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**GEOLOGY**

# Specific Features of Ore Formation in the Epithermal Kubaka Gold–Silver Deposit, Northeast Russia

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The epithermal Kubaka is a unique deposit with a prevalence of gold and quartz in ores. This deposit belongs to the category of large gold deposits (more than 100 t of Au and 100 t of Ag with average grades of 20.2 and 21.3 g/t, respectively). The vertical extent of gold mineralization is 200–250 m, and the average thickness of orebodies is 12 m. The Kubaka deposit is located in the southern part of the Omolon cratonic terrane (Fig. 1). The rock massif is clearly divided into the Precambrian crystalline basement and the overlying sedimentary and volcanosedimentary sequences ranging in age from the Proterozoic to the Upper Jurassic. The massif also includes the Early Cretaceous orogenic cover. Within the Omolon cratonic terrane, the Omolon metallogenic zone is distinguished from the Okhotsk–Chukot volcanogenic belt by long-term and multistage evolution of Au–Ag mineralization. The most prominent Middle Paleozoic stage of Au–Ag mineralization was characterized by the formation of not only the Kubaka deposit, but also other promising deposits, such as Ol'cha, Birkachan, Yunyi, and others.

The ore field is composed of volcanic rocks of the Middle–Upper Devonian Kedon Group (tuffaceous sandstones, tuffaceous siltstones, tuffs, and ignimbrites of intermediate and acid compositions) [1]. At the western and southern flanks, the eroded surface of these rocks is discordantly underlain by terrigenous rocks of the Upper Carboniferous Korba Formation with basal conglomerates. On the right-hand wall of the Kubaka River, Archean rocks are exposed as separate blocks. The Archean rocks underlie ore-bearing volcanic rocks of the Fedon Group. The volcanic rocks make up a monocline gently dipping toward the paleovolcano periphery at an angle of 15°–20°. They are crosscut by subvolcanic rhyolitic and rhyodacitic intrusions and dikes.

According to [2], the ore field represents a collapse caldera that underwent resurgent dome formation in the course of the emplacement of subvolcanic ore-hosting trachydacites. The caldera is filled with effusive volcanic rocks of the Kubaka sequence. The volcanic rocks are crosscut by subvolcanic trachydacites, trachyrhyodacites, and rhyolites that host the orebodies. The circular fracture zone is surrounded by siliceous sequences (banded tuffites, polymictic sandstones, gritstones, and conglomerates) that dip toward the center at an angle of 60°–80°. Based on drilling data, the vertical displacement (collapse) amplitude is 450–500 m. The depression is filled with dacitic lavas alternating with volcanomictic rocks.

Orebodies are confined to the trachydacitic subvolcano. They are mainly represented by vein fillings and stockwork-type zones. Ore veins extend over 2 km in the nearly latitudinal direction. Along the dip, the orebodies and veins merge into a single vein. The mineralization is characterized by the prominent bonanza pattern. The ore lodes include 80–90% of all ores with a grade of more than 30 g/t [3]. In addition, more than 50% of the lodes contain ores with an average grade varying from 66.6 to 162.0 g/t.

*Age of mineralization.* Specific features of mineralization in the Kubaka deposit are scrutinized in [4]. Based on the analysis of a great body of documentary materials, Kotlyar et al. suggested that the age of ores of the Kubaka deposit varies from 335 ± 5 to 337 ± 8 Ma, which corresponds to the Visean Age of the Early Carboniferous. They also noted that ores of this deposit underwent several stages of thermal alteration in the Late Paleozoic and Mesozoic leading to distortion of the isotope system. These processes were responsible for the relatively young dates. Resetting of the isotope system within a wide time interval (212–110 Ma) based on the examination of ores is a debatable issue. Nevertheless, the results of study of several mineralogical

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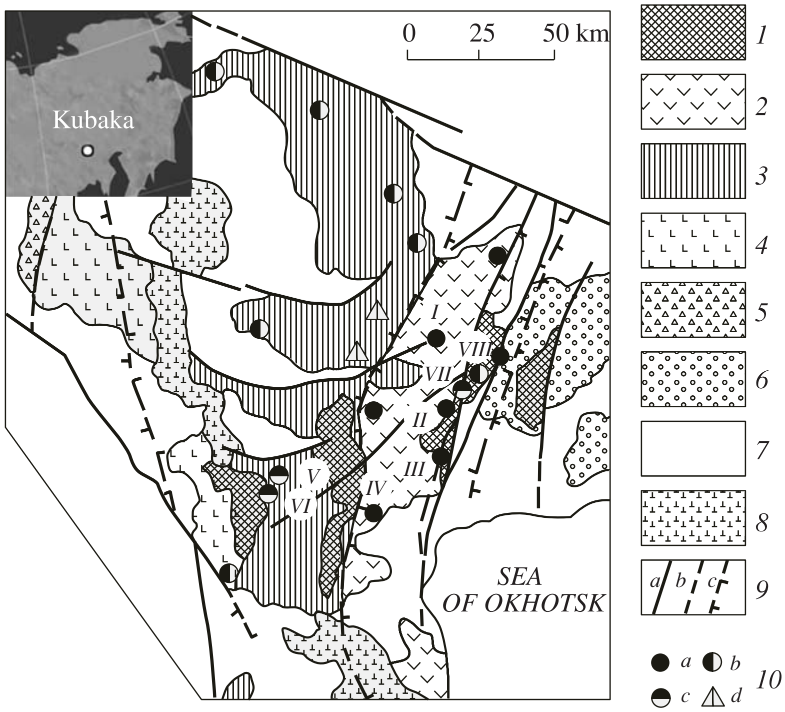


**Fig. 1.** Schematic metallogenic regionalization of the southern Omolon Massif. (*1*) Ridges at the Precambrian crystalline basement; (*2–4*) Kedon structural–facies zone: (*2*) Amandykan subzone, (*3*) Kedon–Omolon subzone, (*4*) Abka subzone; (*5–8*) Aulandzha structural–facies zone: (*5*) volcanogenic molasse formation, (*6*) molasse and siliceous formations, (*7*) Late Carboniferous terrigenous and carbonate formations, (*8*) Late Cretaceous andesite formation; (*9*) fractures: (*a*) bounding the massif, (*b*) dividing the massif into blocks, (*c*) bounding metallogenic zones; (*10*) ore deposits: (*a, b*) epithermal Au–Ag deposits and occurrences, respectively, (*c*) porphyry Cu–Mo type, (*d*) Au-jasperoid type. Deposits: (I) Birkachan, (II) Kubaka; ore occurrences: (III) Dubl, (IV) Elochka, (V) Vechernee, (VI) Khrustal'nyi, (VII) Tabornoe, (VIII) Orlinyi.

features of ores suggest their polychronous formation. For example, the deposit includes numerous veins (adit 1, crosscuts 21–39) composed of quartz–adular–chalcedony aggregates dominated by a silver–selenide assemblage, in which the Au: Ag ratio exceeds 1: 10. The white coarse-crystalline adular (up to 10 mm along the diagonal) in this deposit differs significantly from the pink fine-grained adular in the Central ore zone. The K–Ar age of the white adular is estimated at 110–130 Ma. This mineralization is also characterized by high contents of pyrite and chalcopyrite in the metasomatic rocks and the association of küstelite with the fine-acicular arsenopyrite. We believe that this time interval marks not only the resetting of the isotope system, but also the interaction of minerals in the Okhotsk–Chukot volcanogenic belt (OCVB) domain. The OCVB area is spatially conjugated with the study region and is known as the Ag-bearing metallogenic province.

*Mineral composition of ores.* Ores of the Kubaka deposit represent fragments of vein deposits mainly composed of quartz, adular, and carbonates. Host rocks intensely replaced by hydromicas occur as clasts. Ore minerals are primarily represented by gold–silver intermetallides. The content of other minerals is negligible. The ores are typical epithermal formations with abundant colloform-banded and latticed-laminated aggregates of vein minerals with a fine dissemination of useful components confined to rhythms of the chalcedony-type quartz (Fig. 2). Ores of the Kubaka deposit contain more than 50 hypogene minerals. However, the bulk ore mass (>99%) is composed of the following four minerals: quartz (including chalcedony and the chalcedony-type quartz), adular, native gold (including electrum), and carbonates. Other minerals account for <0.1%. It is worth mentioning that the fluorite content is rather high in orebody 8 and this mineral is rare in other orebodies.

The Kubaka deposit also includes some rare mineral phases. Based on the composition, optical properties, and X-ray parameters, they are assigned to the group of gold–silver sulfides, but the sulfur content in them is significantly variable (Table 1). The optical properties of these phases are also very different. They occur as slightly anisotropic gray hexagonal inclusions (50–200 μm across) in the native gold.

Fineness of the native gold was examined with a microprobe. Based on 83 determinations, the average fineness is 680‰. However, structural etching revealed an inhomogeneous composition of the Kubaka gold. This is evident from the bar chart of gold fineness (Fig. 3). Gold and silver are differentiated in the late productive

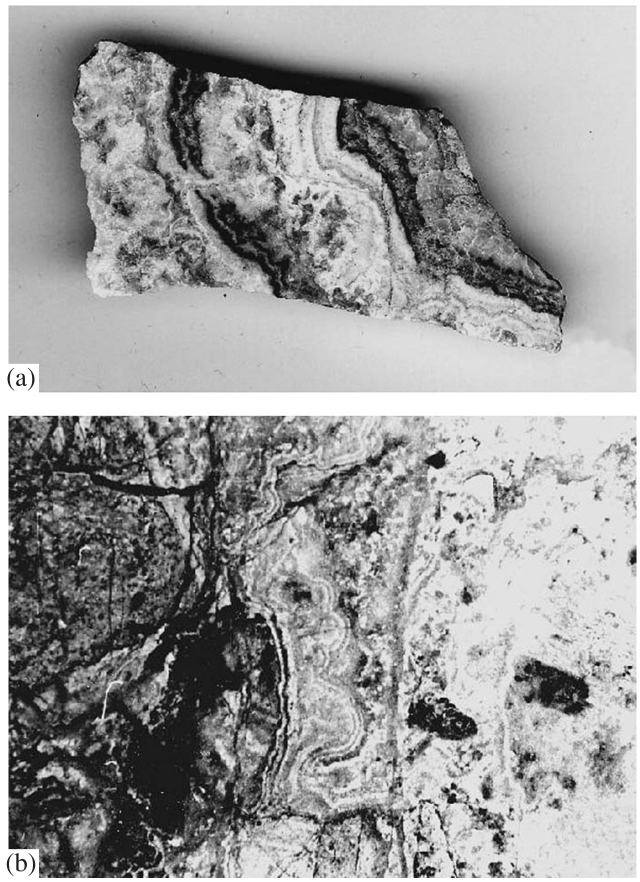


**Fig. 2.** Structures of ores in the Kubaka deposit. (a) Colloform-banded structure of the quartz–feldspar aggregate (fine dissemination of native gold is present in the dark bands); (b) intricate combination of brecciated and colloform-banded structures in the typical Au-bearing ore.

assemblage marked by the redistribution of matter owing to rejuvenation, which produced gold of the second generation (fineness 830‰) and a wide range of

**Table 1.** Compositions of mineral phases in the Au–Ag–S system in ores of the Kubaka deposit

| Analysis no. | Concentration of elements, wt % | | | | |
|---|---|---|---|---|---|
| | Au | Ag | S | Se | Total |
| 1 | 33.5 | 60.9 | 5.8 | 0.0 | 100.4 |
| 2 | 34.6 | 61.8 | 4.0 | 0.1 | 100.5 |
| 3 | 36.5 | 60 | 3.9 | 0.0 | 100.7 |
| 4 | 45.7 | 49.8 | 4.5 | 0.1 | 100.1 |
| 5 | 43.8 | 48.6 | 4.0 | 0.0 | 96.7 |
| 6 | 17.2 | 65.9 | 7.6 | 5.3 | 96.6 |
| 7 | 21 | 63.0 | 6.9 | 5.3 | 97.5 |

Note: Analyses were performed with a CAMEBAX microanalyzer at the Northeastern Complex Research Institute, Magadan (E.M. Goryacheva, analyst).

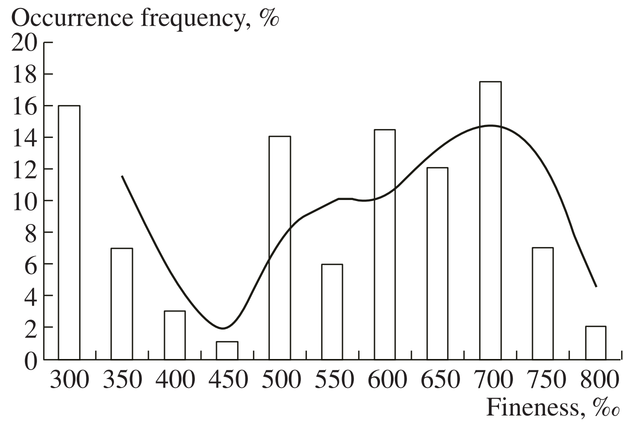


**Fig. 3.** Bimodal distribution of the fineness of native gold in ores of the Kubaka deposit.

silver minerals, including silver selenides and native silver.

The low sulfide content is the most characteristic feature of ores of the Kubaka deposit. Therefore, selenium mineralization is widespread at the late stage. The high-gradient settings of this deposit were responsible for the formation of fine mineral blends. This is indicated by nonstoichiometry of several mineral species (Table 2). The Birkachan deposit located 40 km east of the Kubaka deposit is also characterized by a very low content of sulfides (<0.5%), suggesting a regional-scale distribution of this unusual version of epithermal mineralization. Ores of the Kubaka deposit were formed at two stages.

The early stage (300–330 Ma, Carboniferous) includes three mineral assemblages.

1. The gold–chalcedony assemblage with the participation of colloidal silica and gold. Patches (coagulates) of the colloidal gold are usually composed of dark brown xenomorphic aggregates (up to 200 μm in size) with tiny round-embryonic crystals of electrum and küstelite. Colloidal gold flakes are enveloped by chalcedony globules. The submicroscopic colloidal gold can usually be detected only by analytical methods. Dissemination of colloidal gold is responsible for the pink and green shades of chalcedony.

2. The adular–quartz assemblage is typical of epithermal Au-bearing deposits. Minerals of this assemblage cement chalcedony fragments. The formation of this assemblage is accompanied by the coarsening and recrystallization (polymerization) of native gold and its refinement. One can also see the formation of a wide range of rare minerals, such as argentopyrite, sternbergite, and stromeyerite. An appreciable deficiency of S in sulfides is compensated by Se and less common As. Minerals of this assemblage were formed in a high-gradient setting. Therefore, the ores are characterized by low sulfide content, abundance of fine mineral blends, and high compositional heterogeneity of minerals (Tables 1, 2).

3. The barite–fluorite assemblage is irregularly developed in some orebodies. This assemblage is most intensely developed in orebody 8 located at the northern outer contact of the subvolcano and in the Tsokol'noe sector (southern inner contact). The barite–fluorite assemblage is confined to the outer framing of a subvolcanic body. Although this assemblage is not productive, some sectors are slightly enriched in native gold. The highest fineness of Au (890‰) is recorded at the superposition of fluorite and quartz–adular mineralizations. Structural etching of this gold revealed traces of hypogene alterations. The barite–fluorite assemblage is atypical of the majority of epithermal deposits in the OCVB.

The late stage (110–130 Ma, Early Cretaceous) includes two assemblages.

1. The quartz–adular assemblage (with the Au–Ag–selenide mineralization) is intensely developed at the northeastern flank of the ore field. This assemblage is characterized by the presence of white coarse-crystalline adular (up to 15 mm along the long diagonal) and appreciable black fringes (up to 5 mm thick) of acanthite, aguilarite, native gold, and freibergite. The Au: Ag ratio (from 1 : 50 to 1 : 100) is atypical of the central part of the ore field. In general, this ratio varies from 1 : 1 to 1 : 12 in the Kubaka deposit.

2. The carbonate assemblage is widespread and ubiquitous. Carbonates are mainly represented by calcite. The Mn- and Fe-bearing varieties of this mineral (manganocalcite and dolomite) are the subordinate components. The barium carbonate (witherite) is rare. In some places, the carbonates contain abundant coaly inclusions.

Since the sulfide content is extremely low, the free gold virtually accounts for 100% of the ore. Therefore, the ore is very favorable for the maximal extraction of Au. The average fineness of the native gold is 780‰. The bar chart of its occurrence frequency (Fig. 3) shows a bimodal distribution related to two generations of Au. The first generation (680‰) was deposited together with chalcedony, whereas the second generation (750–830‰) was related to the coagulation and recrystallization of colloids in the course of the formation of the quartz–adular assemblage.

**Table 2.** Compositional inhomogeneity of minerals in ores of the Kubaka deposit

| Mineral | Concentration of trace elements, wt % |
|---|---|
| Se-bearing acanthite | Se 1.5–3 |
| Se- and Fe-bearing galena | Se 2.6–4.0; Fe 0.4–3.0 |
| Se-bearing stephanite | Se 2.4–6.2 |
| As-bearing pyrite | As 1.1–1.6 |
| Sphalerite | Fe 0.5–10.0 |
| Ag-bearing chalcopyrite | Ag 1.5–8 |
| Au-silver | Au 1.5–12.0 |
| Freibergite | Ag 23.0–33.0 |

Based on the results of study of inclusions of mineral-forming media, the Kubaka deposit is assigned to the low-temperature type. The productive quartz was formed at 130–190°C, whereas the postproductive carbonate was generated at 150–160°C [5]. Analysis of water extracts revealed that the minerals were formed from potassium hydrocarbonate solutions (potassium hydrocarbonate accounts for 60–80% of the total content of cations and anions). The distribution of cations and anions shows a distinct trend of increase in the share of K from the barren quartz at upper levels to the productive quartz at deeper levels. The share of $Na^+$, $Ca^{++}$, $Cl^-$, and $F^-$ also increases at deeper levels. The productive quartz demonstrates direct Ag–K correlation and inverse Ag–Na correlation. Relative to epithermal deposits in the overlying Okhotsk–Chukotka complex, hydrothermal solutions in the study region are significantly enriched in K. The anionic portion is similar in both regions (Fig. 4).

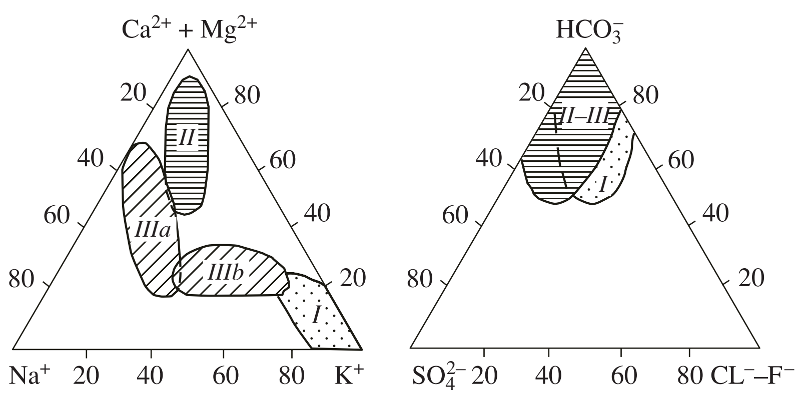


**Fig. 4.** Diagrams of anionic and cationic compositions of water extracts from quartz in gold–silver deposits (modified after [5]). (*I*) Kubaka–Omolon Massif; (*II*) Karamken–OCVB; (*III*) deposits of the gold–silver formation in Yana–Kolyma Mesozoides: (*a*) dike type, (*b*) stringer–dissemination type.

Thus, the Kubaka deposit is characterized by an unusual epithermal mineralization owing to a very low S content in the ore-forming system and relatively calm settings of the accumulation of Au. The abundance of chalcedony in veins of the Kubaka deposit suggests an important role of polymerization of the silicic material. The concentration of Au in pure chalcedony veins of this deposit is as much as 11 g/t. The colloidal Au is also responsible for the reddish and yellowish tints of chalcedony. The formation of gels significantly fostered the solubility of Au and Ag. Colloidal silicic particles made up a stabilizing shell around gold grains in the course of their transport, while the coagulation of gel promoted the extensive precipitation of Au. Relative to epithermal deposits in volcanic belts of Late Mesozoic Okhotsk–Chukotka and Cenozoic Kamchatka regions, the Kubaka deposit is distinguished by very low sulfide content. The Kamchatka region incorporates numerous deposits of native sulfur. The absence of sulfides in ores of the Kubaka deposit can be related to the low S content in Archean crystalline rocks of the Omolon terrane basement. At the same time, reduction (simplification) of mineral assemblages is also typical of rejuvenated (and regenerated) ores [6].

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## REFERENCES

1. V. A. Stepanov and L. N. Shishakova, *The Kubaka Gold–Silver Deposit* (Dal’nauka, Vladivostok, 1994) [in Russian].

2. I. N. Kotlyar, *Extended Abstracts of Doctoral (Geol.–Miner.) Dissertation* (Leningrad, 1990).

3. *Multifactor Prognostic–Prospecting Models of Gold and Silver Deposits in Northeast Russia*, Ed. by M. M. Konstantinov et al. (Kartfabrika VSEGEI, St. Petersburg, 1992) [in Russian].

4. I. N. Kotlyar, I. L. Zhulanova, T. B. Rusakova, and A. M. Gagieva, *Isotope Systems of Magmatic and Metamorphic Complexes in Northeast Russia* (SVKNII DVO RAN, Magadan, 2001) [in Russian].

5. N. E. Savva and V. V. Vortsepnev, in *Genesis of Ore Formations and Applied Significance of the Ore-Formation Analysis in Northeast USSR* (SVKNII DVO RAN, Magadan, 1990), pp. 50–64 [in Russian].

6. A. A. Sidorov, *Ore Formations and Evolutionary-Historical Analysis of the Noble Metal Mineralization* (SVKNII DVO RAN, Magadan, 1998) [in Russian].