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Disseminated Gold–Sulfide Deposits in the Russian Northeast

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Abstract—This paper is devoted to large commercial disseminated gold–sulfide deposits in the Russian Northeast. Their location is controlled by intrusive dome structures and tectonic blocks in zones of tectonomagmatic activation. It is demonstrated that the combination of various mineral and structural types of ore mineralization results in the formation of large and unique deposits. The following types of ore deposits are distinguished, according to different ore settings and the overprinting of various mineralizations in ore bodies: (1) gold–sulfide, proper, (2) gold–sulfide–quartz, (3) gold–stibnite, and (4) gold–stibnite–cinnabar. The ore formation occurred at medium and low temperatures and pressures over a wide range of depths. The large vertical extent of ore mineralization is related to long-term uplift of the ore-hosting blocks during hydrothermal ore formation. The large disseminated gold–sulfide deposits are directly related to zones of antimony and mercury mineralization. The formation of disseminated ores lacking typical vertical zoning is related to the primary influence of hydrocarbon fluid with subsequent hydrothermal transformation. The total amount of metals in the black-shale sequences can be easily remobilized during metamorphic, magmatic, and hydrothermal processes in zones of tectonomagmatic activation (TMA) to form veinlet-disseminated and vein deposits. Isotopic studies indicate that the disseminated gold–sulfide deposits are related to crustal processes, but a portion of ore components could be derived from mantle sources.

INTRODUCTION

Several deposits and numerous ore occurrences of disseminated sulfide ores with dispersed gold (Table 1) have been discovered in the Russian Northeast during the last two decades by extensive geochemical exploration. The reassessment of known gold–quartz and gold–antimony deposits also revealed disseminated gold–sulfide ores. However, no disseminated gold–sulfide deposits in the Russian Northeast are mined now, because the ores are refractory and there are some technological and environmental problems in ore dressing.

Some deposits of this type (Carlin etc. in the United States, Aschanti in Ghana) are exploited successfully. The beneficiation of the refractory disseminated gold–sulfide ores using bacterial leaching technology began in 2001 in the Olimpiada deposit, Yenisei Range. The technological tests were successfully completed with a large-volume sample (1500 t) using the above technology for ores of the Maiskoe deposit in Chukotka in 1991–1992. A new method of strong electromagnetic pulses is developed to increase the gold recovery up to 85% from the refractory disseminated sulfide ores (Chanturiya *et al.*, 2001).

The involvement of the gold–sulfide ore deposits into exploitation may increase and stabilize the gold production in the current century with annual gold recovery of 5–15 t from each deposit. It is highly possible to discover new gold-sulfide deposits in gold ore districts of the Russian Northeast. The gold resources of known deposits could be increased significantly because prospecting was abandoned at early stages at many deposits.

The origin of disseminated gold–sulfide ores and relationships between disseminated and vein mineralizations are debatable. The disseminated ores are traditionally considered to form wall-rock metasomatic aureoles near veins (Kalinin *et al.*, 1992; Gamyanin *et al.*, 2000; Voroshin *et al.*, 1995; Goryachev, 1998; etc.). We believe that this mineralization originates during a separate pre-vein stage of ore formation.

The disseminated gold-sulfide deposits in the Russian Northeast were studied most extensively in 1975–1990. However, new data allowed us to improve the knowledge of these deposits.

In their earlier publications, A.A. Sidorov, V.I. Goncharov, A.I. Kalinin, Yu.I. Novozhilov, A.M. Gavrilov, A.V. Volkov, and other researchers discussed some problems of tectonic setting of individual deposits, their structural, mineralogic, and geochemical features, and the physicochemical conditions of their formation. We suggested a genetic model of ore formation, studied isotopic compositions of Pb, S, C, and O of ore and gangue minerals and considered debatable problem of a genetic relationship between disseminated and vein ores.

This work summarizes new data on the structural setting, genesis, and classification of disseminated

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Table 1. Gold–sulfide deposits and occurrences in the Russian Northeast

Deposit, occurrence	Location	Mean Au content, g/t	Proportion of refractory gold in ores, %	Other valuable components
Tumannoe	Eastern Chukotka	10–14	80	Ag, Sb
Maiskoe	Central Chukotka	12	90	Ag, Sb
Sil'noe	″	7–8	80?	Ag, Sb
Sypuchee	″	3–5	50?	–
El'vinei	Western Chukotka	10–12	80	Ag, Sb, W, Bi
Sluchainoe	″	8–10	90?	Ag, Sb
Yakor'	″	5–10	90?	Ag, Sb
Natalka	Upper Kolyma	2–3	20–40?	Ag, Pt
Pavlik	″	2–4	50?	Ag, Pt
Degdekan	″	2–4	50?	Ag, Pt
Khurchanskoe	Middle Kolyma	2–5	50?	Ag, Pt
Chepakskoe	″	5–8	80?	–
Nezhdaninskoe	Southeastern Yakutia	6	60?	Ag
Bardan	Eastern Yakutia	8–10?	60?	Sb
Sarylakh	″	8?	70?	Sb
Sentachan	Yakutia	8?	70?	Sb
Kyuchus	″	8	80	Sb, Hg

gold–sulfide deposits in the Russian Northeast. The following problems have been considered: (1) geodynamic and tectonic setting of the deposit formation, (2) classification of the disseminated gold–sulfide deposits of the Russian Northeast, (3) geologic, structural, mineralogic, and geochemical aspects of ore formation, (4) relationships between the disseminated and vein mineralizations in deposits of different types, and (5) comparative genetic analysis of ore deposits taking into account new isotopic data.

This paper considers the Tumannoe, Natalka, and Sarylakh disseminated gold–sulfide deposits of different types. They were chosen for the following reasons. The Tumannoe deposit (eastern Chukotka) is an analog of the well-studied Maiskoe deposit, which was characterized by Volkov (1995), Volkov and Sidorov (2001), etc. The disseminated gold–sulfide deposits of this type are abundant in intrusive dome structures in tectonomagmatic activation zones of Chukotka. The Natalka deposit is comprehensively studied by geologists headed by V.I. Goncharov in the Northeastern Multidisciplinary Research Institute, Far East Division, Russian Academy of Sciences. Like the Nezhdaninskoe, the Natalka deposit was previously considered as typical low-sulfide gold–quartz deposit (Gamyanin, 1985; Gamyanin *et al.*, 2000; Kalinin *et al.*, 1992; Goryachev, 1998). However, typical disseminated gold–sulfide ores with dispersed gold in arsenopyrite were discovered recently at deep levels of this deposit, and gold–stibnite veins and veinlets were found at its flanks. Therefore, the Natalka cannot be regarded as a gold-quartz vein deposit only.

The Au–Sb ores locally with cinnabar and native mercury (Sarylakh, Sentachan, Kyuchus, and some other deposits) are genetically or paragenetically related to the low-sulfide gold–quartz association by many researchers (Indolev *et al.*, 1980; Berger, 1978; Amuzinskii *et al.*, 2001). It was suggested that gold in the quartz–stibnite ore bodies was extracted from the low-sulfide gold–quartz veins and veinlet zones. However, the quartz–stibnite veins normally contain no gold in the ore zones lacking the early disseminated Au-bearing sulfide mineralization (Sidorov and Volkov, 1998b; Volkov and Sidorov, 2001).

The prevailing role of stibnite and related free gold and the occurrence of cinnabar, native mercury, and high Hg admixture in native gold allow many geologists to separate specific Au–Sb and Au–Hg groups of deposits (Indolev *et al.*, 1980; Stepanov and Moiseenko, 1993; Amuzinskii *et al.*, 2001). However, the untested disseminated gold–sulfide mineralization is also abundant in these deposits. We would like to emphasize this fact and suggest the great potential of numerous poorly studied Au–Sb and Sb-Hg occurrences in the Adycha–Taryn, Yana, and other metallogenic zones of the Russian Northeast for new discoveries of new disseminated gold–sulfide deposits.

GENERAL DESCRIPTION

The disseminated gold–sulfide deposits are known in gold ore provinces of different ages and are commonly hosted by carbonaceous terrigenous and terrigenous–carbonate (black shale) sequences in orogenic

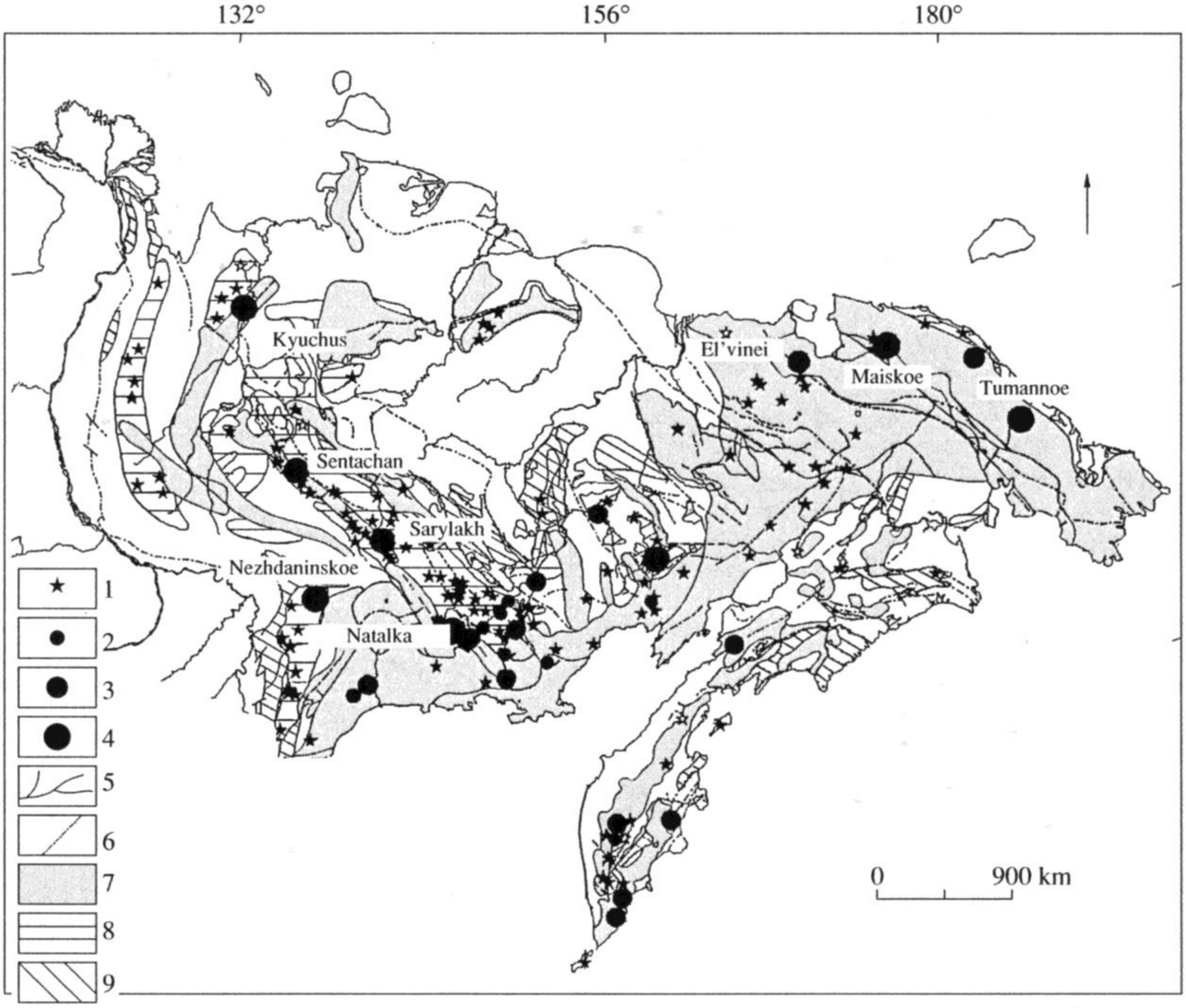

Fig. 1. Distribution of the gold–sulfide deposits in metallogenic belts of the Russian Northeast (modified after *Significant Metalliferous* ..., 1997). (1–4) Gold deposits: (1) <1 t Au; (2) 1–30 t Au; (3) 30–100 t Au; (4) >100 t Au; (5) streams; (6) faults. (7–9) Metallogenic belts: (7) postaccretionary, (8) accretionary, and (9) preaccretionary.

belts. Most of the known deposits are large or unique (>100 t) and some of them include 500 t Au and more. They are commonly related to the completed ore rows comprising the Sb and Hg deposits. The disseminated gold–sulfide mineralization is usually located in the deep fault zones, has relatively uniform mineral composition and high Au/Ag ratio, and shows an almost identical distribution of gold, which occurs as dispersed inclusions in acicular arsenopyrite and As-bearing pyrite (1–5% As) comprising 5–10% of ores. The Au-bearing sulfides form fine dissemination in the cataclastic and shear zones. The disseminated sulfide mineralization continues to depths below 1 km without considerable changes in composition and Au concentration. No lateral and vertical mineralogic zoning of the ore mineralization was reported. The ore bodies locally include quartz veins and veinlets with stibnite, cinnabar, and other sulfides, and native antimony, which are accompanied by late medium-grained high-fineness gold. However, the disseminated gold–sulfide mineralization proper frequently does not associate with quartz veins. A close correlation between Au and As is typical of this mineralization. The fineness of refractory gold dispersed in sulfides was calculated to be close to 1000 (Badalov, 1972). According to Moesbauer spectroscopy, the gold in most of the disseminated gold–sulfide deposits is chemically bound in arsenopyrite or occurs there as metallic inclusions 2 nm in size (Genkin, 1998).

The disseminated sulfide ores in the Russian Northeast deposits do not differ principally from similar ores in deposits of Kazakhstan (Bakyrchik), the Yenisei Range (Olimpiada, Veduga, Udereiskoe), Uzbekistan (Daugyztau, Kokpatas), of Tajikistan (Chore, Konchoch). We believe that the Carlin, Cortez, and Getchel deposits in the Basin and Range Province in the United States and the Aschanti deposit in Ghana should also be affiliated with this type.

Table 2. Characteristics of disseminated gold–sulfide deposits of various types

Characteristics	Deposit type			
	gold–sulfide	gold–sulfide–quartz	gold–stibnite	gold–stibnite–cinnabar
Ore-bearing structures	Intrusive dome structures	Ore-bearing tectonic blocks above intrusions	Ore-bearing tectonic blocks of deep faults	Ore-bearing tectonic blocks of deep faults
Magmatic bodies within a deposit	Numerous dikes of various compositions (up to 30% of the deposit volume)	Rare silicic and intermediate dikes	Absent	Absent
Specific features of ore-bearing structures	Mineralized cataclastic and shear zones	Mineralized cataclastic and shear zones with axial quartz veins and veinlet zones	Sutures with axial quartz–stibnite veins	Mineralized cataclastic and shear zones with quartz–stibnite and carbonate–cinnabar veinlet zones
Specific features of ore mineralization	Domination of disseminated gold–sulfide mineralization	Combination of disseminated gold–sulfide, gold–quartz, and gold–silver mineralizations	Combination of disseminated gold–sulfide and gold–stibnite mineralizations	Combination of disseminated gold–sulfide, gold–stibnite, and gold-cinnabar mineralizations
Wall rock alteration	Sericitization	Berisitization	Sericitization	Sericitization
Proportion of refractory gold in ores, %	50–90	20–40	Not determined	80–90
Au concentration in disseminated ores, g/t	12	2–5	6–8	6–8
Productive mineral assemblages	Gold–pyrite–arsenopyrite	Gold–pyrite–arsenopyrite, gold–quartz, gold–silver–base-metal	Gold–pyrite–arsenopyrite, gold–stibnite	Gold–pyrite–arsenopyrite, gold–stibnite–gold–cinnabar
Au/Ag ratio in ores	3 : 1	3 : 1 (5)	10(5) : 1	10(5) : 1
Geochemical specialization	Au, As, Sb, Ag, Pb, Zn, Mo	Au, As, Ag, W, Pb, Zn, Sb	Au, As, Sb	Au, As, Sb, Hg
Correlation of Au with other elements (>0.5)	As, locally with Sb and Pb	As, Ag, Pb	As, Sb	As, Sb, locally with Hg
Deposits	Maiskoe; Sil'noe; El'vinei; Tumannoe	Nezhdaninskoe; Natalka; Sypuchee	Sarylakh; Sentachan	Kyuchus

STRUCTURAL SETTING OF THE DISSEMINATED GOLD–SULFIDE DEPOSITS IN THE RUSSIAN NORTHEAST

In the Russian Northeast, the disseminated gold–sulfide deposits are located in postaccretionary folded metallogenic belts of the Verkhoyansk–Kolyma and Chukotka terranes of a passive continental margin (Fig. 1). Many deposits are confined to the outer peripheral structures of the post-accretionary Okhotsk–Chukotsk volcanic belt. According to recent studies, large gold deposits in the Russian Northeast are polychronous and developed from the preaccretionary metallogenic epochs to the later stages of the postaccretionary epoch (Sidorov and Volkov, 2001). The geologic–structural setting and mineralogic and geochemical features of the deposits are distinct (Table 2).

The Chukotka metallogenic belt (Fig. 1) is located within a passive continental margin of the North Asian craton. The collisional and post-accretionary granitoid massifs emplacement occurred there in the Late Jurassic–Early Cretaceous. The disseminated gold–sulfide deposits of Chukotka are confined to the intrusive dome structures in the peripheral zone of the Okhotsk–Chukotkask volcanic belt (Fig. 2) and are closely related structurally, mineralogically, and geochemically to gold–silver, gold–quartz, gold–antimony, and gold–rare-metal vein mineralizations (Volkov and Sidorov, 2001). The ores are hosted by Triassic flyschoid sequences composed of siltstones and pelitic shales.

The Yana–Kolyma metallogenic belt (Fig. 1) extends from the North Asian craton in the northwest to the Okhotsk–Chukotsk volcanic belt in the southeast. The belt is traced by a chain of the Late Jurassic granodiorite–granite batholiths, as well as swarms of intermediate dikes and small intrusions preceding the batholith emplacement. The ores are hosted by sandstones, pelitic shales, and flyschoid sequences of the Verkhoyansk complex (Upper Paleozoic–Lower Mesozoic). In the Verkhoyansk–Kolyma terrane, the gold–sulfide deposits are found in the following two geologic

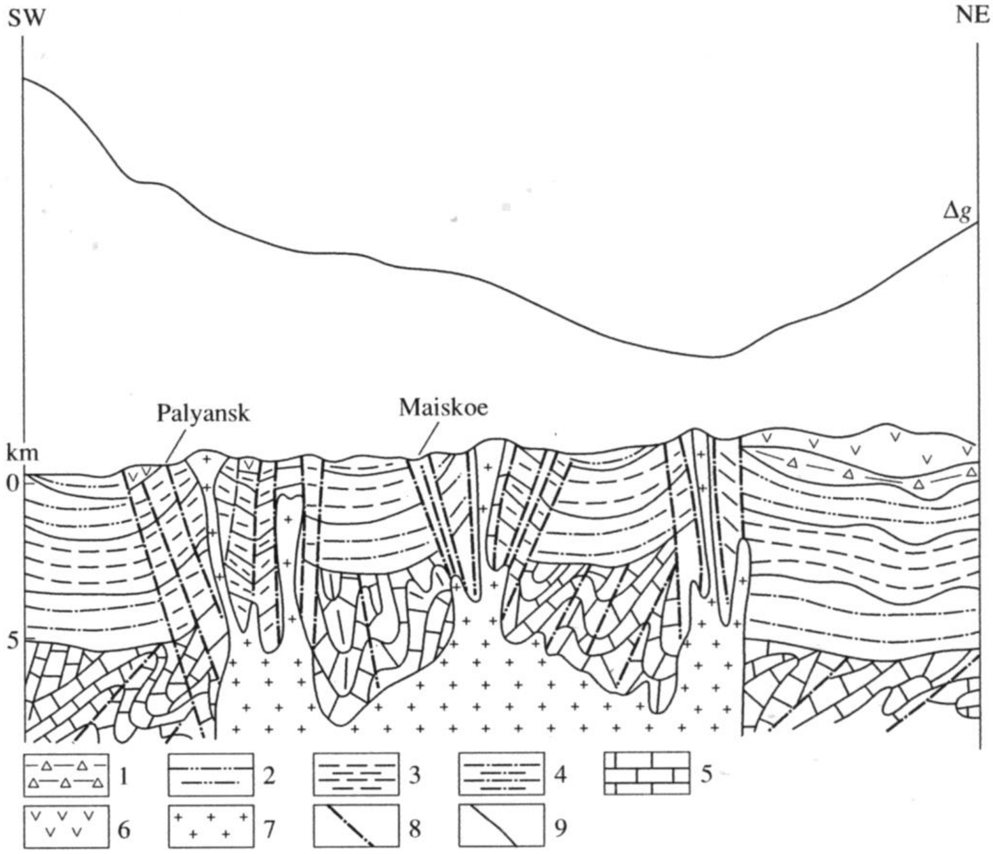

Fig. 2. Deep structure of Central Chukotka [schematic cross section by geologic and geophysical data after Volkov and Sidorov, 2001]. (1) Lower Cretaceous psammitic shale sequences with tuffaceous sandstone interbeds; (2) Norian psammitic shale sequences; (3) Carnian silty shale flyschoid sequences; (4) Lower–Middle Triassic shales; (5) Paleozoic terrigenous–carbonate rocks; (6) Lower Cretaceous andesites; (7) Early- to Late Cretaceous granitoids; (8) magma- and ore-controlling synvolcanic faults; (9) geologic boundaries.

settings: (1) in tectonic blocks of deep fault zones (Natalka, Nezhdaninskoe, and other deposits) above the intrusions; comprising dikes and stocks of various compositions (Fig. 3); and (2) in the "amagmatic" tectonic blocks along the longitudinal faults in the tectonomagmatic activation zones (Sarylakh, Sentachan, and Kyuchus deposits); it is suggested that magmatic chambers existed in these zones at significant depths. However, the magmatic bodies are absent within the ore fields and deposits. Thus, these deposits are classified as telethermal (Indolev *et al.*, 1980) or telemagmatic (Shilo *et al.*, 1978) groups. According to Stepanov and Moiseenko (1993), these fault zones are related to rifting.

We suggest that the activated fault zones extend for more than 2000 km inside the Kolyma terranes and are related to postaccretionary tectonomagmatic processes. However, the deposits located in these zones have some features in common with disseminated gold–sulfide deposits of Chukotka (Volkov, 1989).

Therefore, the disseminated gold–sulfide deposits in the Russian Northeast are found in various structural settings and show various relationships between disseminated and vein mineralizations (Table 2), which

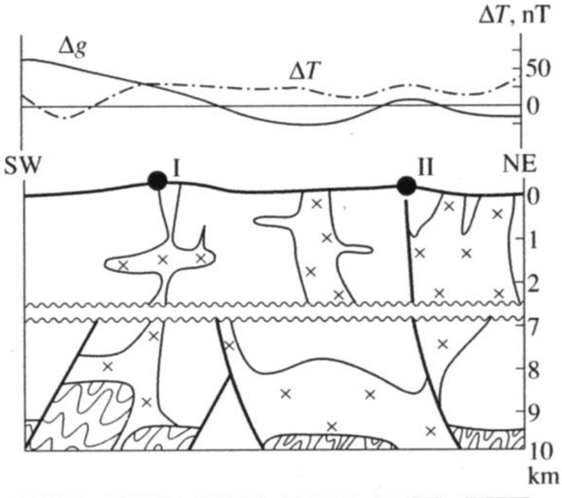

Fig. 3. Deep structure of the Central Kolyma region [schematic cross section by geologic and geophysical data (Kalinin *et al.*, 1992)]. (1) Crystalline basement; (2) terrigenous cover on Mesozoides; (3) collisional granitoids; (4) deep fault zones; (5) geologic boundaries; (6) deposits: (I) Natalka, (II) Vetrenskoe.

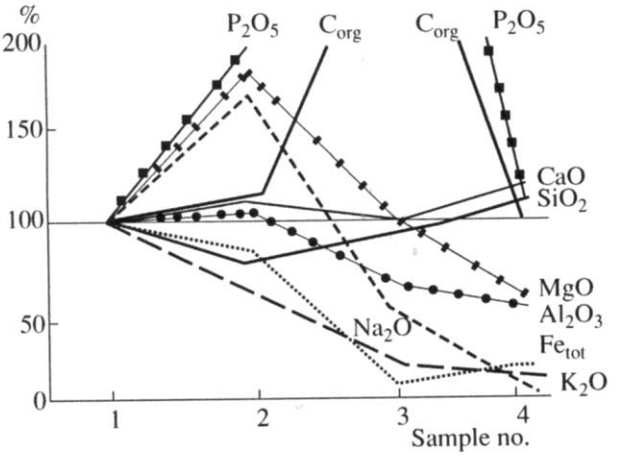

Fig. 4. Chemical composition of mudstones and siltstones in the gold-bearing sulfidization zone, Maiskoe ore deposit. Abscissa shows percentage of element concentrations relative to unaltered rocks. (1) Weakly sulfidized siltstone (1 g/t Au); (2) siltstone from ore zone with fine sulfidization (10 g/t Au); (3) mudstone with patches of carbonaceous matter (10–20 g/t Au); (4) silicified and sulfidized rock (100 g/t Au).

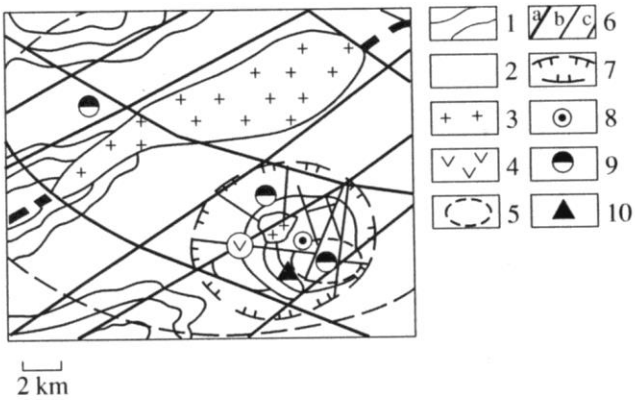

Fig. 5. Schematic tectonic and metallogenic map of the Tumannoe deposit area. (1) Lower Triassic pelitic shales; (2) Middle to Upper Triassic flyschoid deposits; (3) granodiorites; (4) rhyolite subvolcanic body; (5) inferred boundary of the relaxation zone; (6) faults of the Ekug zone of tectonomagmatic activation: (a) deep faults (magma conduits), (b) subordinate contiguous and transverse faults, (c) radial faults of the Ekug dome structure; (7) Ekug dome structure boundaries; (8–10) deposits: (8) Tumannoe disseminated gold-sulfide deposit, (9) Ekug cassiterite-silicate deposit, (10) Promezhutochnoe tin-silver deposit.

allow us to distinguish the following types of deposits: (1) gold–sulfide, proper; (2) gold–sulfide–quartz; (3) gold–stibnite; and (4) gold–stibnite–cinnabar.

GOLD–SULFIDE TYPE

The deposits of this type formed in dome–block structures, which determined the isometric shapes of the ore fields (Fig. 2). The ore mineralization is closely related spatially and genetically with granite porphyry, lamprophyre, and rhyolite porphyry dikes and subvolcanic stocks, and locally with explosive breccias. The deposits are hosted by flyschoid (generally silty) carbonaceous sequences with rare layers and lenses of fine-grained sandstones. The Chukotka deposits (Maiskoe, Tumannoe, El'vinei, etc.) were formed in several stages. At the earlier stages, molybdenite–quartz, wolframite–quartz, and cassiterite–quartz veins and veinlets originated in the sericitic metasomatic aureoles in granite porphyry and diorite dikes and stocks. The disseminated gold-bearing sulfidization in the cataclastic and shear zones is structurally separated from rare-metal mineralization. However, the sulfidization of the terrigenous sequences is polychronous and, in some cases, begins prior to these earlier stages. The disseminated mineralization is overprinted by gold–quartz, silver–base-metal sulfide, and gold–stibnite–quartz (locally, with native arsenic) vein and veinlet mineralizations. The ores have high Au concentrations (12 g/t, on the average). The Au is refractory and is confined to the disseminated sulfides. The amount of easily recoverable gold exceeds 10–20%. There is no distinct correlation between the gold and carbonaceous matter concentrations, although the areas with elevated carbon contents typically show the most homogeneous distribution of gold. For example, C_{org} content in the Au-bearing metasomatites of the Maiskoe deposit vary from 0.08–1.44% (Volkov and Sidorov, 2001). The following relationships are observed between hydrothermal alteration and element distribution in this metasomatic zone. The host rocks are dark (to black) in the ore body parts with homogeneously elevated gold contents, C_{org} and P_2O_5 contents increase, and SiO_2 content slightly decreases. In the areas of rock silification, the Au concentrations are highly variable (1–100 g/t), and C_{org} and P_2O_5 contents strongly decrease (Fig. 4). Therefore, C_{org} is removed or inhomogeneously redistributed in the metasomatic zones during the hydrothermal alteration of the carbonaceous metasomatites. The gold fineness varies from 850 to 950. Let us consider a deposit of this type, where the gold mineralization was discovered by analogy with the well-studied Maiskoe deposit.

The Tumannoe deposit is situated in the Ekug satellite intrusive dome structure (Figs. 1, 5) located at the eastern closure of the Palyavaam zone of gentle folds (Eastern Chukotka). The intrusive dome structure is confined to an intersection of the northeastern and northwestern regional faults. The structure is composed of the Lower, Middle, and Upper Triassic terrigenous flyschoid sequences and relics of the Upper Cretaceous volcanic sheets unconformably overlying the dislocated Triassic rocks. The Ekiatap granite–granodiorite massif outcrops in the central part of the intrusive dome structure and is dated to the Early Cretaceous [92 Ma after Zagruzina (1977)]. The massif is accompanied by several small granitoid stocks 0.5–10 km^2 in area, which form satellite domes. The compositionally vari-

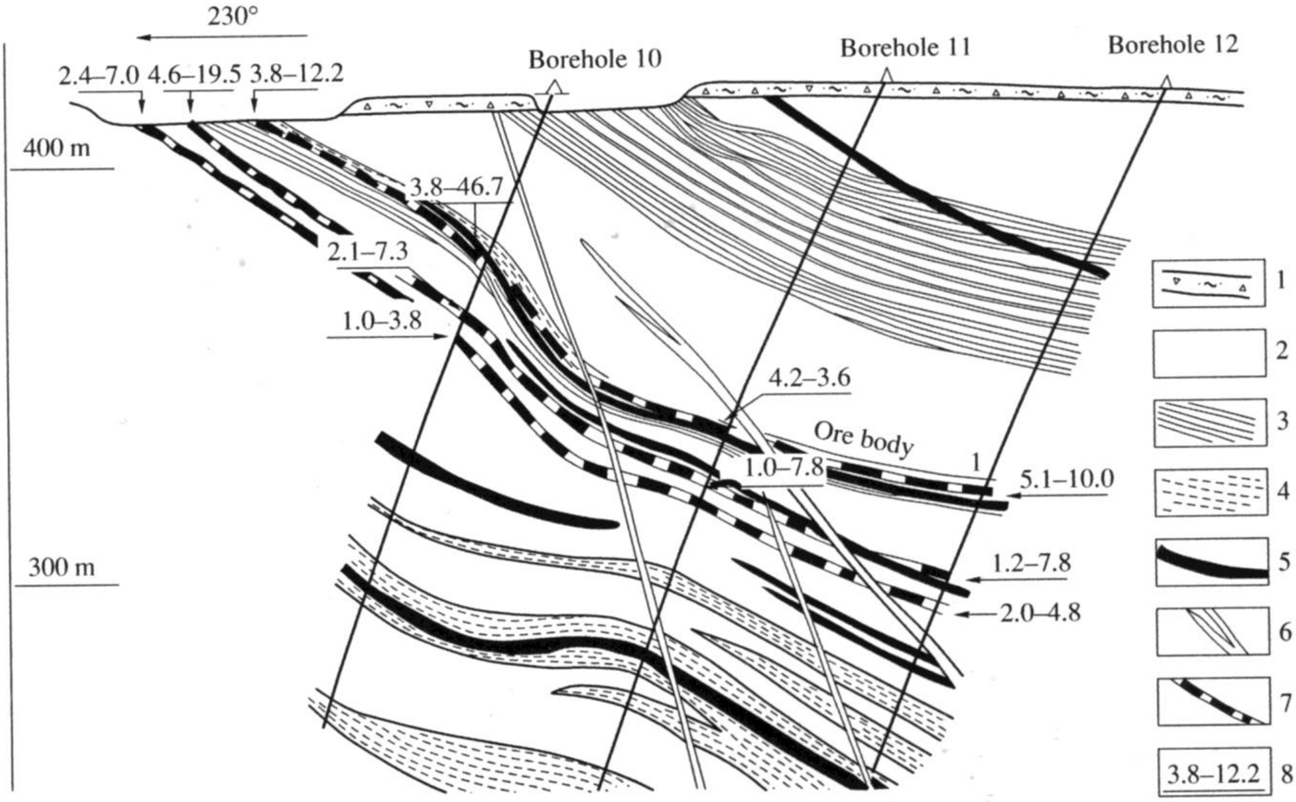

Fig. 6. Geologic cross section of the Tumannoe deposit by drilling data. (1) Quaternary residual and talus deposits; (2–4) Upper Triassic terrigenous flyschoid sequences (Mymlernet Suite): (2) sandstones, (3) black shales, (4) siltstones; (5) Early Cretaceous (?) granite porphyry dikes; (6) postore basaltic andesite dikes; (7) ore bodies; (8) ore body thickness (m) and Au concentration (g/t).

able Late Cretaceous dikes are abundant there. Small subvolcanic rhyolite stocks are also present (Fig. 5), as in the Maiskoe deposit area (Volkov, 1995). Brachyform folds within the intrusive dome structure originated during the tectonic block movements. The intrusive dome structure corresponds to an ore field including the Ekug tin deposit, Tumannoe gold and antimony deposit, Promezhutochnoe tin and silver deposit, Skalistoe tungsten ore occurrence, and several poorly studied Au, Sb, and Sn occurrences.

The Carnian terrigenous rocks compose a brachysyncline 4 km long and 2 km wide, which strikes northeast and plunges north. It is comprised of two members of the Mylernet Suite. The lower siltstone–shale member outcrops in the core of the fold, while the upper siltstone–sandstone member is exposed in its limbs. The rocks dips at low angles (15°–30°) in the fold limbs.

The dome structure of the deposit is traced by concentric and radiate ore- and magma-controlling faults (Fig. 5). The faults can be subdivided into two genetic groups: (1) regional faults which originated during the Mesozoic folding and formation of the superimposed structures of the Ekug tectonomagmatic activation zone and (2) local faults which resulted from intrastructural tectonic deformations.

The Tumannyi granodiorite porphyry stock is exposed in the central part of the deposit. The stock is accompanied by biotite hornfelses.

The host terrigenous rocks at the deposit are intruded by numerous Late Cretaceous granite-porphyry and trachybasalt dikes and Early Cretaceous granodiorite and lamprophyre dikes (Fig. 6). The granite porphyry and granodiorite porphyry dikes are beresitized, while the basic and intermediate dikes are carbonatized and chloritized. The terrigenous wall rocks are altered and represented by quartz–sericite–carbonate metasomatites.

The ore bodies of the deposit are confined to fragments of concentric faults in the outer contact zone of the stock and are mineralized cataclastic and shear zones conformable with the host rock stratification. The latter are composed of sandstones, siltstones, and pelitic shales with disseminated sulfides, pyrite and arsenopyrite (5–8 vol %, collectively).

The deposit consists of 20 ore bodies 0.4–10 m thick with Au concentrations from 0.5 to 110 g/t. The ore bodies extend for 200–800 m along the strike and for >300 m along the dip (they are not outlined). The main identified resources are comprised in ore body 1 (Fig. 6). This ore body is traced for 1000 m along the strike and for 300 m along the dip and has an average thickness of

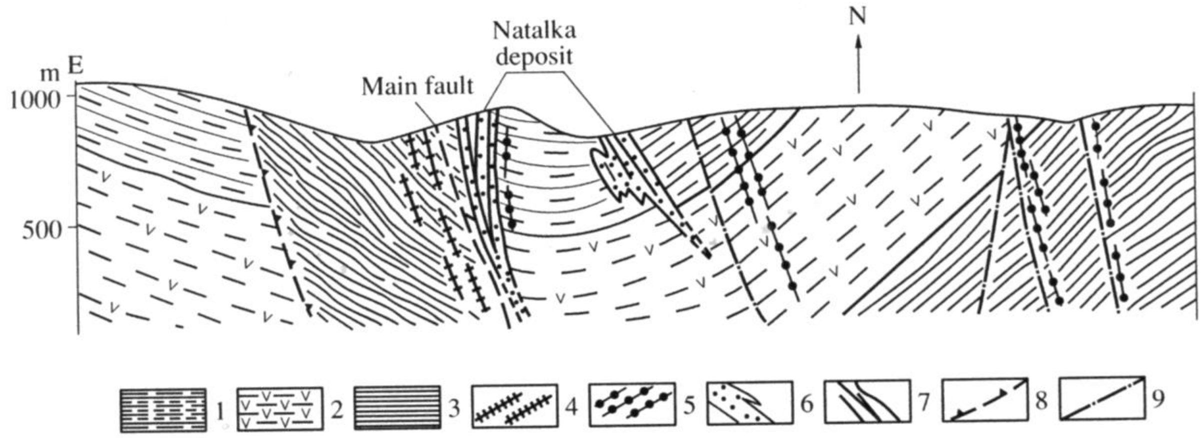

Fig. 7. Schematic geologic cross section of the Natalka deposit. (1) Psammitic–pelitic shales (Neryucha Suite); (2) tuffaceous shales (Atkan Suite); (3) pelitic and carbonaceous pelitic shales (Tass Suite); (4) rhyolite dikes; (5) kersantite dikes; (6) ore zones; (7) ore bodies; (8) ore-controlling faults; (9) subordinate faults.

4.1 m and Au content of 14.6 g/t. In addition to the disseminated sulfide ores, the ore body includes quartz veinlets. Four mineralization stages are distinguished at the deposit. The nonproductive stage yielded the sericite–molybdenite and cassiterite–quartz greisen mineralization composing separate ore bodies at the neighboring Ekug tin deposit. The first ore stage produced disseminated gold–sulfide ores, spatially and genetically related to the beresitization zones. The second ore stage generated gold–quartz veins and veinlets localized within the ore pipes of the deposit. Numerous (>70) quartz–stibnite veins formed during the final stage. The study of the technological properties of the primary ore of the Tumannoe deposit revealed that 80% Au is refractory submicroscopic and is included in disseminated sulfides.

GOLD–SULFIDE–QUARTZ TYPE

The deposits of this type compose elongated linear ore fields more than 20 km^2 in area. The ores are hosted by monotonous Permian terrigenous sequences. The ore mineralization is spatially related to lamprophyre, diorite porphyry, and rhyolite dikes, granodiorite and diorite stocks and subvolcanic bodies being emplaced in zones of the activated deep fault. Some evidence for mobilization and redeposition of early sulfides and gold was found in ores (Eremin and Osipov, 1974; Bortnikov *et al.*, 1998; Gamyanin *et al.*, 2000). The deposits have low Au concentrations in disseminated ores (2–6 g/t). The amount of free gold with an average fineness of 750 ranges from 50 to 80%.

The Natalka deposit is confined to a tectonic block above intrusions (Fig. 3) in the Ten'kino zone of tectonomagmatic activation extending along the southwestern boundary of the Ayan–Yuryakh anticlinorium. It presents a large-volume stockwork deposit. The deposit has been mined for more than 55 years. Eighty five tons of gold have been developed from 1944 to 1999 (Gal'chenko *et al.*, 2000). The geologic structure and composition of the deposit is described in numerous publications (Voroshin *et al.*, 1995; Kalinin *et al.*, 1992; etc.). Some new data on the disseminated gold–sulfide mineralization are discussed in this paper.

The Natalka ore field 40 km^2 in area is bounded by faults and consists of a system of tectonic blocks complicating the elongated Mesozoic folded structures within the Ten'kino zone of tectonomagmatic activation. The ore field is composed of the Lower and Upper Permian tuffaceous and less abundant pelitic and psammitic shales more than 2000 m in total thickness. The sedimentary rocks are intruded by Late Jurassic–Early Cretaceous spessartite dikes and Late Cretaceous rhyolite dikes.

The Natalka deposit is situated in a wedge-shaped tectonic block bounded by the Main and Northeastern faults (Fig. 7). The ore-bearing block is confined to the southwestern limb of a simple synclinal with limbs dipping at 40°–50°. The main northwesterly shear faults of the ore field are normal and strike-slip faults with separation up to 700–800 m. The ore mineralization is controlled by a complex system of conjugate steeply dipping faults. The ore bodies are represented by linear stockworks 10–15 m thick composed of veinlet–disseminated mineralization. The veinlets are 5–30 mm thick (50% of them are 5 mm thick). Thus, a veinlet zone includes from 5–10 to 40–50 veinlets per meter. The veinlet zones transform to short lens-shaped veins 0.3–0.7 m thick and up to 100 m in extent along the strike (so-called apophyses) or to zones of netlike or massive metasomatic silification. In a cross section, the ore zones are composed of a fan-shaped system obviously converging at a depth (Fig. 7). The boundaries of the ore bodies are uncertain and are determined by testing. The ore pipes are elongated, bedding-parallel, or discordant. The ore pipe location is caused by bending, branching, and crossing of the faults. Some ore pipes are controlled by lamprophyre dikes (Uchastkovaya zone). The lithologic control is important for rich ore distribution. The volcano-sedimentary and carbonaceous rocks of the Atkan Suite are the most favorable environments for ore accumulation (Fig. 7).

Quartz is dominant among the gangue minerals; while albite, orthoclase, adularia (at the upper levels of the deposit), calcite, and dolomite are subordinate minerals; sericite and chlorite are abundant. The main ore minerals are arsenopyrite, pyrite, native gold, galena and pyrrhotite. Scheelite, cassiterite, ilmenite, rutile, sphalerite, chalcopyrite, and electrum are scarce. Gold associates with quartz and sulfides. The gold grains vary from 0.2–0.5 to 2 mm in size. The interstitial, spongy, and dendritic gold varieties are dominant. Its fineness varies from 620 to 800 (750, on average).

The deposits of the gold–quartz association are characterized by low-grade quartz veins filling the shear fractures and ruptures and also containing ankerite, albite, and calcite. The ores of this association contain no more than 2–3 vol % sulfides and commonly include native gold with fineness 800–900. The wall rock alteration is weak, extends only over a distance of 3–5 cm from the vein contacts, and is represented by albitization, silicification, sericitization, and chloritization.

However, some ore bodies of the Natalka deposit, contrary to many deposits of the gold–quartz association, exhibit a significant role of gold-bearing sulfides, generally acicular arsenopyrite and less abundant As-bearing pyrite, which are disseminated in the sheared, folded, and boudinaged rocks. Two stages of productive ore mineralization can be distinguished, which are characterized by sequential mineral assemblages: (a) arsenopyrite–pyrite with dispersed gold and (b) gold–base-metal. Sulfides of the second assemblage commonly replace sulfides of the first assemblage (Eremin and Osipov, 1974). In the first assemblage, pyrite crystallized later than arsenopyrite. The former includes euhedral arsenopyrite grains. Fine-grained arsenopyrite aggregates are replaced by pyrite patches. Arsenopyrite dominates over pyrite and its content is about 2 wt % in the disseminated ore, while pyrite contents usually do not exceed 0.5–1 wt %. The arsenopyrite grains show crystal habits and distinct features of metacrystals of rhombic and acicular shape. Pyrite usually forms cubic crystals. Gold concentrations in arsenopyrite crystals are 70–220 g/t by microprobe data and exceed 470 g/t by atomic absorption. Sulfidization is slightly more extensive in the mineralized zones in the sheared tuffaceous rocks than in their undeformed varieties.

A notable positive correlation between gold and arsenopyrite and between gold and galena indicates that the hydrothermal solutions were dominated by certain complex compounds, which precipitated as productive mineral assemblages. The calculations demonstrate that sulfides accumulate up to 50% of the total gold amount. However, the proportion of gold dispersed in sulfides does not exceed 20% of the total gold amount in the outlined ore bodies. They are dominated by the gold–base-metal assemblage related to quartz veins and veinlet zones. The native gold crystallization in quartz veins and quartz veinlet zones occurred at the gold–base-metal mineralization stage.

Thus, the extensive disseminated sulfide mineralization in the ore zones related to hydrothermal metasomatic processes at the gold–sulfide stage played an important role in the formation of the Natalka deposit. The highly extensive development of disseminated ore mineralization makes this deposit outstanding among many other gold–quartz deposits. Due to the character of the disseminated sulfide mineralization the Natalka deposit is close to the disseminated gold–sulfide deposits, where almost all the gold is confined to the disseminated metasomatic sulfides.

The Pt and Pd admixtures were revealed recently in the ores of the Natalka deposit. The highest contents of these elements are confined to spessartite dikes localized within the Uchastkovaya ore zone (Sidorov *et al.*, 1997).

Specific features of the Natalka deposit allow us to distinguish the gold–sulfide–quartz type of the disseminated gold–sulfide deposits. The unique Nezhdaninskoe deposit could be also classified with this type, and additionally to some deposits and ore occurrences of the Omchak ore district.

GOLD–STIBNITE AND GOLD–STIBNITE–CINNABAR TYPES

The ore fields of these deposits are linearly elongated in the map as a system of ore-bearing tectonic blocks in deep longitudinal fault zones. The ores are hosted by silty carbonaceous flyschoid sequences. Rich ores of some deposits (Sarylakh, Sentachan) contain up to 50% stibnite; native gold has a fineness up to 998. The regeneration of early Au-bearing sulfides was found in some cases (Indolev *et al.*, 1980; Amuzinskii *et al.*, 2001). Cinnabar and native mercury occur in some deposits (Kyuchus). The disseminated sulfide ores are poorly studied in some deposits and not evaluated economically, although they contain up to 8–9 g/t Au. For example, the Sarylakh deposit includes disseminated ores with gold dispersed in sulfides.

The Sarylakh deposit is confined to the southeastern termination of the Adycha-Taryn zone of tectonomagmatic activation. The geologic structure and ore composition of the deposit were studied by many geologists: V.G. Vladimirov, V.I. Berger, G.Ya. Prushinskaya, L.N. Indolev, P.M. Polyanskii, V.A. Amuzinskii, and E.A. Sibiryakov, whose data are used in this section. These studies was were focused on the late-stage Au–Sb vein mineralization, while the earlier disseminated gold–sulfide ores were traditionally considered as wall-rock sulfidization aureoles. The analysis of the original and published data on the Au–Sb deposits of the Adycha-Taryn zone and a comparison of these deposits with the disseminated gold–sulfide deposits of

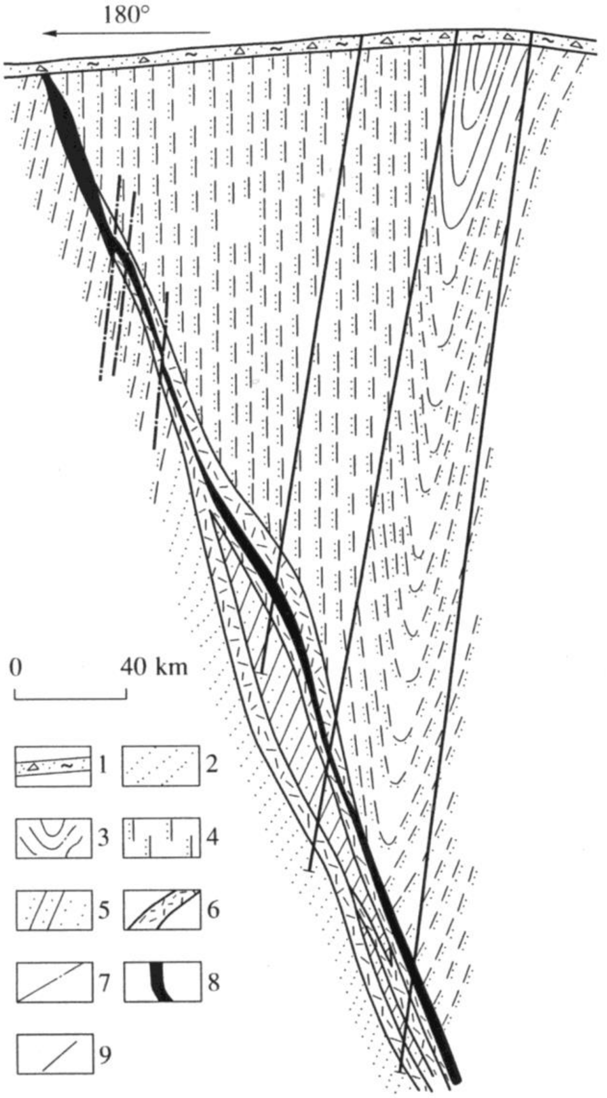

Fig. 8. Schematic geologic cross section of the Sarylakh deposit (geological exploration data). (1) Residual and talus deposits; (2) sandstones; (3) mudstones and pelitic shales; (4) intercalation of sandstones and siltstones; (5) siltstones; (6) mineralized cataclatic and shear zones; (7) faults; (8) ore bodies; (9) geologic boundaries.

Chukotka allow us to suggest that these deposits have many similar geologic, structural, mineralogic, and geochemical features (Volkov, 1989). We believe that the mineralizations of the following types associate with the Au–Sb deposits of the Adycha-Taryn zone (e.g., Sarylakh deposit): (1) disseminated gold–sulfide, (2) gold–quartz, and (3) gold–antimony.

According to Amuzinskii *et al.* (2001), the Sarylakh ore field is situated in the area that projects from the deep boundaries of the Sarylakh subvolcano and unexposed Talov intrusion expressed in a large magnetic anomaly. However, magmatic rocks are absent within the Sarylakh deposit. The folded and faulted structures prevail within the ore field.

The main structure of the deposit is the Sarylakh anticline. Its core is composed of Norian sandstones (80%) and subordinate siltstones with a total thickness of 700 m. Its limbs are complicated by lower order folds. One of these folds confines ore bodies (Fig. 8). The Rudnyi fault, a segment of the central suture of the Adycha-Taryn zone, divides the fold into two blocks. One of them consists of sandstones, the other, of carbonaceous silty shales. The rocks strike subparallel to the fault in its footwall, whereas they are oriented normally to the fault in its hanging wall. The rocks dip southwest at angles 60°–90° within the deposit. In the southeastern flank, the Rudnyi fault zone is shifted by the Poperechnyi northeasterly preore fault for 10–13 m. The Rudnyi fault is a normal–strike-slip fault. It is a cataclastic and shear zone composed of intensely fractured, sheared, and boudinaged siltstones and sandstones. The host rocks are beresitized (ankerite, sericite, quartz, epidote, and graphite) and include disseminated pyrite and arsenopyrite. The economic potential of the deposit is concentrated in the ore body 1, which is an Au-bearing quartz–stibnite plate-shaped vein extending for 2 km along strike and >0.5 km along the dip (Fig. 8). The thickness of the ore body varies from 0.1 to 17.2 m. The ores are valuable in stibnite and native gold. The gold is uniformly distributed in ores. The Au and Sb contents decrease with depth. The Sb ores are poor in admixture elements. Only As concentrations are noticeable (0.22% on the average). The As, Ag, and Ba contents in ores increase with depth (up to 0.45%, 1.1 g/t, and 0.012%, respectively).

We could reveal here at least three stages of ore mineralization (by analogy with known deposits of the gold–sulfide type): (1) disseminated gold–sulfide, (2) gold–polysulfide–quartz, and (3) gold–stibnite.

The first stage is represented by arsenopyrite–pyrite assemblage, which is abundant in the deposit (Fig. 9). However, these ores have not been involved in the calculation of resources. The disseminated gold–sulfide mineralization is confined to the central part of the cataclastic and shear zone, generally near the ore body, locally spreading 50 m from it. This mineralization is also found in the quartz–stibnite ore body, in host rock xenoliths. The minerals of this assemblage are diffused in the rocks of the shear zone. Pyrite and arsenopyrite are characterized by boxlike and skeletal shapes of metacrystals. The minerals do not exceed 1–2 mm in size. The arsenopyrite–pyrite assemblage has high Au concentrations, which are finely dispersed in the minerals. Mean Au concentrations are 340 g/t in arsenopyrite and 19.5 g/t in pyrite (Amuzinskii *et al.*, 2001).

The second stage produced the quartz vein portion of the ore body with sphalerite, arsenopyrite, pyrite, chalcopyrite, fahlore, miargyrite, and native gold with fineness from 627 to 976 (890, on average). The gold of this stage contains the largest grains 0.5–3 mm. However, this gold proportion is negligible in the economic resources.

The third stage yielded gold–stibnite ores cementing the quartz fragments with polysulfide–quartz mineral assemblage and host-rock fragments with Au-bearing sulfide dissemination. Distinctive features of native gold deposited at this stage, after stibnite, are small gold grains (<0.16 mm), abundant metacrystals and spongy forms, and a high fineness (982–999.9) independent of depth.

RELATIONSHIPS BETWEEN DISSEMINATED AND VEIN ORES

All disseminated gold–sulfide deposits of the Russian Northeast and other regions are characterized by the association of early disseminated and late vein mineralizations within the same structures and at the same depth levels (Table 2). The disseminated ores are confined to the cataclastic and shear zones, while the vein and veinlet mineralizations fill the ruptures and fracture zones. Thus, ductile deformations changed to brittle deformations the ore-hosting structures of the deposits. According to the known schemes of vertical zoning, ductile deformations occur at deep levels, while brittle deformations are characteristic of near-surface conditions. The association of deformations of various types at a similar level of a deposit could be accounted for by continuous uplift of the ore-hosting structures synchronous to the ore formation (Novozhilov, 1990). The above scheme is consistent with similar geodynamic conditions of ore formation in all the deposits considered. These conditions were related to the processes of tectonomagmatic activation of the passive continental margin terranes.

The large disseminated gold–sulfide deposits of the Russian Northeast are directly related to the antimony and mercury mineralization zones. Stable and long-term medium- to low-temperature conditions probably facilitated the gold concentration in ores. The Hg and Sb deposits are important guides for the discovery of disseminated gold–sulfide deposits. All large Hg and Sb zones bear Au, but the gold mineralizations have some peculiarities. For example, the Maiskoe gold–sulfide deposit is surrounded by an aureole of quartz–stibnite vein and gold–silver epithermal mineralizations. The gold mineralization is confined there to intrusive dome structures. The quartz–stibnite veins bear gold only within these structures. Earlier, we emphasized some similarity between the ores of the Maiskoe deposit and the Carlin deposit in the United States (Sidorov and Volkov, 1998a). A Hg-bearing zone trending roughly south–north is revealed west of the Maiskoe ore field (Fig. 2). The Palyansk mercury deposit is explored within this zone. The ores of this deposit are comparable to the Maiskoe ores in textural, mineralogical, and geochemical features. Like the Maiskoe ores, the Palyansk ores contain (but in other proportions) cinnabar, native arsenic, galena, sphalerite, pyrite, chalcopyrite, marcasite, realgar, dickite, barite, gypsum, and carbonates. Kim and Tsvetkov (1968) subdivided the hypogene minerals of the deposit into hydrothermal–sedimentary (pyrite, galena, sphalerite, and chalcopyrite), metamorphic (anthraxolite, pyrrhotite, and quartz), and hydrothermal (all other minerals). The Au concentrations in ores have not been studied systematically. It is known, however, that the mineralized carbonaceous pelitic shales locally contain up to 10 g/t Au. The ores of the Palyansk deposit lie in the Upper Triassic black shale sequences; while the Maiskoe ores, lie in the Lower–Middle Triassic sequences. The northern extension of the Palyansk ore field intersects the Ichuveem anticline, which is also composed of Lower–Middle Triassic sequences. These sequences confine numerous gold–quartz veins, the sources of unique gold placers of the Ichuveem river basin. The Hg mineralization is located at a higher stratigraphic layer. Therefore, we could suggest a zonality in distribution of Sb–Hg- and Au-bearing ores. However, the Hg and Sb ore bodies bear Au only within the gold–sulfide mineralized zones.

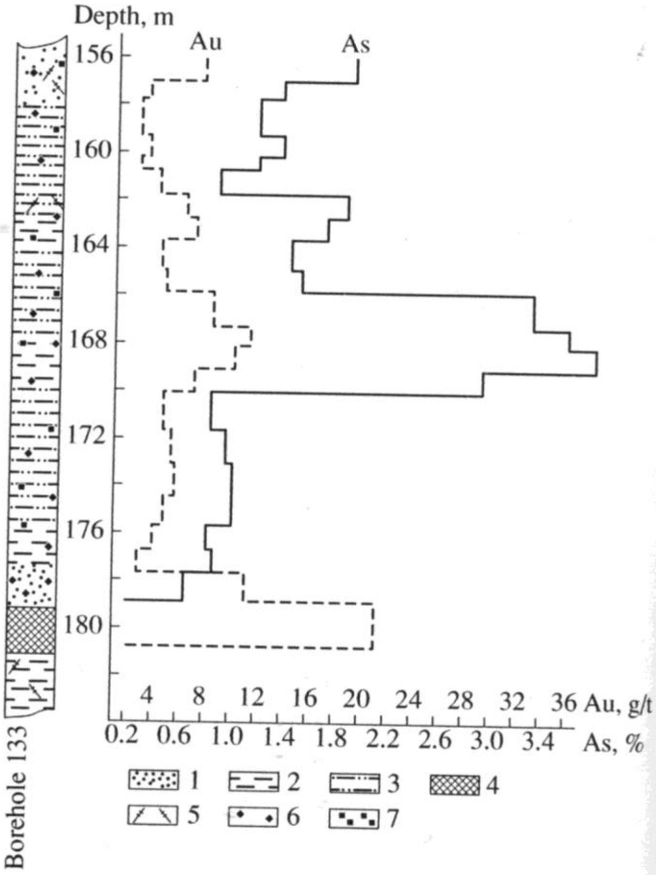

Fig. 9. As and Au distribution in ore body 1 of the Sarylakh deposit (geological exploration data). (1) Sandstones; (2) siltstones; (3) silty sandstones; (4) quartz–stibnite vein; (5) stibnite dissemination; (6) arsenopyrite dissemination; (7) pyrite dissemination.

The Kyuchus deposit is also located within a Middle Triassic black shale sequence (Kular–Nera terrane of turbidite basins) within the post-accretionary metallo-

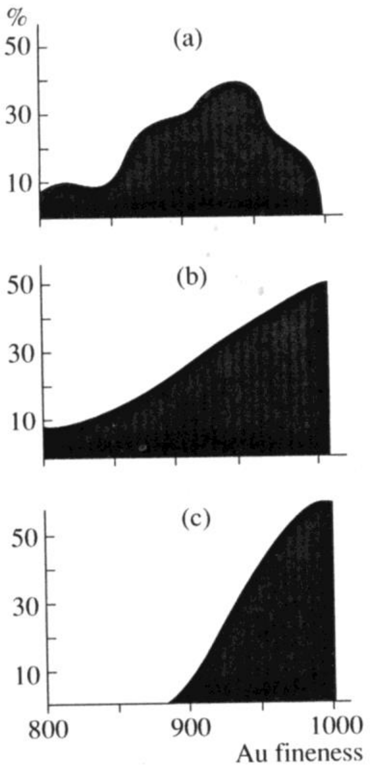

Fig. 10. Distribution of gold fineness in deposits of various types: (a) gold–quartz, (b) gold–sulfide, and (c) gold–stibnite.

genic zone (Fig. 1). The ores of this deposit are close in composition to the Maiskoe gold ores and Palyansk mercury ores. All of them contain disseminated acicular gold-bearing arsenopyrite (in the carbonaceous pelitic shales), quartz–stibnite veins and realgar–orpiment–cinnabar–stibnite and kaolinite–carbonate mineral assemblages. The mean Au content in arsenopyrite is 450 g/t, and gold contains up to 12% Hg. The Hg and Sb mineralization reveals no noticeable Au beyond the Au-bearing zone.

Thus, the Au occurrence in the Hg and Sb ores only within the zones of intensive Au mineralization indicates a superimposed nature of these ores, which is also supported by mineralogical data. The precipitation of Au, Sb, and Hg ores were almost coeval, and their structural environment did not change. The ores were deposited under stable middle- to low-temperature conditions. The highly inhomogeneous patchy gold–quartz mineralization originated at higher temperatures (≥250°C), while the inhomogeneous patchy gold–stibnite–quartz and gold–cinnabar mineralizations formed at temperatures below 200°C.

In our opinion, the disseminated gold–sulfide deposits differ from the Au–Sb and Au–Hg deposits only by the intensity of the late Sb and Sb–Hg stages of ore formation. The late quartz–stibnite mineralization is superimposed on the disseminated mineralization with an abrupt tectonic change, locally with formation of intra-ore breccias, where the disseminated ore fragments are cemented by quartz–stibnite aggregates. Stibnite in the ore zones often overprints the earlier quartz or forms separate veins and veinlets. This quartz–stibnite mineralization is typically developed in the upper parts of ore bodies. The formation of ore pipes is also related to this mineralization. It was found that the quartz–stibnite veins contain no Au beyond ore zones in deposits lacking the disseminated gold–sulfide mineralization.

The native gold of the Au–Sb deposits is finely dispersed and has a high fineness, which does not vary with depth. The gold grains are 0.1–0.25 mm in size and are relatively homogeneously distributed in ore bodies (Amuzinskii *et al.*, 2001).

The gold fineness distribution in the Au–Sb deposits differs from that in the gold–quartz low-sulfide deposits and is closer to its distribution in the disseminated gold–sulfide deposits (Fig. 10). The calculated fineness of the gold dispersed in sulfides is nearly 1000 and is very close to the fineness of the late native gold in the Au–Sb deposits (995–998). It is known that the regenerated gold forms small and very small grains. The regenerated origin of the gold is also indicated by the rounded and oval shapes of its grains in stibnite and a great abundance of specific Au–Sb minerals, e.g., aurostibite and Au-bearing stibnite. It is noteworthy that the amount of disseminated sulfides does not vary laterally and vertically within ore zones. The fineness of gold dispersed in sulfides also does not change. These features determine the relatively homogeneous distribution of the late regenerated gold and small variations of its fineness in the quartz–stibnite ore bodies.

The gold potential of the quartz–stibnite veins of the Maiskoe disseminated gold–sulfide deposit directly depends on Au concentration in the early disseminated sulfide ores (Sidorov and Volkov, 1998a). It is probable that the quartz–stibnite ore bodies with high Au concentrations in the Au–Sb deposits were formed at the expense of the disseminated ores with comparable Au concentrations, rather than from the low-grade gold mineralization, as is implied by some geologists (Indolev *et al.*, 1980; Amuzinskii *et al.*, 2001).

The general similarity of Sb–Hg and other mineralogical and geochemical assemblages in the disseminated gold ores in different deposits in the carbonaceous shale (clay–carbonate) sequences is probably related to the composition of undifferentiated primary sources, from hydrocarbon fluids to hydrothermal solutions (Tomson *et al.*, 1984). However, the Sb and, particularly, Hg geochemical anomalies occur above the ore zones in most ore deposits. Some features of this geochemical zoning also occur in the disseminated gold–sulfide deposits. However, the areas with Sb–Au mineralization superimposed on the gold-bearing zones usually include disseminated ore bodies with economically valuable Au concentrations. The relationships

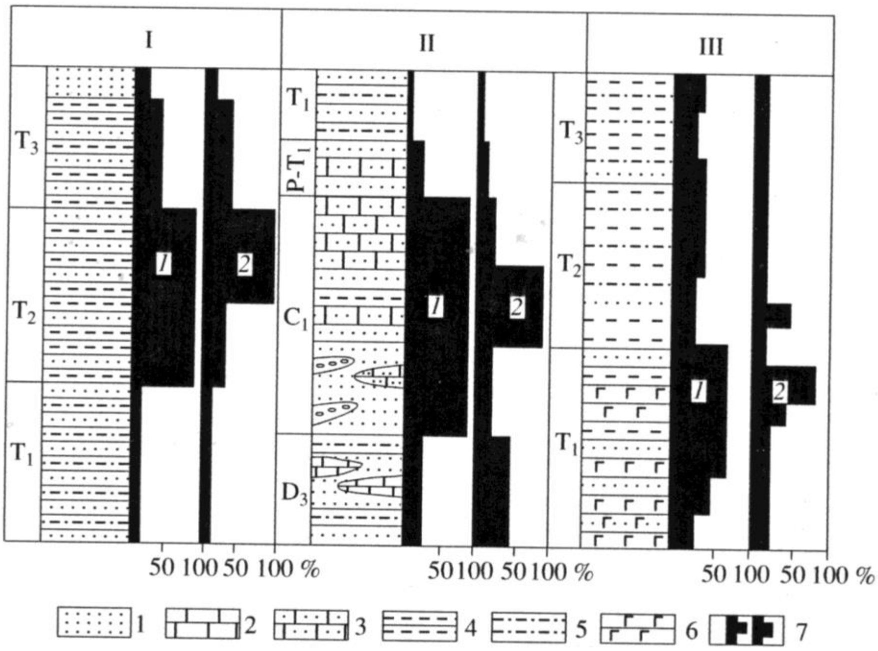

Fig. 11. Distribution of placer and ore gold resources over stratigraphic sections in the ore districts of Chukotka. (1) Sandy sequences; (2) carbonate sequences; (3) carbonate–sandy sequences; (4) black shales; (5) siltstones; (6) gabbro sills; (7) distribution of resources: (*1*) placer gold; (*2*) ore gold. (I–III) Ore districts: (I) Central Chukotka, (II) Kuul', (III) Keperveem.

between the Au and Sb–Hg mineral assemblages show that the earlier stages in the formation of the Sb and Hg deposits are favorable for Au concentration in hydrothermal solutions.

The available thermobarogeochemical data (Goncharov and Sidorov, 1988; Gamyanin *et al.*, 2000) and results of structural drilling in the Maiskoe and Nezhdaninskoe deposits, where the disseminated ores were traced from the surface to depths of 1200 and 1500 m, respectively, suggest that the ore formation in the disseminated gold–sulfide deposits occurred at medium and low temperatures (180–350°C) and relatively high pressures of 1.2–1.7 kbar over a large vertical interval, which is related to long-term uplift of the ore-hosting blocks during hydrothermal ore formation.

The black shale flyschoid sequences enriched in ore elements are often considered as intermediate sources of ore components (Fig. 11). According to Sidorov and

Table 3. Formation scheme of the polychronous gold deposits in the black shale sequences of the Russian Northeast

Stages	Deposits		
	Nezhdaninskoe (Yakutia)	Natalka (Kolyma)	Maiskoe (Chukotka)
Preaccretionary	Pyrite mineralization (with gold–quartz veins in turbidites of adjacent areas)	Pyrite mineralization with chlorite, carbonates, rutile, and carbonaceous material	Pyrite mineralization (poorly developed)
Synaccretionary	Early quartz–pyrite mineralization with Pb–Zn–Cu sulfides and gold, late pyrite–arsenopyrite ores with Pb–Zn–Cu sulfides and gold	Early quartz–pyrite mineralization with Pb–Zn–Cu sulfides and gold (Degdekan type), late quartz–pyrite–arsenopyrite mineralization with Pb–Zn–Cu sulfides and gold	Quartz–pyrite–arsenopyrite mineralization with Pb–Zn–Cu sulfides and gold in the adjacent areas (Middle Ichuveem)
Postaccretionary	Gold–pyrite–arsenopyrite disseminated ores in metasomatites	Gold–pyrite–arsenopyrite disseminated ores in carbonaceous metasomatites	Pyrite–arsenopyrite disseminated ores with dispersed gold in carbonaceous metasomatites; quartz veins with Ag-sulfosalts
	Gold–sulfide–scheelite–quartz ores with Ag-sulfosalts and stibnite	Adularia–quartz veins with electrum	Gold–rare-metal mineralization (quartz–arsenopyrite veins with Sn, W, Mo, Bi, and Sb minerals)

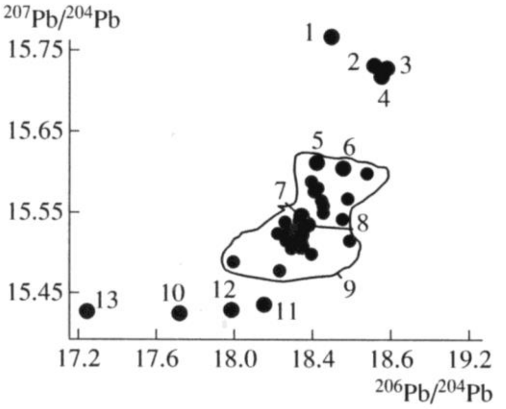

Fig. 12. Lead isotopic composition in arsenopyrite and galena of gold–sulfide deposits of the Russian Northeast (*Izotopy svintsa ...*, 1988; Goryachev *et al.*, 2000). (1–13) Deposits: (1) Sarylakh; (2) Plamennoe; (3) Maiskoe; (4) Tumannoe; (5) Sovinoe; (6) Nezhdaninskoe; (7) Natalka; (8) Shkol'noe; (9) gold–quartz deposits of the Yana–Kolyma belt and epithermal Au–Ag deposits of the Okhotsk–Chukotka volcanic belt; (10) Baimskoe; (11) Palyansk; (12) Sentachan; (13) Kubaka.

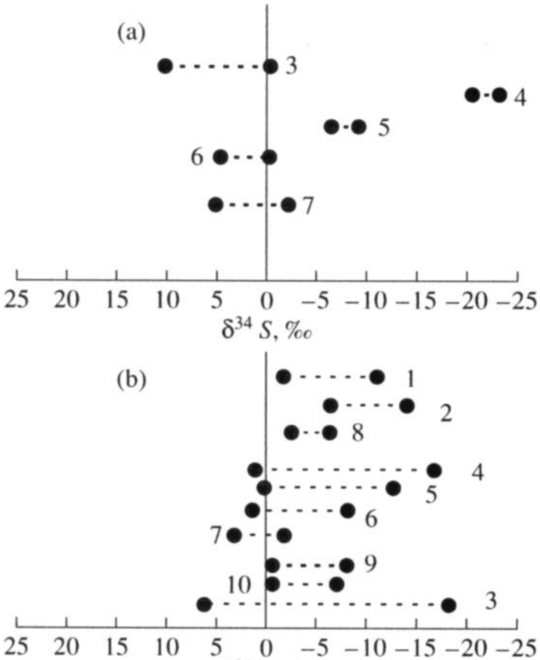

Fig. 13. Sulfur isotopic composition in sulfides of the disseminated gold–sulfide deposits in the Russian Northeast. (a) Host rock sulfides; (b) ore body sulfides. Some analyses are obtained in IGEM RAS, analyst L.P. Nosik. Data of Ozerova *et al.* (1991), Voinkov *et al.* (1976), and Gamyanin *et al.* (2000) are also used. (1–9) Deposits: (1) gold–quartz deposits of the In'yali–Debin district of the Yana–Kolyma belt, (2) gold–quartz deposits of the Keperveem district of the Chukotka belt, (3) Nezhdaninskoe, (4) Maiskoe, (5) Tumannoe, (6) Natalka, (7) Sarylakh, (8) Kyuchus, (9) Sentachan, (10) Palyansk.

Tomson (2000), the formation of the metal-bearing black shale sequences could associate with pulses of mantle degassing. The fluid flows ascended to the Earth's crust and its surface resulted in the addition of hydrocarbons and some elements and stimulated the accumulation of biogenic organic matter concentrating the main components of these fluids. During further remobilization the gold was separated from other elements due to differences in their physicochemical properties. Thus, the geochemical anomalies related to black shales have endogenic–biogenic origin. The central parts of these anomalies often present large multielement deposits of disseminated ores. The Maisk ore district is an example of such anomalies in Central Chukotka. Drilling data show that almost all the fault zones within this district contain Au-bearing sulfide dissemination. The Au contents are from 0.5 to 3 g/t and indicate probable remobilization of disseminated sulfides from the black shale flyschoid sequences of the district.

The total amount of metals in the black-shale sequences could be remobilized during metamorphic, magmatic, and hydrothermal processes in zones of tectonomagmatic activation (TMA) to form veinlet-disseminated and vein deposits.

Mineralization was developed during three stages in the largest gold–sulfide deposits of the Russian Northeast (Table 3): (1) preaccretionary hydrothermal–sedimentary, syngenetic with sedimentation, (2) syn-accretionary plutonogenic–metamorphic, and (3) post-accretionary.

These suggestions are supported by Pb and S isotopic data (Figs. 12, 13). Lead is most radiogenic in ores of the Maiskoe, Tumannoe, Plamennoe, and Sarylakh deposits with poorly developed pre- and syn-accretionary mineralizations. It is significantly less radiogenic in the Natalka deposit with considerable pre- and syn-accretionary mineralizations. Lead of the Nezhdaninskoe deposit shows intermediate isotopic ratios, which could be accounted for by overprinting of postaccretionary mineralization, related to the formation of the Okhotsk–Chukotsk volcanic belt.

The ore minerals of the gold–sulfide and gold–quartz deposits of the Yana–Kolyma belt and the Au–Ag deposits of the adjacent sector of the Okhotsk–Chukotsk volcanic belt show generally similar Pb isotopic ratios (Fig. 12) and coincide with Pb isotopic ratios of arsenopyrite of the gold–rare-metal skarn deposits and tin deposits genetically related to the Late Mesozoic granitoids with postcollisional and island-arc geochemical signatures (Goryachev *et al.*, 2000).

The sulfur isotopic composition in stibnite and other sulfides of the gold–sulfide deposits (Fig. 13) is hybrid with predominant negative δ^{34} S values and indicates that sulfur could be mobilized from host rocks and derived from magmatic chambers. The arsenopyrite and stibnite from the Nezhdaninskoe, Maiskoe, and Tumannoe deposits is extremely enriched in light isotope. These deposits are characterized by inhomogeneous distribution of sulfur isotopic compositions indicative of multistage ore formation. The gold–sulfide deposits of the Russian Northeast have generally similar sulfur isotopic compositions, which probably resulted from similar conditions of formation.

The results of isotopic studies show that the ore formation in the disseminated gold–sulfide deposits was related to crustal and subcrustal processes of tectonomagmatic activation. Some ore components could be derived from mantle sources.

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