and minerals of platinum group (MPG) [45], as well as the joint presence of Au and Pt group minerals in the heavy fraction of the concentrate, represented by polyxene (60%), rhodic platinum (25%), hongshiete (6%), and palladium platinum (9%). Discovery of palladium gold individuals in growth with ferruginous platinum, as well as the joint presence of Au and Pt group minerals in the heavy fraction of the concentrate, represented by polyxene (60%), rhodic platinum (25%), hongshiete (6%) and palladium platinum (9%), are evidence of a single source of gold and MPG [45]. The predicted mineralization of the gold–platinoid formation are probably localized in the stratified norite–anorthositic plutons of the Kotuikan–Monkholin zone of the Anabar Shield, where, according to D.A. Dodin [46], the contents of Au (up to 0.5 g/t), Pd (up to 0.17 g/t), and Pt (up to 0.11 g/t) are determined.

Figure 6. Indicators of gold typical of ore sources of the gold–platinoid formation: (a) the content of impurity elements in the placer gold of the Lena–Vilyui interfluve (atomic emission spectral quantitative analysis), N—number of detections; (b,c) inclusions of exotic Pt and Ti phases in gold; (d) cross-section and chemical composition of palladium gold (%); (e) detail: intergrowth of palladium gold and ferruginous platinum.

3.2. Indicators of Placer Gold of Ore Formations of the Mesozoic Stage of Ore Formation

Identification of characteristic indicators in placer gold of type II of the Mesozoic stage of ore formation, characteristic of certain ore formations, allowed us, for the first time, to predict the formation of gold ore sources of gold–silver, gold–sulfide–quartz and gold–rare metal formations in the east of the Siberian platform (Table 2).
Table 2. Indicators of placer gold of ore formations of the Mesozoic stage of ore formation.

<table>
<thead>
<tr>
<th>Types of Gold Ore Formation</th>
<th>Granulometry (Mm)</th>
<th>Shape</th>
<th>Fineness (%)</th>
<th>Impurity Elements</th>
<th>Microinclusions</th>
<th>Internal Structures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold–silver</td>
<td>&lt;0.25–1–2 and more</td>
<td>Lamellar, tabular, lumpy</td>
<td>&lt;500–870</td>
<td>Ag &lt; 47.7 wt.%, Hg &lt; 1.46 wt.%, Pb 20–90 g/t, Zn 110–170 g/t, As 20–70 g/t (up to 1000 g/t), Sb 12–60 g/t, single Te 40 g/t</td>
<td>Strontium barite, arsenopyrite, pyrite, quartz, adular, calcite</td>
<td>Two-phase gold, porous structure</td>
</tr>
<tr>
<td>Gold–rare metal</td>
<td>&lt;0.25; 0.25–0.5 and more</td>
<td>Lamellar, tabular, lumpy, dendrite-like</td>
<td>&lt;400–990</td>
<td>Bi 480 g/t, Fe 1000 g/t, Cu 1109 g/t</td>
<td>Native bismuth, maldonite, arsenopyrite, silver tellurides</td>
<td>Medium-grained, unclear zonal, clearly zonal</td>
</tr>
<tr>
<td>Gold–sulfide–quartz</td>
<td>&lt;0.1–0.25–1–2 and more</td>
<td>Lamellar, tabular, lumpy</td>
<td>750–999</td>
<td>Hg up to 5 wt.%</td>
<td>Pyrite, arsenopyrite, calcite, tellurides, minerals with rare-earth elements</td>
<td>Coarse-grained, medium-grained, unclear zonal</td>
</tr>
</tbody>
</table>

Note: Impurity elements Ag, Cu, Hg—microprobe analysis (wt.%), Pb, Zn, As, Sb, Te, Bi, Fe, Cu—atomic emission spectral analysis (g/t). Department of physical–chemical methods of analysis of DPMGI SB RAS. Analysts: Korkina S.Yu. and Naryshkina E.L.

**Gold–silver formation.** The indicators of placer gold for mineralization of the gold–silver formation, predicted in the paleorift zones (Udzhai, Vilyui), are lamellar and lumpy fractions > 0.25–2.0 mm (Figure 7a–c), medium and low fineness, a high content of Ag and Hg, a wide range of micro-impurities, monocrystalline, sometimes porous internal structure (Figure 7d–f), and the presence of micro-inclusions of adular, strontium barite, and calcite (Figure 7g–i). Such a complex of identified indicators of placer gold is typical for gold of shallow low-temperature primary sources of the gold–silver formation [47].

Shallow mineralization of the gold–silver formation is predicted in the river sources of the Lena–Vilyui interfluve (Kempendyai, Namana, Tonguo, Chebyda, etc.) in the Kempendyai dislocation zone based on the discovery of the following indicators in placer gold: lamellar and lumpy shape, a fraction > 0.25–2.0 mm, medium and low fineness (from 500 to 870‰) with an increased high of Ag (up to 47.7 wt.%) and Hg (up to 1.46 wt.%), a wide range of impurity elements including Pb, Zn, As, Sb, Cu, Te, etc., as well as the presence of micron inclusions of native Ag and inclusions of adular, strontium barite, and calcite in native gold (Figure 7) [47]. The internal structures of placer gold differ mainly in their monogranular nature; there are multiphase and porous individuals, typical for native gold from near-surface low-temperature deposits [19,48]. It should be noted that in the stream bed alluvium of these rivers, along with abnormally high gold content (1.5 g/m³), there is a wide distribution of nonrounded grains of barite, hematite, and chalcedonic quartz. The evidence of formation of mineralization of the gold–silver formation is also provided by the data of the predecessors [49], who found quartz–calcite–barite veins with an Au content of up to 1.4 g/t in the Early Jurassic and Cretaceous sediments.

The primary sources of the gold–silver formation are also predicted in the northeast of the Siberian platform in the basin of the Udzhai River, based on the identification of an increased Ag content in placer gold (up to 60 wt.%), which often has a nonuniform zonal distribution, and the presence of microphases (1–2 microns) of native Ag, as well as a porous structure. The revealed indicators give us reason to assume the formation of ore occurrences of shallow gold–silver formations at the Biliro–Udzhai uplift; this is confirmed by the discovery of small chalcedonic quartz pebbles in the alluvial deposits of the Udzhai River, in which the smallest mineral phases of gold, silver, pyrite, and barite have been established by microprobe analysis [45].
with the occurrence of tectonic magmatic activation of the Mesozoic age, spatially confined to the mobile zone of the East Anabar fault.

Gold is represented by various shapes (lamellar, dendritic, lumpy–angular, and hook-like) and is characterized by a very wide variation in fineness (307‰–950‰) and by micro-inclusions of native bismuth, maldonite, arsenopyrite, and silver tellurides (Figure 8a,b). Gold is represented by various shapes (lamellar, dendritic, lumpy–angular, and hook-like) and is characterized mainly by a medium-grained zonal internal structure (Figure 8c). The formation of the mineralization of the gold–rare-metal formation is probably associated with the occurrence of tectonic magmatic activation of the Mesozoic age, spatially confined to the mobile zone of the East Anabar fault.

Mineralization of the gold–rare metal formation of the Mesozoic stage of ore formation is characterized by indicators of placer gold—a very wide variation in fineness and the presence of micro-inclusions of native bismuth and maldonite. The mineralization of this formation is predicted for the first time in the basin of the middle course of the Bol. Kuonapka River (the eastern framing of the Anabar Shield) [45]. Here, gold is characterized by a very wide variation in fineness (307‰–950‰) and by micro-inclusions of native bismuth, maldonite, arsenopyrite, and silver tellurides (Figure 8a,b). Gold is represented by various shapes (lamellar, dendritic, lumpy–angular, and hook-like) and is characterized mainly by a medium-grained zonal internal structure (Figure 8c). The formation of the mineralization of the gold–rare-metal formation is probably associated with the occurrence of tectonic magmatic activation of the Mesozoic age, spatially confined to the mobile zone of the East Anabar fault.

Gold–sulfide–quartz formation. The indicator signs of placer gold mineralization of the gold–sulfide–quartz formation include lamellar and lumpy shapes, size from dust-like (less than 0.1 mm) to large (>2 mm), a wide range of fineness (600‰–900‰), increased content of Ag (10.07‰–33.39‰) and Hg (up to 7%), a diverse range of impurity elements, a mono- and coarse-grained internal structure, and the presence of micro-inclusions of quartz, calcite, pyrite, and arsenopyrite.

**Figure 7.** Indicators of gold, characteristic of ore sources of the gold–silver formation. Forms of placer gold: (a) lamella, (b) plate, (c) lump; internal structures: (d) porous, (e) thin high-grade shell, (f) multiphase gold; micromineral inclusions in placer gold: (g) adular (Adl), (h) barite (Brt), and (i) calcite (Cal).

**Figure 8.** Indicators of placer gold characteristic of ore sources of the gold–rare metal formation: (a) fineness; (b) growth of native bismuth (Bi) and maldonite (Mdo); (c) zonal internal structure.
Mineralization of this formation is predicted in the south-east area of the Siberian platform within the Urinsky anticlinorium in the Middle Lena basin at the mouths of the Bol. Patom and Kamenka rivers, based on the discovery of placer gold of a lamellar and lumpy shape (Figure 9a,b), with a size from dust-like to >0.25 mm, with a wide variation in the fineness of 600‰–900‰, with a constant content of Hg (>6%), as well as up to 40% of spongy brittle aggregates, consisting of intergrowths of small gold particles (up to 0.01 mm) with iron hydroxides (Figure 9). Spongy varieties have low fineness (664‰–727‰) and a constant trace impurity of Hg (>2%). The internal structures of gold are mono- and coarse-grained with thin and intermittent high-grade shells; sometimes, there is unclear zonation, spotty heterogeneity, porosity, different phasal nature, granulation, and disintegration (Figure 9d–f). Micro-inclusions of quartz, calcite, pyrite, arsenopyrite, tellurides, selenides, and rare-earth phosphates have been found in gold (Figure 9g–i). The abovementioned indicators are characteristic of mineralization of the gold–sulfide–quartz formation. According to the revealed complex of mineralogical and geochemical features, placer gold is similar to the gold of the Kuranakh ore-placer cluster. In this regard, the formation of a gold deposit of the Kuranakh type is predicted for the first time in this territory.

**Figure 9.** Indicators of placer gold, characteristic of ore sources of gold of the gold–sulfide–quartz formation. Morphology: (a) scale, (b) lump, and (c) dendrite; internal structure of gold: (d) medium-grained, (e) unclear zonal, and (f) porous; micro-inclusions in gold: (g) telluride, (h) selenide, (i) and rare-earth phosphate.

The formation of mineralization of the gold–sulfide formation is also predicted in the northeast region of the Siberian platform, based on the identification of the following indicators in placer gold of the Anabar River basin (Mayat, Morgogor and Kurung Yuryakh): lamellar and lumpy shapes, medium and low fineness, a wide range of impurities (Hg, Fe, Cu, Zn, Pb, Sb, As) and the presence of micro-inclusions of pyrite and arsenopyrite [45]. The formation of ore occurrences of this type is probably related to the occurrence of the tectonic–magmatic activation of the Mesozoic age. Mineralization with a content of Au of 0.6 g/t, spatially confined to metasomatite zones and widely occurring in the Paleozoic carbonate strata, is widely developed both in the Molodo–Popigai and Anabar–Eekite fault systems, and this gives us reason to predict the formation of analogs of gold deposits of the Carlin type in this territory.
4. Discussion

The revealed indicators of placer gold made it possible to determine the formation types of ore sources characteristic of certain geological and structural settings. It is known that each gold ore formation assumes appropriate geological and structural control, and this makes it possible to more correctly select methods of searching for gold deposits, especially in closed areas [14].

4.1. Mechanisms of Placement of Predicted Gold Deposits of the Precambrian Stage of Ore Formation

Low-sulfide gold–quartz ore occurrences are predicted at ancient outcrops of the basement throughout the eastern Siberian Platform. Back in the 1960s, V.I. Timofeev [49] suggested that the placer gold content of the Vilyui River basin was formed due to the supply of gold from primary sources, localized in the Precambrian horst uplifts. Later, Y.N. Trushkov et al. [3] in the Lena–Vilyui and B.R. Shpunt [4] in the Anabar–Olenek interfluves also explained the formation of placers due to the primary gold ore sources of the Early Proterozoic–Archean age. According to their data, quartz–carbonate veins of the Early Proterozoic contain Au up to 2 g/t. Moreover, V.A. Mikhailov [50] determined that the gold-bearing deposits of the Vilyui synclise contain a complex of minerals similar to the mineral parageneses of metamorphic rocks of Subgan AR and Udokan PR age.

Long-term studies have shown that gold in placers of alluvial deposits of most watercourses, draining the outcrops of the basement of the Siberian platform, is mainly represented by a small fraction and scaly forms. The fineness of gold is high, and impurity elements are practically absent (Table 1). It is characterized by recrystallized internal structures, high-grade shells, traces of plastic deformations and micro-inclusions of sulfides, quartz, feldspar, and carbonates. The determined mineralogical and geochemical features of placer gold and the complex of minerals associated with it make it possible to predict the presence of primary sources of the low-sulfide gold-quartz formation in the places of the basement outcrops and their framings both in the northeast and in the central part of the east of the Siberian Platform, and in the south-east part in the area with its junction with the Baikal–Patom fold–thrust belt (Figure 1).

It is assumed that these ore occurrences are represented by mineralized crush zones in metamorphic rocks of the Archean and Early Proterozoic (Table 3). Ore-bearing rocks are terrigenous–carbonate and volcanogenic strata, crystalline schists, granite gneisses, and granitoids, in which sulfide quartz–carbonate veins with an Au content of up to 2.7 g/t were found.

<p>| Table 3. Geological and structural characteristics of the proposed gold ore sources of the Precambrian stage of ore formation (east of the Siberian platform). |</p>
<table>
<thead>
<tr>
<th>Formation</th>
<th>The Main Indicator Minerals and Impurity Elements in Gold</th>
<th>Geological Positions</th>
<th>Potentially Ore-Bearing Formations</th>
<th>Structural Position of Ore Location</th>
<th>Characteristic Ore-Bearing Rocks</th>
<th>Morphological Type of Ore Bodies</th>
<th>Location of the Supposed Gold Ore Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low-sulfide gold-quartz</td>
<td>Quart, pyrite, arsenopyrite, carbonates</td>
<td>Outcrops of the basement of the uplift, arches, highs</td>
<td>The Archean and Early Proterozoic metamorphic rocks</td>
<td>Mineralized crush zones of ancient basement outcrops</td>
<td>Terrigenous–carbonate strata, volcanogenic rocks, crystalline schists, granite gneisses, granitoids</td>
<td>Sulfide quartz–carbonate veins with an Au content up to 2.7 g/t</td>
<td>Anabar Shield, Olenek and Biliro–Udzha uplift, Suntar Arch, Verkhnesinsky, Bappagaisky, Yakut highs, etc.; zone of junction with the Baikal–Patom fold–thrust belt</td>
</tr>
</tbody>
</table>
It should be noted that according to the totality of the identified mineralogical and geochemical features, this gold is comparable to the mineralogical features of placer gold of ancient platforms (North American, Australian, African, Indian, etc.) [23,24,51–53], where it forms a wide dispersion halo near the basement outcrops and is related to the mineralization of the low-sulfide gold–quartz formation of the Precambrian stage of ore formation. The analysis of mechanisms of the distribution of gold in the east of the Siberian platform allowed us to establish that it is also widespread near the outcrops of the basement and its marginal parts, i.e., on the northern edge of the Baikal–Patom thrust belt, in the framing of the Anabar and Aldan shields, near the Olenek, Biliro–Udzha, Yakut uplifts, the Suntar Arch, etc. In these territories, gold content of up to 2 g/t was found in the Early Proterozoic quartz–carbonate veins [3,4]. Based on the mineralogical and geochemical similarity of native gold and the revealed mechanisms of its spatial distribution, it is reasonable to assume that mineralization of the low-sulfide gold–quartz formation is the primary sources of the extensive dispersion halo of gold in the east of the Siberian platform, as well as on other ancient platforms. This gives us reason to predict analogues of large deposits, such as Porcupine, Kirkland Lake, etc., in the east of the Siberian platform.

**Gold–copper–porphyry ore occurrences** are predicted only in the northeast of the Siberian platform, since in the high-grade placer gold of the Bolshaya Kuonapka River, we have revealed a stable increased Cu content from 0.5 to 4%, characteristic of gold–copper–porphyry occurrences, which is confirmed by the data obtained by A.V. Tolstov [38], A.P. Smelov et al. [39], and A.A.Kravchenko and co-authors [40]. In this regard, it has been suggested that the formation of the gold–copper–porphyry type of mineralization is possible in the northeast of the Siberian platform in the granitoid massifs of the Anabak Shield and its framing. Ore sources of the gold–copper–porphyry type deposits probably represent stockworks and linear zones in granitoid massifs (Table 3). The ore-bearing rocks are diorites, granodiorites, plagiogneisses, granite gneisses, and crystalline schists with quartz veins with sulfide mineralization.

**Gold–ferruginous quartzite ore occurrences** are predicted only in the south-east of the Siberian platform, based on the discovery in high-grade scaly gold of an increased iron content and micro-inclusions of a number of minerals (hematite, ilmenite, corundum), typical for deposits of the gold–ferruginous quartzite formation (Table 1). Gold with such

<table>
<thead>
<tr>
<th>Formation</th>
<th>The Main Indicator Minerals and Impurity Elements in Gold</th>
<th>Geological Positions</th>
<th>Potentially Ore-Bearing Formations</th>
<th>Structural Position of Ore Location</th>
<th>Characteristic Ore-Bearing Rocks</th>
<th>Morphological Type of Ore Bodies</th>
<th>Location of the Supposed Gold Ore Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold–copper–porphyry</td>
<td>Average Cu content from 0.5 to 4 wt.%, sometimes up to 25 wt.%, sulfides.</td>
<td>Anabar Shield</td>
<td>Igneous rocks</td>
<td>Granitoid massifs, stockworks, linear zones</td>
<td>Diorites, granodiorites, plagiogneisses, granite gneisses, crystalline schists</td>
<td>Quartz veins, sulfide disseminated mineralization with Au content up to 2.5 g/t</td>
<td>Anabar Shield, Kotuikanskaya and Bilyakh zones</td>
</tr>
<tr>
<td>Gold–ferruginous quartzite</td>
<td>Hematite, magnetite, corundum, ilmenite</td>
<td>Aldan Shield</td>
<td>Stratigraphic levels of the formations of ferruginous quartzite</td>
<td>Basalt terrigenous–volcanogenic strata with ferruginous quartzites</td>
<td>Deposits of disseminated mineralization</td>
<td>Framing of the Aldan Shield, basin of the Torgo and Tokko rivers</td>
<td></td>
</tr>
<tr>
<td>Gold-platinoid</td>
<td>Intergrowths of Au with Pt, impurity elements in gold: Pt, Pd, Ni.</td>
<td>Anabar and the framing of the Suntar Arch</td>
<td>Igneous rocks, basites</td>
<td>Massifs, intrusions</td>
<td>Anorthosites, gabbrrodolites</td>
<td>Veinlet-disseminated sulfide ores</td>
<td>Anabar Shield (Kotuikan–Morkhoolinskaya zone); framing of the Suntar Arch</td>
</tr>
</tbody>
</table>
indicators was found in the watercourses of the southeastern Siberian Platform in the northwestern marginal part of the Aldan Shield in the basins of the Torgo, Chara, and other rivers (Figure 1). It is assumed that the primary sources of gold are confined to the metamorphogenic deposits of the Archean, and the ore-bearing strata are terrigenous–volcanogenic deposits with ferruginous quartzites, bearing disseminated mineralization (Table 3). Earlier in this area, researchers identified an Au content of up to 0.6 g/t in the Archean ferruginous quartzites of the Aldan Shield. Gold is represented by high-grade scaly gold particles, measuring 0.1–0.25 mm. The possibility of discovery of ore occurrences of this formation is assumed in the basins of the Togo and Chara rivers, similar to the Tarynnakh and Ymalakh iron ore deposits, which have a gold content of up to 10 g/t.

**Ore occurrences of the gold–platinoid formation** are predicted both in the northeast and in the central part of the east of the Siberian Platform. Gold with the characteristics of gold–platinoid ore occurrences was found in the framing of ancient basement outcrops in the northeast region of the Siberian platform (Anabar Shield), and in the central part, such as in framing of the Suntar Arch, which is confirmed by the analysis of geophysical data [44]. They proved the presence of the Early Proterozoic mobile belt in the east of the Siberian platform, with which they associated the main metal content, including gold and platinum. Evidence of the presence of gold–platinoid sources in the framing of the Suntar Arch is also provided by the data of V.L. Masaitis and co-authors [5]. They revealed gold ore occurrences with a content of Au up to 1 g/t and Pt up to 0.3 g/t, paragenetically associated with basite magmatism. Mineralization of this formation is also predicted on the Anabar Shield in the Kotuikan–Monkholin zone, where intrusions of anorthosite and gabbro-dolerite composition are developed, in which veinlet-disseminated sulfide ores are noted (Table 3).

4.2. Mechanisms of Placement of Predicted Gold Deposits of the Mesozoic Stage of Ore Formation

**Gold–rare metal ore occurrences** are predicted for the first time on the territory of the Anabar Shield in placers of the Bolshaya Kuonamka River basin, where gold has characteristic indicators for the mineralization of a gold–rare metal formation (Table 2). The formation of this type of mineralization is probably related to magmatic activity in the mobile zone of the East Anabar fault. The ore-bearing rocks are granitoid massifs and host sedimentary rocks; zones of hornfelsing and potassium metasomatites may be potentially gold-bearing, in which veins and veinlets of quartz with visible gold are observed (Table 4). Formation of potassium metasomatites and hornfelsing of ore-bearing rocks in the mobile zone of the East Anabar fault, repeatedly renewed in the Mesozoic period, indicates that tectonic–magmatic activation occurs in this territory, which served to form this type of mineralization.

Ore occurrences of the gold–sulfide–quartz formation are predicted both in the northeast and in the southeast of the Siberian platform. Placer gold with typomorphic features characteristic of gold sulfide deposits has been found in the basins of the Anabar and Ebelyakh rivers in the northeast, as well as in the southeast of the Siberian Platform in the Middle Lena basin at the mouth of the Vitim, Khalamanda, Nyuya, Namana, Bol. Pathom, and Kamenka rivers, among others. This gold is characterized mainly by high fineness, less often by medium fineness with a high content of silver and mercury, and with a wide range of granulometric composition, and it is represented by both dust-like (0.1 mm—up to 90%) and large fractions (0.5–1 mm or more—up to 10%).

Probably, such ore occurrences were discovered earlier during thematic and geological prospecting operations in the basin of the Middle Lena and its tributaries (Peledui, Nyuya, Namana, Dzerba, Kubolakh, Chara, etc.) in terrigenous–carbonate strata. These ore occurrences are represented by mineralized zones of crush, silification, and limonitization with an Au content of 0.1–2 g/t; as a rule, they are confined to deep faults of discontinuous faults.

The formation of primary sources of gold–sulfide mineralization is also possible in the northeast of the Siberian platform in the basins of the Anabar and Ebelyakh rivers in the Molodo–Popigai fault system [45]. The supposed sources are localized in the zones
of metasomatites (ferruginization and silification) developed in the Paleozoic terrigenous–carbonate rocks, spatially related to deep faults that were repeatedly renewed during the Mesozoic. Thus, the presence of ore sources of the gold–sulfide–quartz formation is predicted for the first time both in the south-east of the Siberian platform in the Middle Lena basin at the mouth of the Bolshoy Patom and Kamenka rivers, spatially confined to the Bappagai deep fault, such as Kuranakh, and in the Molodo–Popigai fault system of the Carlin type.

Table 4. Geological and structural characteristics of the proposed gold ore sources of the Mesozoic stage of ore formation (east of the Siberian platform).

<table>
<thead>
<tr>
<th>Formation</th>
<th>Main Indicator Minerals</th>
<th>Position of Metallogenic Zones</th>
<th>Potentially Ore-Bearing Formations</th>
<th>Structural Position of the Ore Location</th>
<th>Characteristic Ore-Bearing Rocks</th>
<th>Morphological Type of Ore Bodies</th>
<th>Location of the Supposed Gold Ore Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gold–rare metal</td>
<td>Bismuth, maldonite, silver tellurides</td>
<td>Anabar Shield, East Anabar fault</td>
<td>Hornfelsing zones and K-metasomatites</td>
<td>Near-intrusive, over-intrusive, intra-intrusive</td>
<td>Granitoids and adjacent hornfelsen sedimentary</td>
<td>Veins and veinlet zones</td>
<td>Anabar Shield, basin of the Bol. Kuonamka River</td>
</tr>
<tr>
<td>Gold–sulfide–quartz</td>
<td>Pyrite, arsenopyrite, calcite, tellurides, minerals with rare-earth elements</td>
<td>Deep faults, Molodo–Popigai fault system, Bappagai, Kempendyai, and others</td>
<td>Metasomatite zones</td>
<td>Mineralized zones of crushing, brecciation, silification, and ferruginization</td>
<td>Terrigenous-carbonate strata</td>
<td>Deposits of disseminated mineralization up to 10 g/t</td>
<td>Basin of the Ebeljakh, Morgogor, Kamenisty rivers, etc. The mouths of the Bolshoy Patom, and Kamenka rivers</td>
</tr>
<tr>
<td>Gold–silver</td>
<td>Quartz, calcite, chalcedony, barite, adular, tellurides</td>
<td>Intracontinental paleoriffs (Udzha Vilyuyi)</td>
<td>Volcanic rocks, andesite–dacite, rhyolites, etc.</td>
<td>Fluid explosive structures, caldera</td>
<td>Sandstones</td>
<td>Quartz–barite, calcite veins up to 1 g/t</td>
<td>Udzha River basin, river sources of the Kempendyai dislocation</td>
</tr>
</tbody>
</table>

Ore occurrences of the gold–sulfide formation are predicted in the area of the Kempendyai dislocation (Vilyui paleorift, the central part of the Siberian platform) and in the Udzha paleorift (Molodo–Popigai fault system), based on the identification of a complex of mineralogical and geochemical features of placer gold, characteristic of gold–sulfide deposits (Table 2). Such a set of impurity elements and associated minerals allows us to assume the formation of gold–sulfide ore occurrences related to subvolcanic or volcanic conduit systems, both on the Vilyui and Udzha paleorifts (Table 4). A number of researchers have linked the origin of these ore occurrences with acid volcanism of the Early Jurassic and Cretaceous age. In addition to the mineralogical and geochemical criteria identified in placer gold, characteristic of the primary sources of the gold–sulfide formation, geological and structural critical assumptions have also been established, indicating the formation of such mineralization in the area of the Kempendyai dislocations (Vilyui paleorift). According to our data, the supposed ore sources of the gold–sulfide formation are located in the fields of development of volcanic rocks of andesite–dacite composition occurring on the Lower Cretaceous deposits, firstly identified by us in the area of the Kempendyai dislocation of the Vilyui paleorift [54,55]. Field studies have revealed that the maximum concentrations of placer gold and chalcedonic quartz pebbles in riverbed sediments spatially coincide with the fields of development of volcanic formations of andesite–dacite composition, occurring on the Early Cretaceous sediments. These volcanic rocks are represented by andesite–dacites, fragments of acidic glass and pumice, as well as psammite tuffs cemented with volcanic glass. Based on the conducted spectral and chemical analyses, it was found that a stable Ag-Pb-Zn-Cu geochemical association is clearly visible in both volcanites
and low-to-medium-grade gold, allowing establishing a paragenetic connection between epithermal gold–silver mineralization and the volcanism that occurred in the area of the Kempendyai dislocations. In this regard, based on the similarity of the mineralogical and geochemical features of placer gold and the geological development of this territory (the intracontinental Vilyui paleorift), it is legitimate to assume the formation of a gold and silver deposit of the Mz-Kz Cripple Creek type in this area, which is also confined to the zone of the Rocky Rift, where volcanism of an andesite–dacite composition widely occurred.

The following geological and structural conditions are characteristic of the proposed ore sources of the gold–silver formation. According to E.E. Milanovsky [56], the ancient rift zones of the east of the Siberian Platform were repeatedly regenerated in the Mesozoic, where volcanism of andesite–dacite composition occurred. Indeed, the data from previous studies [Kirina, 1966 year; Kiselev, 1970 year] indicate the occurrence of this type of volcanism and the formation of gold–silver mineralization within the Vilyui paleorift. They found quartz–calcite–barite veins with a gold content of up to 1.4 g/t in the deposits of the Early Jurassic and Cretaceous, the origin of which they linked with acid volcanism. Based on the results of the analysis of geological history of the Vilyui synclise and the central part of the Aldan Shield, V.I. Timofeev [49] was the first to prove the synchronicity of the tectonic regime and magmatism in the Mesozoic. This gave him the reason to link the origin of ore gold in the Kempendyai dislocation with Late Jurassic–Early Cretaceous magmatism. V.A. Mikhailov [50] analyzed the mineral associations of the concentrated dispersion halo and the petrographic composition of the pebble–gravel material of the Lena–Vilyui interfluve and came to the conclusion that the formation of the Mesozoic gold mineralization was related to magmatism of the acid composition. Potential sources of ore-bearing hydrotherms, according to G.I. Tugovik [57] and V.A. Mikhailov [50], were fluid explosive structures (FESs) in the form of pipe-like bodies, as well as mineralized zones of discontinuous faults, hydrothermal argillized, rocks and dyke-type bodies.

5. Conclusions

1. The identified indicators of placer gold characteristic of certain formation types of gold deposits, allowed us, for the first time, to prove the formation in the east of the Siberian platform of gold ore sources of low-sulfide gold–quartz, gold–ferruginous quartzite, gold–copper–porphyry, and gold–platinoid formations of the Precambrian and the formation of ore occurrences of silver–gold, gold–sulfide–quartz, and gold–rare metal formations of the Mesozoic stages of ore formation.

2. It is proved that the supposed minerogenic types of the primary sources of placer gold content are related to certain geological and structural positions. Ore sources of low-sulfide quartz–gold, gold–copper–porphyry, gold–ferruginous quartzite, gold–rare metal, and gold–platinoid formations are confined to the outcrops of the basement and to their framings. The primary sources of the gold–sulfide–quartz formation (hydrothermal metasomatic formations) are spatially connected with deep fault zones, and they were formed in terrigenous–carbonate strata. Ore occurrences of the gold–silver formation are predicted in the zones of intracontinental paleorifts in the fields of the development of volcanism of andesite–dacite composition.

3. It is determined that the identified minerogenic types of primary sources determine geological and structural control based on the indicators of placer gold and, therefore, contribute to a more correct selection of methods for searching for gold deposits of various formations and assessing the prospects for gold content in platform areas.

Thus, the indicators determined in placer gold are characteristic of certain minerogenic types of ore sources, allow us to predict, for the first time, in the east of the Siberian Platform, deposits of the Kirkland Lake and Porcupine type (low-sulfide gold–quartz formation) of the Precambrian age, as well as the types of Cripple Creek (silver–gold) and Carlin (gold–sulfide–quartz) of the Mesozoic stage of ore formation, widely known on the North American platform. The identified criteria for determining the types of mineralization
based on the indicators of placer gold are an indisputable indication of ore genesis, and they can be successfully used in forecasting, searching for, and evaluating gold deposits in closed territories.

**Funding:** The study was conducted within the framework of the state assignment of the Institute of Geology of Diamonds and Precious Metals of the Siberian Branch of the Russian Academy of Sciences. The founder of the project financing is the Ministry of Science and Higher Education of the Russian Federation. Funding number: FUFG-2024-0006.

**Data Availability Statement:** The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

**Conflicts of Interest:** The author declares that there is no conflicts of interest.

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