
GEOLOGY

Plutonic Deposits of Fine-Dispersed Gold in Northeast Russia

A. V. Volkov^a, N. E. Savva^b, and Corresponding Member of the RAS A. A. Sidorov^a

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At the beginning of the 1940s, geologists discovered a new type of gold ore occurrence in the Sn-bearing regions of northeastern Russia. They were distinguished from deposits of the gold–quartz formation in terms of mineral association and geological setting. In the past 20 years, more than 30 gold ore occurrences have been discovered in the Magadan district alone (Fig. 1). Many of these objects can be classed as large and superlarge deposits [1, 2]. Extensive prospecting for gold in this region was stimulated by the discovery of the medium-scale Shkol'noe deposit in 1980. Gold output from high-grade ores (Au grade >35 g/t) of this deposit is as much as 0.6–0.8 t/yr. In recent years, interest in such deposits has been stirred up by the successful exploitation of gold deposits in Alaska (Fort Knox, Au resource >350 t; Pogo, 150 t), Canada (Dublin Gulch, >100 t), and Australia (Tefler, >500 t) [3].

As early as 1949, P.I. Skorniyakov had referred this unusual mineralization to the tourmaline–quartz formation and divided it into four mineral types (gold–cobalt, gold–tellurium, gold–tungsten, and gold–cassiterite). Based on the analysis of specific features of gold deposits in the northeastern part of the Soviet Union, Shilo et al. [4] suggested that gold–rare metal mineralization should be classed as an autonomous formation. Osipov and Sidorov [5] reviewed the available material concerning ore occurrences of the gold–rare metal formation in the northeastern part of the Soviet Union and compared it with data on analogous ore mineralization in other metallogenic provinces of the Soviet Union. Such objects are classed as granitoid-related gold deposits in other countries [3].

In Northeast Russia, deposits of this type are widespread in different-aged volcanosedimentary zones

(e.g., the Okhotsk–Chukotka volcanic belt) and median masses with intrusive magmatism. The deposits are usually confined to granitoid intrusions or contact-metasomatic zones. Orebodies often follow the morphology of the intrusive contact. In contrast to porphyry copper–tin deposits, the gold–rare metal deposits are associated with granitoids of various compositions and ages. Their orebodies make up veins (0.1–0.6 m thick and 2–100 m long), stockworks (up to 1–2 km² in area and more than 10–20% of quartz material per 1 m³), and crush zones (up to 2–3 m thick and up to 200–300 m long) with different amounts of the quartz material. One can often see the combination of crush zones with ore lodes or stockworks. Metasomatites, up to 1 m thick near the veins, are developed in the entire stockwork zone. The majority of deposits are characterized by low Au contents but large ore volumes and gold reserves. The vertical extent of the mineralized zone is as much as 300 m. The table presents specific features of the most studied deposits of the gold–rare metal formation.

These deposits are characterized by multistage mineralization and specific association of rare metal minerals in each type. However, the quartz–tourmaline–arsenopyrite, gold–tellurium, and quartz–carbonate associations are common for all types defined above.

The early (preore) stage of hydrothermal activity is related to volatile-rich reactive solutions and marked by an abundance of tourmaline and quartz. This stage was followed by an increase in alkalinity of solutions and the precipitation of sulfides of Pb, Cu, As, and Bi.

The final phases of productive stages were characterized by a drastic decrease in both the temperature of solutions and the partial pressure of sulfur. Such an environment is favorable for the precipitation of tellurides of Au, Ag, and Bi. Each type of gold–rare metal deposit is characterized by specific mineral associations. We can identify three types (cobalt, bismuth, and tin deposits).

In deposits of the *cobalt type*, the quartz–tourmaline–arsenopyrite association is overlapped by cobalt minerals (Co-löllingite, cobaltite, and safflorite) that contain fine-grained overgrowths of native gold with

^a Institute of Geology of Ore Deposits, Petrography, Mineralogy, and Geochemistry, Russian Academy of Sciences, Staromonetnyi per. 35, Moscow, 119017 Russia; e-mail: alexandr@igem.ru

^b Northeastern Complex Research Institute, Far East Division, Russian Academy of Sciences, ul. Verkhneportovaya 16, Magadan, 685000 Russia

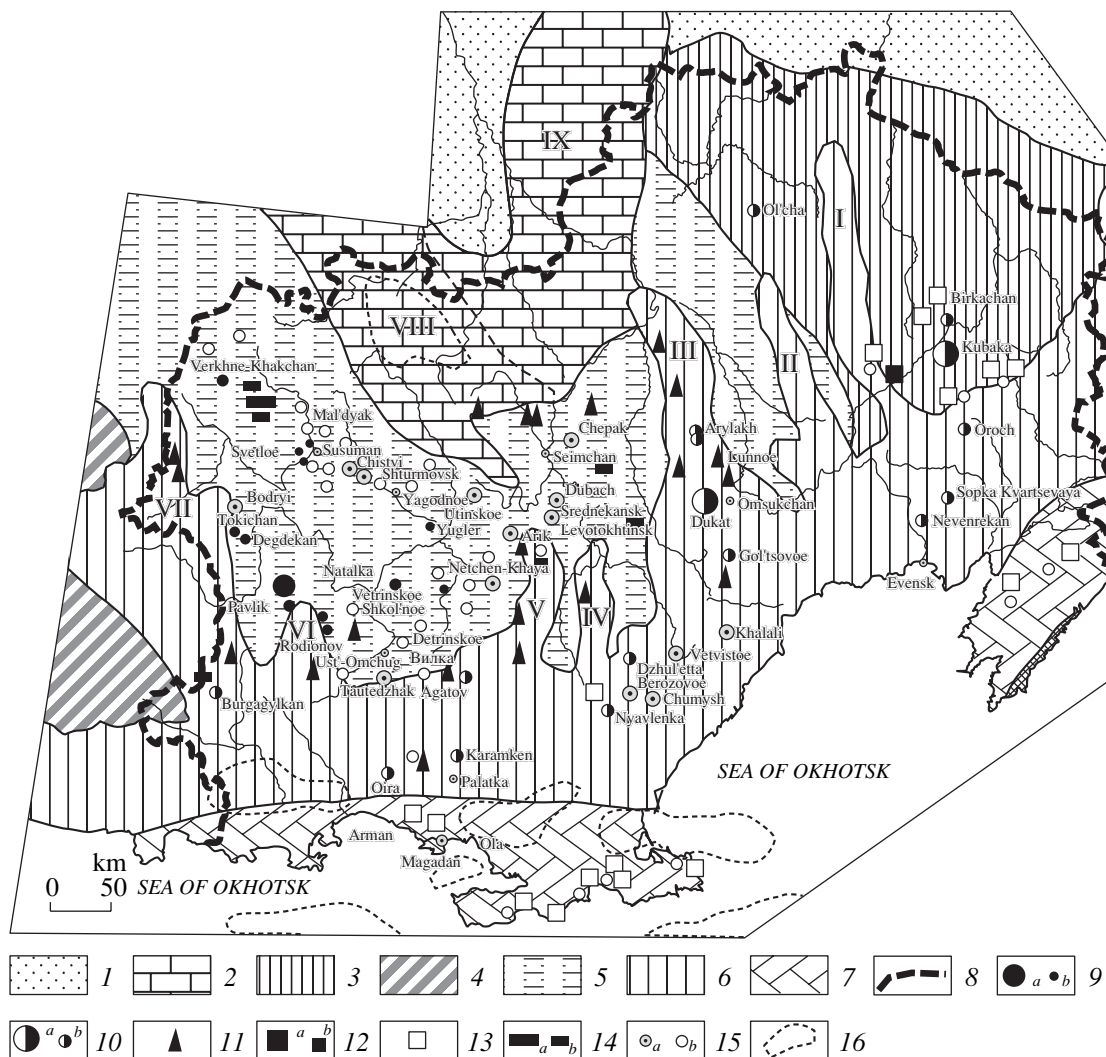


Fig. 1. Schematic metallogenic regionalization of the Magadan district. (1) Alazei–Oloi metallogenic province; (2) Near-Kolyma–Chersk–Polousnen metallogenic belt; (3) Omolon metallogenic province; (4) Okhotsk metallogenic province; (5) Yana–Kolyma metallogenic belt; (6) Okhotsk–Chukotka metallogenic belt; (7) Taigonos–West Koryak metallogenic belt; (8) boundary of the Magadan district; (9) deposits of the gold–quartz formation: (a) large, (b) medium and small; (10) deposits of the gold–silver formation: (a) large, (b) medium and small; (11) tin deposits; (12) iron ore deposits: (a) large, (b) small; (13) occurrences of the porphyry copper formation; (14) coal deposits: (a) medium, (b) small; (15) granitoid-related gold: (a) deposits, (b) occurrences; (16) areas with oil-and-gas potential. (I–IX) metallogenic zones: (I) Kongin, (II) Korkodon–Nayakhan, (III) Balagychan–Sugoi, (IV) Tan’ya–Nur, (V) Khurchan–Orotukan, (VI) Ten’kin, (VII) Tas–Kystabyt, (VIII) Omulev, (IX) Near-Kolyma.

tellurides of Au and Ag, petzite, hessite, sylvanite, and calaverite.

Deposits of the *bismuth type* contain bismuth minerals in the gold–tellurium association (native bismuth and bismuthinite). Bismuth tellurides (tetradymite, tellurobismuthite, emplectite, and joseite) are widespread. Tellurides of Ag and Au (petzite and hessite) are minor components.

Deposits of the *tin type* contain a quartz–cassiterite–muscovite association that predated the quartz–arsenopyrite association. The quartz–tourmaline association is less developed. Tellurides of Au, Ag, and Bi (tetradymite, sylvanite, and petzite) are equally developed.

In tectonomagmatic reactivation zones branching off the Okhotsk–Chukotka volcanic belt, the gold–rare metal deposits are characterized by anomalously high Ag contents (100–300 g/t or more). Such deposits can be recognized as a new type of gold–silver mineralization [6].

All types of gold–rare metal deposits described above contain fine isometric dissemination of gold in arsenopyrite and Bi–Co minerals. The extremely rare free gold is typically associated with late quartz. It is worth mentioning that deposits of the tin type are relatively enriched in free gold.

Detailed mineralogical analysis carried out in recent years at several gold–rare metal deposits (Basugun’in,

Comparative characteristics of gold–rare metal deposits in various metallogenic epochs

Deposit	Position relative to intrusion	Age of intrusion	Contact-metasomatic alterations	Geochemical specialization of ores	Fineness of native gold
Dzhugadzhak	Near-intrusive	D ₂	Pyrrhotite development: epidote, hematite, and chlorite	Fe–Cu–Au–Ag–Bi–Te	880–970
Chepak	Supraintrusive	J ₁	Greisens: muscovite and tourmaline	Au–Fe–As–W–Bi–Te	880–940
Podgornoe	Near-intrusive	K ₁	Tourmaline and chlorite	Fe–Co–As–Ag–Bi–Te	680–800
Basugun'in	Near-intrusive	K _{1–2}	Tourmaline, chlorite, and muscovite	Fe–As–Sb–Te–Bi	680–940
Teutedzhak	Supraintrusive	K _{1–2}	Pyrrhotite development: skarns, epidote, hematite, and chlorite	Au–Ag–Bi–Te	650–940

Dubach, Teutedzhak, Verkhneurul'tun, Chistoe, and Chepak) in Northeast Russia has revealed that gold is mainly developed as fine dispersion in disseminated sulfide ores. Such gold particles have a dimension of 1–30 μm (Fig. 2a), which is significantly different from that of nanosized or invisible gold (hereafter, nanogold) particles in sulfides. Therefore, the fine-dispersed gold can be extracted by cyanidation. In contrast to nanogold particles, the fine-dispersed variety is associated with commensurate segregations of Au–Bi tellurides and native bismuth (Fig. 2b) and characterized by a lower fineness (850–970). Medium- to fine-crystalline arsenopyrite and pyrrhotite are the major carriers of the fine-dispersed gold. The role of pyrite and löllingite is subordinate in this process. Both the nanosized and fine-dispersed varieties of gold are developed as dissemination, suggesting similar conditions of ore formation. We should also mention a very important prospecting feature of these deposits: they do not make up placers because gold is in the fine-dispersed state.

In 2005, we obtained the first results of the detailed mineralogical investigation of ores from the Chepak deposit located at the northeastern margin of the Yana–Kolyma auriferous belt (Fig. 1). Early mineralization in this deposit is assigned to the disseminated gold–sulfide type with invisible gold in sulfides similar to those with refractory ores of the Maisk deposit (Central Chukotka).

The mineralogy of ores of the Chepak deposit is characterized by a high content of As, the absence of free gold, and high concentrations of scheelite (W 0.06%) and bismuth minerals. In some places of metasomatized orebodies, the content of sulfides (mainly, arsenopyrite and löllingite) is as high as 50%. The predominance of quartz and white mica among gangue minerals suggests that some veins belong to the class of quartz–mica greisens (Fig. 3). The composition of fissure-filling veins differs from that of replacement veins by the coarse-grained structure, the presence of pure quartz, the lower content of silicates (micas and chlo-

rite), the prevalence of arsenopyrite over löllingite, and the abundance of pyrrhotite.

Arsenopyrite and löllingite are the main carriers of gold. Arsenopyrite typically occurs as well-developed short-prismatic crystals (up to 2.5 mm in size), while löllingite makes up columnar and radial inclusions in the arsenopyrite. According to the technological sampling data, the Au content in two arsenopyrite samples varies from 56.6 to 108.4 g/t. The Au content in löllingite is 84.4 g/t. The Ag content in these minerals is 3.0, 10.0, and 10.7 g/t, respectively.

We detected fine-dispersed gold and native bismuth in ores from the Chepak deposit (Fig. 2c). In addition, tiny inclusions of native bismuth occur in sulfide minerals, as well as in vein and stringer-disseminated ores. This type of gold is mainly transported by coarse- to medium-crystalline arsenopyrite and pyrrhotite. Pyrite and löllingite are the subordinate carriers. In terms of size (Fig. 2c), fine-dispersed gold (1–20 μm) appreciably differs from nanogold, which can also be developed in these sulfides and extracted by cyanidation.

Study of fluid inclusions in minerals [8] revealed the following features of the formation of various types of ore deposits: (a) the temperature range of their formation varied from >650 to <100°C; (b) minerals of early associations were deposited from high-temperature and strongly concentrated pneumatolytic-hydrothermal solutions; (c) productive associations were characterized by high initial temperatures of weakly concentrated pneumatolytic-hydrothermal solutions and Au-bearing minerals were deposited at terminal stages of the productive quartz crystallization (350–210°C); and (d) minerals of the postproductive quartz–carbonate association were deposited at the final stage of ore formation (200–90°C).

Study of fluid inclusions in quartz grains from various types of deposits revealed the following regularity: (a) quartz grains from deposits of the cobalt type contain strongly concentrated multicomponent fluid inclusions with a small amount of water solution (the inclu-

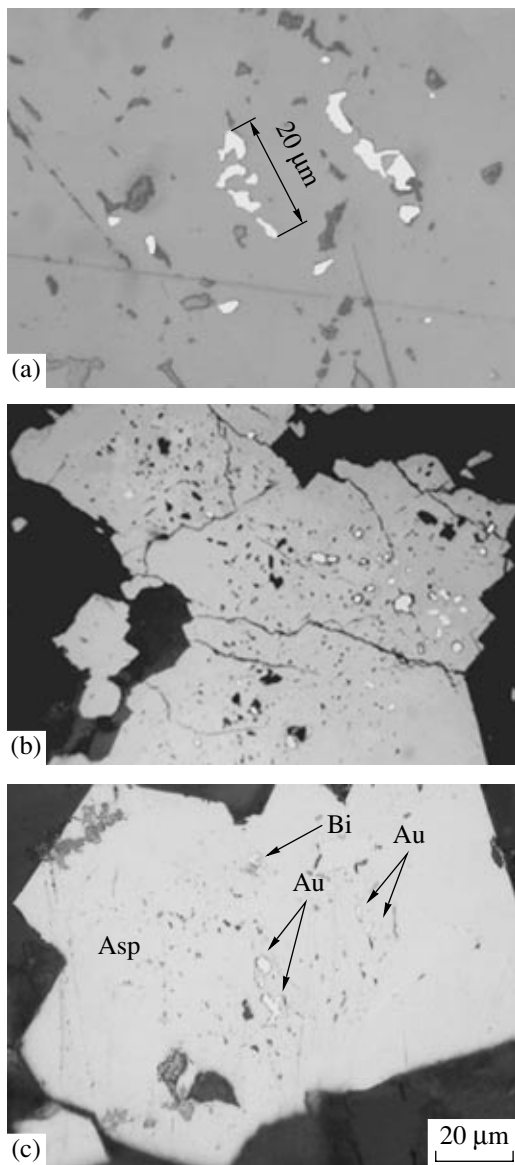


Fig. 2. Fine-dispersed gold and tellurides in arsenopyrite from gold-rare metal deposits. Photomicrographs (a) and (b), courtesy of A.V. Al'shevskii. (a) Fragment of a large arsenopyrite grain with numerous inclusions of native gold, Basugun'in deposit, arsenopyrite grain size 1–2 mm, gold inclusions up to 10–20 µm, magn. 300; (b) fragment of a large grain of fine-porous arsenopyrite with numerous inclusions of Au-bearing bismuth-telluride intergrowths, Teutedzhak deposit, arsenopyrite grain size 1–2 mm, bismuth-telluride inclusions up to 25–30 µm in size, magn. 150; (c) fine-dispersed native gold and bismuth in the fine-grained arsenopyrite developed in sulfide veins of the Chepak deposit, magn. 400.

sions are heterogeneous in some sectors at 700–680°C); (b) quartz grains from productive associations in deposits of the bismuth type contain inclusions with pneumatolytic and pneumatolytic-hydrothermal, moderately or weakly concentrated solutions (5% of the total number of inclusions homogenize into the gaseous phase);

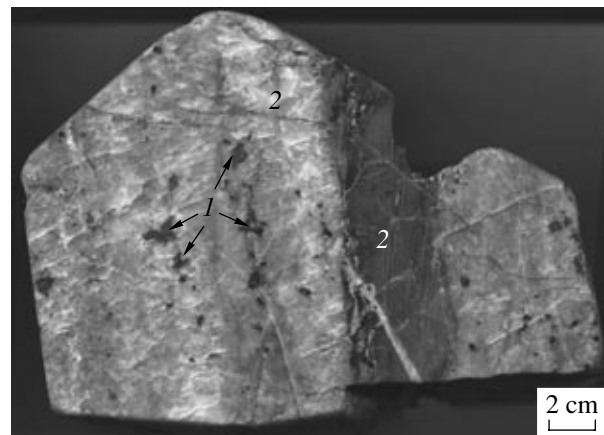


Fig. 3. Quartz-mica greisen (Chepak deposit). (1) Coarse-crystalline arsenopyrite grains and aggregates; (2) sericite and muscovite developed along fissure zones in quartz and fine-grained sandstone relict (dark band). Scanned image of polished specimen.

(c) quartz grains from productive associations in deposits of the tin type contain inclusions with high-temperature hydrothermal solutions.

In general, minerals of the productive association were deposited at a wide range of temperatures (500–210°C). However, the Au-bearing productive paragenesis was formed at 350–210°C.

Thus, discrepancies in the paleotemperature setting of certain deposits or deposit groups are probably related to their positions relative to the parental intrusion. Plutonic deposits of fine-dispersed gold are characterized by large-scale persistence and the evolutionary trend of the ore-forming process. The pneumatolytic (gaseous) phase of mineralization played a significant role in the transport and deposition of ore material. Such processes are highly favorable for the formation of large ore deposits.

In disseminated sulfides, the fine-dispersed gold (1–30 µm) associated with Au–Bi tellurides and native bismuth plays the role of a mineralogical signature of the mineralization type.

The results obtained indicate that additional investigations (e.g., mineralogical-technological mapping) are essential for deciphering the mode of occurrence and the amount of fine-dispersed gold in granitoid-related gold deposits. Such works will make it possible to refine significantly the ore dressing technology.

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