SILVER MINERALIZATION OF THE NORTH-WESTERN PART OF THE VERKHOYANSK-KOLYMA MESOZOIDS

G.N. Gamyanin, A.V. Kostin (Yakut Institute of Geological Sciences, 39 Lenin avenue, Yakutsk, Russia, 677891)

ABSTRACT

The northwestern part of the Verkhoyansk-Kolyma mesozoic complex is considered to be a large-scale prospective auriferous province. Silver deposits divided in different types. They are silver near-surface, argentiferous pyrite-polymetallic, tin-silver, and silver-lead-zinc ore deposits. Their distribution is controlled by a number of geological factors, i.e. volcanic belts, regional fold structures, and deep faults. The occurrence and economic potential of the deposits are not equivalent. Based on areal distribution and the presence of large and unique deposits, the most important is the silver-lead-zinc type, the deposits of which are developed within the West- and South-Verkhoyanie metallogenic zones. These deposits are similar to the Mount Isa-type deposits, but are not distinctly related to volcanogenic bodies. The most favorable structural environment for the occurrence of large deposits during the development of a given formation is in areas of regional thrust zone junctions and their tectonic elements. Also significant, are argentiferous pyrite-polymetallic ore deposits (the Kuroko-type), located in the Uyandina-Yasachnaya volcanic belt. Argentiferous near-surface and tin-silver ore deposits associated with subvolcanic bodies (K_2) are small but sometimes have concentrated mineralization.

INTRODUCTION

Silver mineralization of the Verkhoyansk-Kolyma mesozoic complex has been well known since the late 18th century. Silver was recovered from silver-lead ores by primitive technical methods. The first investigations of the ores from West Verkhoyanie were carried out under the guidance of S.S. Smirnov in the 1930's. Silver mineralization of the type in Yakutia was studied in detail by Indolev and Nevoisa (1974).

In the last thirty years, as a result of geologic prospecting, a great number of ore occurrences and silver deposits have been discovered under different geological conditions.

Detailed mineralogic-geochemical studies of silver mineralization show that its geologic-genetic types are various and are represented by the following ore types: silver near-surface proper, argentiferous pyrite-polymetallic, tin-silver, silver-lead, and silver-lead-zinc. The occurrence and economic potential of these types are not equivalent and there is no information about the potential prediction of these deposits.

GEOLOGICAL CONTROL OF SILVER MINERALIZATION

As with other metal deposits, the localization of silver ore is controlled by a number of geological factors, such as geodynamic environments, volcanic belts, regional fold structures, and deep-seated faults (Fig. 1). Depending on these factors, silver mineralization is distributed as linear zones. The most extended are the argentiferous West- and South-Verkhoyanie, Adycha-Taryn, Uyandina-Yasachnaya, and Ulakhan-Tass zones. According to Parfenov et al. (1988), the location of these zones are as follows: the first two are located among terrigenous complexes of the Verkhoyansk passive continental margin, the Adycha-Tarun zone is in fore-arc basin deposits, the Uyandina-Yasachnaya and Ulakhan-Tass zones are restricted to the Middle-Upper Jurassic collision volcanogenic-sedimentary complex. These formations are discussed below.

SILVER NEAR-SURFACE TYPE

Silver near-surface deposits proper are restricted to the Uyandina-Yasachnaya volcanic belt, Ulakhan-Tass horst-anticline, Berezovsky basin, and Adycha-Taryn zone. Spatially and genetically, mineralization of this type is generally related to extended volcanic belts. Silver mineralization in these regions is associated spatially and genetically to post-collision 'island' volcanic generation represented by medium-acid subvolcanic bodies occasionally followed by blanket rhyolites, dacites, and their tuffs. The intensity of volcanism and thickness of volcanogenic rocks of the mesozoid midland regions are not comparable with that of typical volcanic belts (the Okhotsk-Chukotka volcanic belt). This may partially account for the peculiar geologic setting of silver mineralization of this formation. In addition to occurring in the typical setting of argentiferous ore bodies within subvolcanoes (Taryn and Buordakh), they are often located in a sandy-shale sequence of the Verkhoyansk complex (Caucasus and Adycha-Taryn zone), in hornfels near the Upper Cretaceous granitoid plutons (Chibagalakh), or in plutons themselves (Yeiyemyu). Unlike the deposits of the Okhotsk-Chukotka volcanic belt, volcanite adularization is absent here. At the same time, irrespective of localization, silver mineralization is distinctly controlled by long-lived repeatedly activated zones of deep-seated faults (Darpir, Ulakhan-Siss, Elga, etc.).

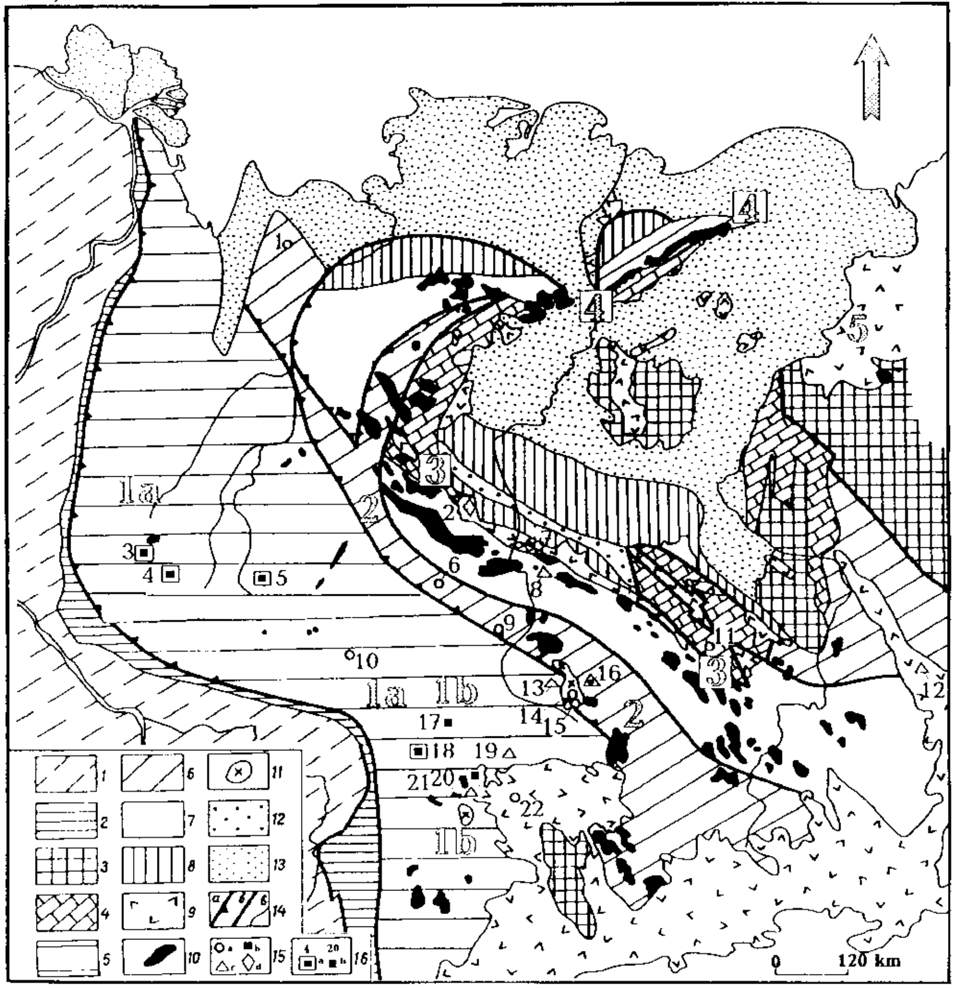

Fig. 1. Location map of silver ore formation deposits of the northwestern part of the Verkhoyansk-Kolyma mesozoids. 1 - plate complexes of the Siberian platform; 2 - plate complexes in folded zones adjacent to the Siberian platform; 3 - plate complexes of microcontinents; 4 - carbonate platform complexes; *passive continental margin complexes*: 5 - marginal seas and small ocean basins; 6 - sedimentary and volcanogenic-sedimentary deposits; *active continental margin and island arc complexes*: 7 - fore-arc basins; 8 - back-arc basins; 9 - volcano-plutonic belts; *collision generations*: 10 - granitoid and dyke belts; 11 - subvolcanic generations; 12 - intermontane troughs; 13 - Cenozoic continental generations; 14 - a) thrusts; b) faults; c) geological boundaries; 15 - silver ore types: a - silver near-surface, b - silver-lead-zinc, c - tin-silver, d - argentiferous pyrite-polymetallic; 16 - deposits and their numbers on the map: a) large and unique, b) median and small. 1. Alfa; 2. Khotoy-dokh; 3. Chochimbalsky ore district; 4. Mangazeisky ore district; 5. Prognoz; 6. Caucasus; 7. Tykhon; 8. Khatys; 9. Primetnoye; 10. Nochnoye; 11. Urultun; 12. Dukat; 13. Kurdat; 14. Aid; 15. Dichek; 16. Kupolnoye; 17. Altaiskoye; 18. Menkeche; 19. Vysokogornoye; 20. Kuta; 21. Dzhaton; 22. Atundzha. *Structural-metallogenic zones*: 1a-1a - West-Verkhoyanie; 1b-1b - South-Verkhoyanie; 2-2 - Adycha-Taryn; 3-3 - Uyandina-Jasachnaya; 4-4 - Ulakhan-Tass; 5 - Berezovsky basin.

The morphology of argentiferous ore bodies is diverse, although most of them (70%) are represented by simple lens-like veins that are characteristically thin (up to 0.5 m), extend up to 80 m, and are generally confined to shear fractures and detachment joints (Dichek, Aid). Vein-stockwerk zones (Tykhon and Caucasus) and mineralized shatter zones (Tykhon) are rarely developed (Fig. 2). Diverse ore structures and textures are characterized by complex combinations and sharp textural transitions. The presence of chalcedony-like, and cryptograined quartz, alternating with microgranular, comb, and spherolitic-drusoid quartz is typical. The most argentiferous are freibergite, pyrargyrite, miargyrite, stephanite, and the whole group of rare sulphosalts and silver intermetallides (Nekrasov et al., 1987 and Gamyanin and Goryachev, 1988).

Silver distribution in ores is extremely irregular (bunch and bonanza), sometimes reaching 10 ppm and more. This geological situation indicates a poor-prospectiveness for mineralization of the type; probable reserves of concrete deposits are small. Taking into account the increase in gold content of silver mineralization on the margins of metallogenic zones (Kysylga, Alfa), the economic potential of the concrete deposits will be higher.

ARGENTIFEROUS PYRITE-POLYMETALLIC TYPE

Mineralization of the argentiferous pyrite-polymetallic type is currently known from the Middle-Upper Jurassic collisional volcano-genic-sedimentary deposits of the Uyandina-Yasachnaya volcanic belt. Volcanogenic-sedimentary rocks contain shales, siltstones, and sandstones alternating with basalts, andesites, rhyolites, and their lithoclastic tuffs (Grinberg et al., 1974). Mineralization is clearly controlled by zones of deep faults. Mineralized parts of this type contain quartz-albite-chlorite and carbonate-chlorite propylites superimposed by more local elongated areas of pre-ore quartz-sericite-pyrite metasomatites hosting pyrite-polymetallic ore deposits as shown in Fig. 3 (Khotoydokh; Gamyanin, 1978). Ore bodies are represented by thick (up to 20 m) and extended (to 500 m and more) deposits, and are generally restricted to synclinal limbs. The deposits cut these limbs across strike and down-dip at a steep angle (10-150 m). Ores are composed of pyrite, sphalerite, chalcopyrite, and galenite in various combinations and abundance ratios. In addition to quartz, nonmetallic minerals are represented by barite, also contained in near-vein metasomatites.

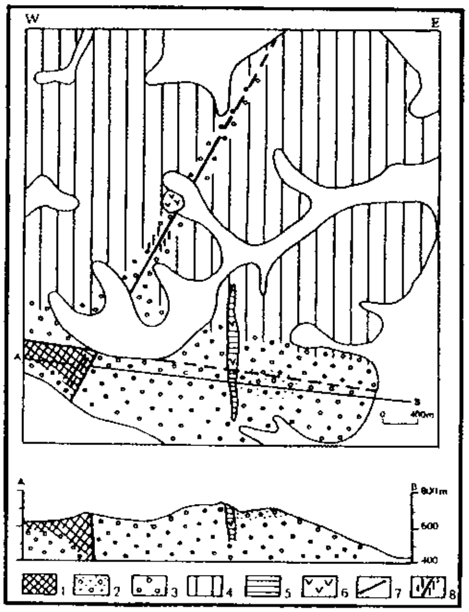

Fig. 2. Sketch geological map of the Tykhon ore deposit.
1 - 3 - metasomatites: 1 - quartz-sericitic, 2 - sericite-adular, 3 - adular; 4 - 5 - propylites: 4 - carbonate-chlorite, 5 - carbonate-epidote; 6 - andesite intrusive bodies; 7 - dislocations; 8 - ore bodies.

Initial ratios of minerals are complicated by complex ribbon-festoon structures created by dynamic metamorphism during ore development. Argentiferous ores include tetrahedrite-tennantite fahlore and galenite. Silver grade are relatively stable, in the range of 200-500 ppm. Gold is present in conetents of 1-3 ppm (sometimes more). Ores and metasomatites not subjected to dynamic metamorphism are characterized by a stable Au/Ag ratio ranging from 1:100 to 1:300. Ore bodies are zonally covered by quartz-sericite-pyrite metasomatites, which are characterized by contrasting geochemical anomalies of zinc, lead, and silver. We can use these relations as a criterion for prospecting for concealed ore bodies.

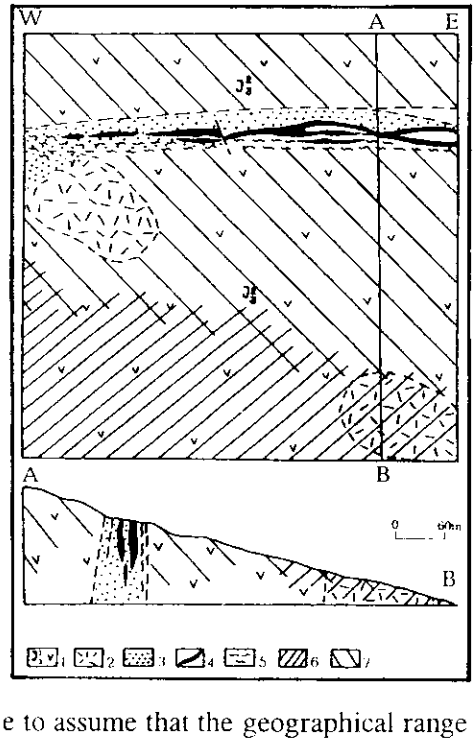

Fig. 3. Sketch geological map of the Khotoydokh ore deposit.
1 - Jurassic sandy-shale rocks; 2 - subvolcanic rhyolites; 3 - quartz-sericitic metasomatites; 4 - ore bodies; 5 - zones of disturbance with attrition clay; 6 - 7 - propylites: 6 - quartz-albite-chlorite facies, 7 - carbonate-chlorite facies.

Genetically this mineralization is of sedimentary-volcanogenic origin and it is analogous with metalliferous deposits of Altai, Kazakhstan, Carpathians, Australia (Broken Hill), and Japan (Kuroko). Taking into account the significant geological parameters of ore body mineralization, this type may be considered highly prospective with probable reserves being large in some areas. Numerous unexplored pyritization zones of the Uyandina-Yasachnaya belt, allow us to consider this belt as having high potential for complex silver-pyrite mineralization. The other prospective region with this type of mineralization is the Sepyakine-Kamenskaya zone of Prikolymie.

TIN-SILVER TYPE

With regard to economic Ag concentrations, tin-silver deposits are generally rare and located mainly in the South-Verkhoyanie zone (Altaiskoye, Dzhaton and Vysokogornoye), bordering the Okhotsk-Chukotka volcanic belt. The fact that most tin-sulphide deposits contain young argentiferous sulphoantimonite associations, it would be reasonable to assume that the geographical range of mineralization of deposits of this type could be expanded. But, it should be kept in mind that argentiferous tin-sulphide deposits spatially and genetically are generally related to granitoid magmatism, and those deposits we consider to be tin-silver ones are either generally 4 km (and more) of granitoid outcrops, or are associated with felsic subvolcanic bodies like granite-porphyry, granodiorite-porphyry, and rhyolite-dacite. Typomorphic features of quartz from these deposits are indicative of their origination at a low depth.

Ore bodies from the tin-silver type are mostly represented by lens-like vein systems that are thin (to 1 m) and extend up to 150 m in length. More rarely developed are stockwerk-like vein systems (Kuta) or large mineralized zones (Vysokogornoye and Kurdat). All the morphological types of ore bodies are confined to systems of dislocations and joints mainly with a northwestern trend, which cross-cut submeridional fold structures. The most argentiferous ores are freibergite, diaphorite, owyheeite. Silver abundances in ores are unequal, ranging from small (100-200 ppm) to extremely large in ore pockets. But on the whole, low indicative parameters for ore bodies indicate low parameters for potential of deposits, as well. At the same time, individual veins of some deposits are interesting enough to be silver-mined without organized mining operations.

SILVER-LEAD-ZINC TYPE

Silver-lead-zinc deposits are characterized by variable ratios between galenite and sphalerite because of their zonal distribution in the vertical plane of ore bodies. In many respects, they are analogous to world deposits like Mount Isa, but unlike the latter they do not have a distinct relation to volcanogenic rocks. On the contrary, they are located in terrigenous series of the Verkhoyansk passive continental margin, where magmatism is only weakly displayed. Therefore, metalliferous silver-lead-zinc deposits of the West- and South-Verkhoyanie argentiferous zones, contain only rare dykes of granodiorite- and granite-porphyry. In other zones (Adycha-Taryn and Ulakhan-Tass) there are granitoid plutons in addition to dykes. With respect to magmatic bodies, silver mineralization is obviously younger. Indolev and Nevoisa (1974) gave a detailed description of the geology and mineralogy of ore districts with mineralization of this type in Yakutia. A number of deposits and prospective ore occurrences are characterized both by cross-cutting and subconformable mineralized zones. Cross-cutting linear ore-bearing zones (Prognoz, Fig. 4) are of large dimensions, up to 3-5 km long, 3-4 m thick, and reaching 10-20 m in swells.

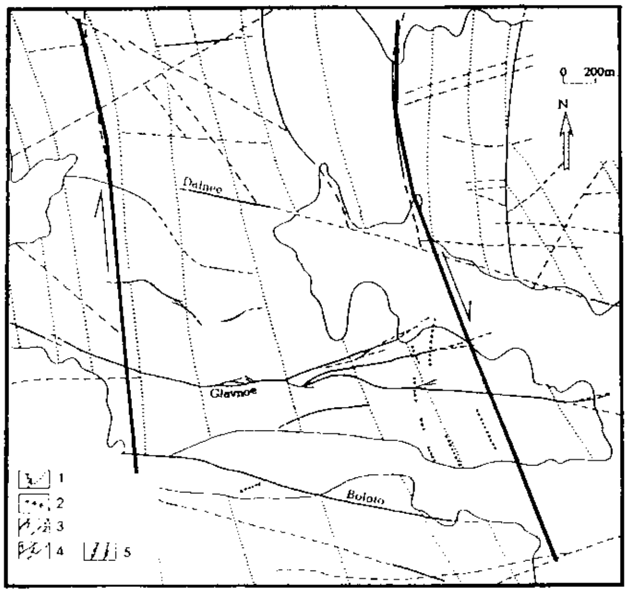

Fig. 4. Sketch geological map of the Prognoz deposit. 1 - quartz sandstones T_2 interbedded with siltstones; 2 - quartz porphyry dykes; 3 - orebodies: a - established, b - supposed; 4 - faults (dislocations with a break in continuity): a - revealed, b - supposed; 5 - supposed shifts.

Mineralization is stable both along strike and at depth. There are no significant features of alteration of productive associations and silver concentrations at a depth of 400 m in the Prognoz deposit (Fig.5). On the whole, along with a generally stable amount of Ag (200-600 ppm) in ore bodies, there are possible deposits in unextended areas with concentrations of Ag as high as 3,000-5,000 ppm. These areas are abundant throughout the whole complex in both basic argentiferous minerals (freibergite, pyrargyrite, miargyrite, and owyheeite) and in rare minerals (diaphorite, andorite, stephanite, matildite, gustavite, and polybasite). The silver content in galenite rises sharply and sphalerite, chalcopyrite, stannite, and lead-antimony sulphoantimonites become argentiferous here.

Deposits of the Mangazeisky ore district are represented by zones, where galenite substantially prevails over sphalerite. They form the most prospective areas and are localized in West-Verkhoyanie argentiferous zone. Mineralization of this zone is genetically related to the Newktominskaya zone of longitudinal strike-slip dislocations where, on the western flank, commercial silver and silver-lead mineralization is associated with successive strike-slip and thrust faults, and then just thrust faults (Fig.6). The West-Verkhoyanie metalliferous zone is more than 17 km long and 1.5-2 km wide.

The studied structure is characterized by various combinations of angles of incidence of ore-bearing sandstones and by kinematics of dislocations with a break in continuity that formed the structure of the specific deposit (Fig. 7). Combinations of low-angle sandstone occurrences with a wide-spread development of leaf-by-leaf decollements and high-dipping strike-slip faults resulted in the formation of a linear stockwerk in the South-Endybal deposit. The aforementioned combinations gave rise to the type of branching subconcordant veins in the Bezymyanny deposit that are 500 m long and 0.1-1 m wide. The steep dip of sandstone beds enabled the planes of leaf-by-leaf decollements and strike-slip faults to coincide. Under these conditions, lens-like veins (more than 100 m in length and 0.5 m in width) developed in the Mangazeya deposit.

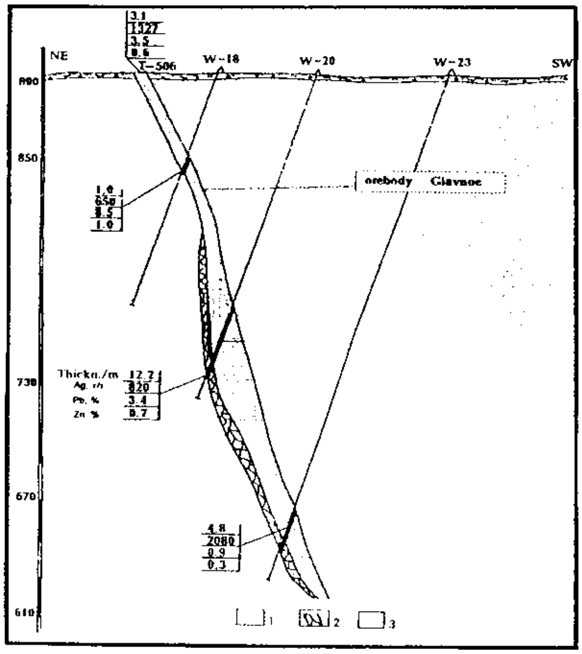

Fig. 5. Cross section of the Glavnoe orebody of Prognoz deposit.
1 - sandstones; 2 - quartz together with sulphides; 3 - carbonate together with sulphides.

The amount of silver in ores varies greatly, sometimes reaching 30,000 ppm. Commercial ores give 500-2,000 ppm for vein bodies and 100-500 ppm of Ag for stockwerk.

Ag-bearing ores from the Mangazeya district deposits are diverse in mineral composition. In addition to discovered general silver minerals, there are varieties of antimony silver type deposits. The silver content in fahlore varies widely from 0 to 50-55 percent, prevailing values being 20-25 percent. The ore-bearing district is prospective both for its gold content of ores, and due to the areas enormous linear dimensions. Silver resources in this region can be increased by means of isostructural deposits of the Newktominskaya ore district (Chochimbal, Khadaryn'ya, etc.).

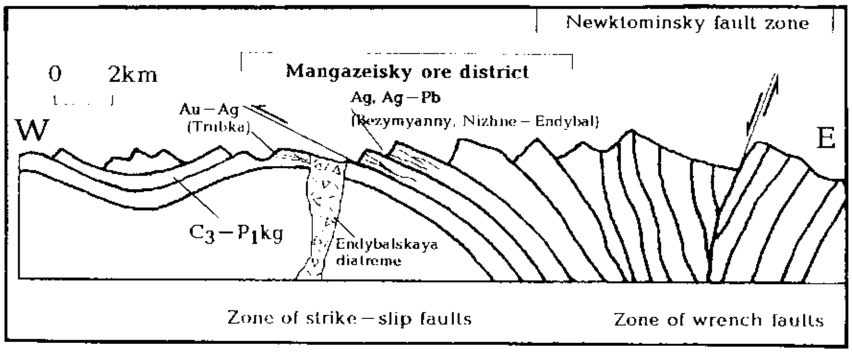

Fig. 6. Cross section of the Mandazeisky ore district. Ore deposits are confined to zones of strike-slip faults and thrusts shift-generated along the Newktominskaya fault zone.

Stable Ag grades and large dimensions of ore bodies indicate a high economic potential for silver-lead-zinc deposits of this morphological type. Restriction of these deposits to the West-Verkhoyanie zone enables us to consider this zone the most highly-prospective with the areas being large and unique.

CONCLUSIONS

On the whole, proceeding from genetic relations of argentiferous types of the Verkhoyansk-Kolyma mesozoids, we can state that affinities are observed only between tin-silver and silver-lead-zinc types, which resulted from the evolutionary development of a granitoid ore magmatic system producing either tin-silver (shallower) or silver-lead-zinc (more deep-seated horizons of origination) types in different periods of its origination. Tin is nearly absent in the silver-pyrite formation and in the silver proper one. They are not related to each other because formation of silver-pyrites started at the collision stage of regional development and under subfluvial sedimentary-volcanogenic series deposition. The silver (proper) type is postcollisional and the youngest in the whole complex of ore-bearing types of the Verkhoyansk-Kolyma Mesozoic system. It is associated with activation of long-lived regional faults and with manifestation of continental subvolcanic magmatism. The latter circumstance, as well as the fact that various argentiferous types are developed in one and the same metallogenic zones, created favorable conditions for formation of polychronous and polyformation silver mineralization in more active and disturbed areas of the fault systems. This is exemplified by the Kupolnoye deposit where mineralization of cassiterite-quartz, tin-silver, and silver proper types are present.

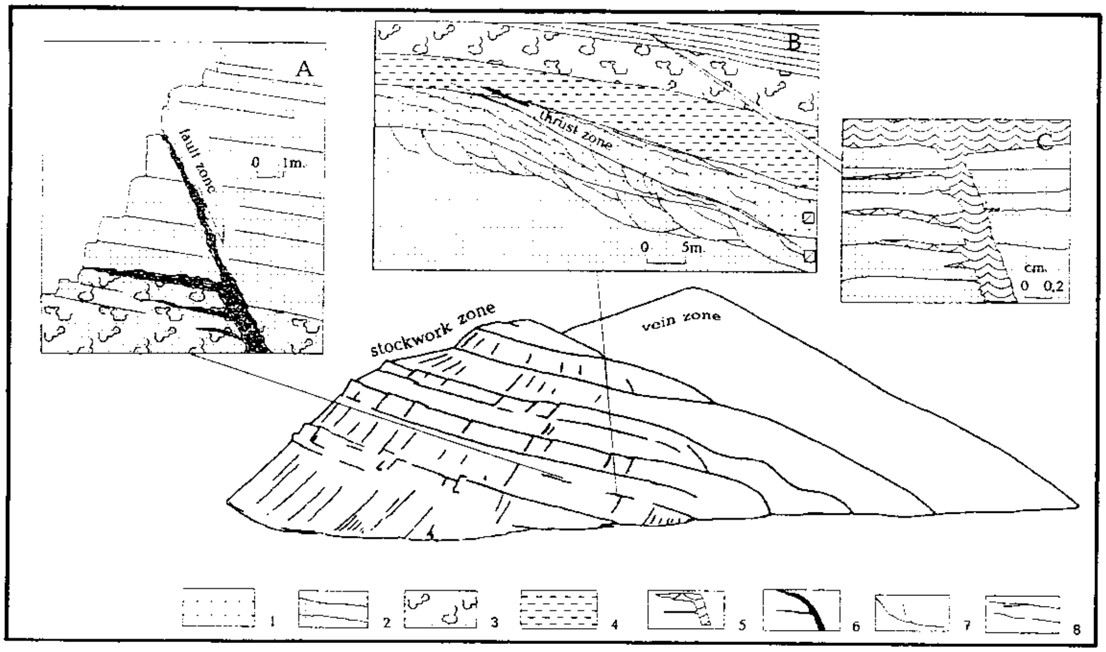

Fig. 7. The Nizhne-Endybal stockwork Ag-Pb deposits and fragments of a lode vein structure. A - cross vein (along fault zone) fringing with conformable (along leaf-by-leaf decollments) veinlets composed of quartz-carbonate-galenite-diaphorite-fahlore. B - underthrust cleavage fractures within a thrust zone filled with galenite-pyrargyrite veins in the flat wall, subconformable quartz-siderit-pyrite-arsenopyrite-galenite-pyrargyrite veins in the hanging wall, and conformable silver-sulphosalt veins in lumpy sandstones. C (a fragment of B structure) - calcite-galenite-pyrargyrite cross veins in thin-laminated sandstones. Transforming into conformable interlayer veinlets.

1 - medium-grained massive sandstone, 2 - fine-grained thin-laminated sandstone, 3 - fine-grained lumpy sandstone, 4 - siltstone, 5 - calcite-galenite-pyrargyrite veins, 6 - quartz-carbonate-galenite-diaphorite-fahlore veins, 7 - galenite-pyrargyrite cross veins, 8 - quartz-siderite-pyrite-arsenopyrite-galenite-pyrargyrite conformable veins.

In summary, we can state that the region of the Verkhoyansk-Kolyma mesozoids is productive with regard to the gold, tin, antimony, and silver mineralization. The South- and West-Verkhoyanie metallogenic zones can be considered a highly-prospective silver province.

ACKNOWLEDGMENTS

The authors are grateful to Gennady Ivanov and Vyacheslav Levin, the representatives of Geological Department of the Sakha (Yakutia) Republic, for their assistance in fulfillment of the present study.

REFERENCES

Gamyanin, G.N., 1978. Barit-polimetallicheskaya formatsiya Kolymskogo seredinnogo massiva. - In: Novye dannye po geologii rudnykh mestorozhdenii vostochnoi Yakutii. Yakutsk: Izd-vo YaF SOAN SSSR: 56-71. (in Russian)

Gamyanin, G.N., Goryachev, N.A., 1988. Blizpoverkhnostnoe orudenenie vostochnoi Yakutii. - Tikhookean. geol. 2: 82-89. (in Russian)

Grinberg, G.A., Bakharev, A.G., Nedosekin, Yu.D., Surnin, A.A., 1978. Vulkanicheskie kompleksy tsentralnoi chasti Uyandino-Yasachinskogo poyasa. - In: Novye dannye o magmatizme Yakutskoi ASSR. Yakutsk: Izd-vo YaF SO AN SSSR: 50-107. (in Russian)

Indolev, L.N., Nevoisa, G.G., 1974. Serebro-svintsovye mestorozhdeniya Yakutii. - N-k: Nauka. 250 p. (in Russian)

Nekrasov, I.Ya., Gamyanin, G.N., Goryachev, N.A., Zhdanov, Yu.Ya., Leskova, N.V., 1987. Mineralogo-geochimicheskie osobennosti serebryanogo orudeneniya Verkhoyano-Kolymskoi skladchatoi oblasti. - Mineral. J. 6: 5-17. (in Russian)

Nekrasov, I.Ya., Gamyanin, G.N., Goryachev, N.A., Zhdanov, Yu.Ya., Leskova, N.V., 1988. Mineralogo-geochimicheskie osobennosti serebryanogo orudeneniya Verkhoyano-Kolymskoi skladchatoi oblasti. - Mineral. J. 1: 3-14. (in Russian)

Parfenov, L.M., Trunilina, V.A., Gamyanin, G.N., Yakovlev, Ya.V., 1988. Geodinamika, magmatizm, metallogeniya Verkhoyano-Kolymskikh mezozoid. - In: Zakonomernosti razmeshcheniya poleznykh iskopaemykh. 15. M.: Nauka: 179-188. (in Russian)