# THE LATE CRETACEOUS TIN-SILVER-POLYMETALLIC MINERALIZATION IN NORTHEASTERN RUSSIA

*A.A. Plyashkevich* (North-East Interdisciplinary Scientific Research Institute, 16 Portovaya St., Magadan 685000, Russia)

**ABSTRACT**

The Omsukchan and Tenka metallogenic zones in northeastern Russia are compared by their tin-silver-polymetallic mineralization. This comparison is made in terms of the geologic environment, mineral composition, the succession of mineralization processes and particular composition of main sulphides and silver minerals. According to the type of silver mineralization, mineral deposits under consideration are distinguished into sulphostibnite deposit type of the Omsukchan zone and sulphostannate deposit type of the Tenka zone, and, in all cases, this is a near-surface volcanogenic mineralization. A sulphostibnite deposit type features different silver sulphostibnites, insignificant initial cassiterite and constant stannits in polysulphide stage occurrences, and relatively high antimony concentrations (the formation of gudmundite-native antimony paragenesis). The most wide-spread silver minerals includes Fe-freibergite and pyrargyite. A sulphostannate deposit type features a wider occurrence of main sulphides and the predominance of canfieldite and hokartite among silver-bearing phases. The galena-fine needle cassiterite paragenesis seems to be a result of the decay of initial teallite. The ore fields of sulphostannate deposits type feature three stages of mineralization, which is the difference from a single-stage sulphostibnite mineralization. Mineral deposits under consideration are classified as terminating Late Cretaceous-Paleogene (?) homologous of the mineral deposit assemblage. The tin and silver grades are often commercial, but mineral deposits are not large.

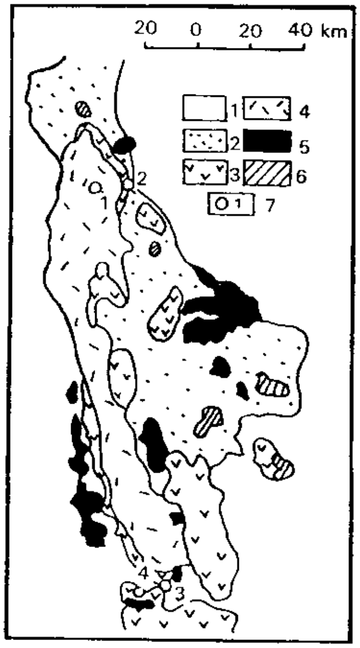
## INTRODUCTION

A near-surface mineralization in northeastern Russia is related to the structures of the Okhotsk-Chukchi volcanic belt. Different mineral deposit assemblages are present here, and the potential of mineral deposits is different. Gold-silver epithermal mineralization has always been of a primary geologic interest in this area, and as a result, several mineral deposits of this type have been discovered here. Small mineral deposits and occurrences bearing polymetallic ores, high silver and tin contents were also found in the process of geologic mapping, exploration and specific metallogenic studies of structures of the volcanic belt and its perivolcanic zone (Umitbaev, 1986). Such mineral deposits and occurrences usually correspond to different cassiterite-silicate-sulphide and cassiterite-sulphide mineralization types within ore districts. In Yakutiya, such mineral deposits were defined as terminating homologous of tin mineral deposit assemblages of Late Cretaceous, and , probably, Paleogene (Indolev, Nevoisa, 1974). The studies of silver-bearing properties of tin deposits in northeastern Russia allowed for their systematizing in terms of the ore body-to-halo contrast values (Plyashkevich, Pristavko, 1992); the obtained results also served as a basis for the assumption that tin-silver-polymetallic deposits belong to the same mineral deposit assemblage, and this ore is the most contrasting by silver content. This paper deals with the geologic and mineralogic description of this deposit type, as exemplified by the Omsukchan and Tenka major metallogenic zones of the East Asia-Arctic belt of mineral deposits of magmatic arcs.

## THE GEOLOGIC ENVIRONMENT AND PROCESSES OF MINERALIZATION

Mineral deposits and occurrences of the Omsukchan metallogenic zone including the Mechta, Tidid, Goltsovy and Porfirovy deposits are located within the major Kanskaya and Dzhagyn ore zones and the Pestrin ore district (Politov, 1980; Fig. 1) and are often confined to peripheries of local volcanic structures (Kolesnikov, Shatkov, 1994). Ore bodies consist of shear zones containing on echelon veins and veinlets (Fig. 2) and usually occur in felsic volcanics of Late Cretaceous and underlying terrigenous rocks making up a one- or two-stage structure of ore fields. Host rocks are subject to low- and mean-temperature propylitization. Tin and silver mineralization of the Omsukchan metallogenic zone is understood as related to the Late Cretaceous rhyolite-granite rock assemblage (Rodnov, Zaitsev, 1985), which influenced the formation of major volcanotectonic depressions and intrusive domes.

Mineral deposits and occurrences of the Tenka metallogenic zone including the Tokichan, Tigrets-Industriya and Kochevoi deposits are located within the major Degdekan-Arga-Yuryak tectonomagmatogenic dome-shaped structure, that is the most northern structure among the like ones (Fig. 3) in this area. Ore bodies consist of veins, lenticular occurrences and veinlets hosted in Permian sediments. Effusive rocks of Late Cretaceous including andesites, trachydacites, rhyolites and their tuff lavas occur to southwest. Effusive rocks and sediments are intruded by stock-like subvolcanic granite-porphyry bodies of Late Cretaceous, which often contain




←Fig. 1. The schematic structure of the Omsukchan metallogenic zone (Politov, 1980).
1 - sedimentary sequences T -J; 2 - effusive rocks and sediments $K_1$; 3 - intermediate and felsic volcanics $K_1$-$K_2$; 4 - rhyolites of the Glavnaya linear volcanic structure; 5 - tin-bearing granitoids; 6 - other intrusive rocks; 7 - mineral deposits: 1 - the Mechta, 2 - the Tidid, 3 - the Goltsovy, 4 - the Porphyrovy.

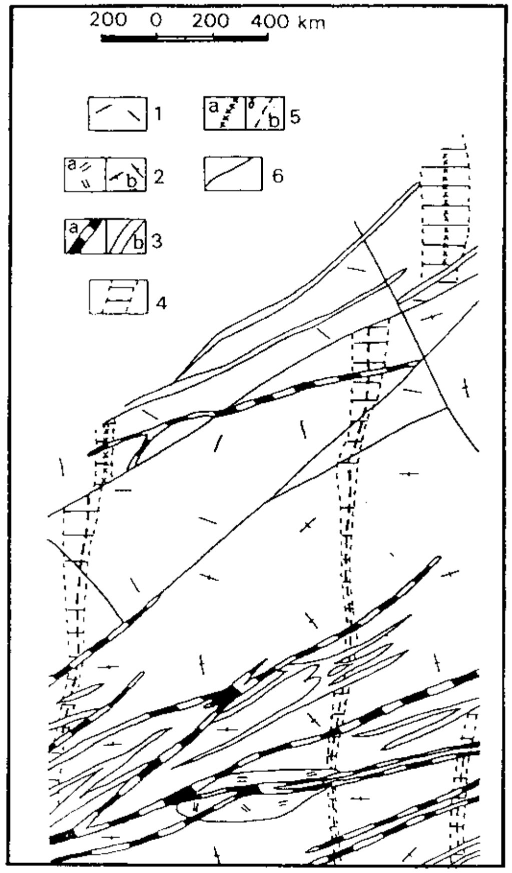
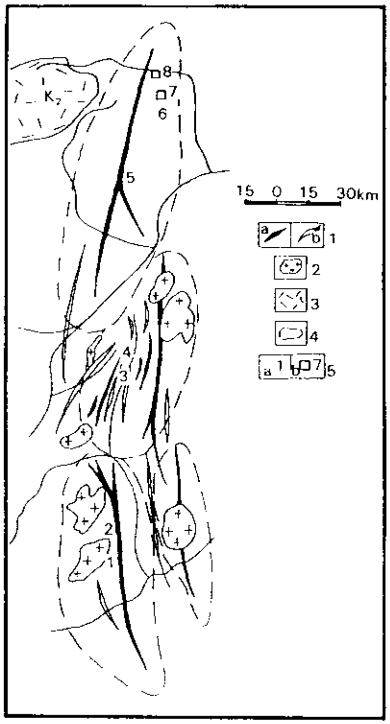



Fig. 2. The schematic geologic structure of the Mechta ore field → (Kolesnikov, Shatkov, 1994).
1 - nappe polyphyric rhyodacites $K_2$; 2: a - subvolcanic aphyric rhyolites $K_2$, b - extrusive polyphyric rhyodacites $K_2$; 3 - dike rocks: a - basaltic andesites P?, b - aphyric and oligophyric rhyolites $K_2$;4- wall rock argillizites; 5: a - sulphide and quartz-sulphide veinlet zones, b - veins; 6 - fault structures.




←Fig. 3. The schematic structure of the Tenka metallogenic zone (Voroshin et al., 1989).
1: a - anticline axes, b - syncline axes; 2 - granitoid rock masses; 3 - nappe volcanics $K_2$; 4 - conventional outlines of tectonomagmatogenic dome-shaped structures; 5 - mineral deposits: a - Au quartz de-posit type: 1 - the Rodionov deposit, 2 - the Igumen deposit, 3 - the Pavlik deposit, 4 - the Natalka deposit, 5 - the Degdekan deposit, 6 - the Tokichan de-posit; b - tin-silver-polymetallic deposit type: 7 - the Tokichan deposit, 8 - the Tigrets-Industriya deposit.

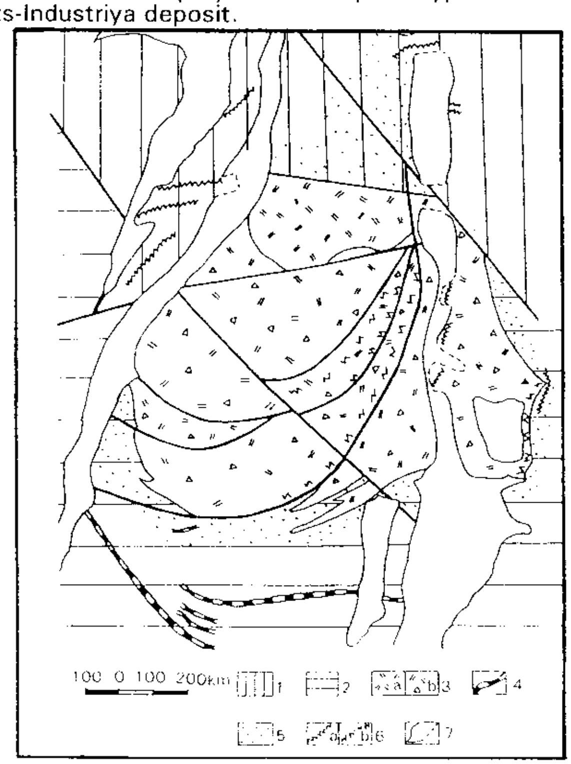


Fig. 4. The schematic structure of the Tigrets-Industriya ore field (according to Yu.P.Karelin and A.I.Beltsov). →
1, 2 - terrigenous strata $P_2$; 3 - subvolcanic body $K_2$: a - dacites, b - automagmatic trachydacite breccias; 4 - greisenized grano-diorite-porphyry dikes $K_2$; 5 - zones of contact metamorphism; 6 - hydrothermal occurrences: a - adularia-quartz, carbonate-quartz and quartz veins, b - veinlet zones; 7 - Quaternary rocks.

automagmatic breccias (Lychagin, 1967. Fig. 4). Sedimentary rocks are subject to an insignificant metamorphism including sericitization, biotitization and silicification, and, within ore fields, they are altered to propylites and/or argillizites.

Table 1. The succession of tin-silver-polymetallic mineralization in northeastern Russia.

| Metalogenic zones | | | | |
|---|---|---|---|---|
| The Omsukchan metallogenic zone | | The Tenka metallogenic zone | | |
| Mineralization stages | Mineral parageneses | Stages | Mineralization stages | Mineral parageneses |
| Arsenopyrite-chlorite-quartz | Chlorite-quartz | Cassiterite-silicate-sulphide | Quartz-cassiterite | Cassiterite-quartz |
| | Arsenopyrite quartz (pyrite-cassiterite) | | | Pyrite-Arsenopyrite |
| Polysulphide | Arsenopyrite-quartz (pyrrhotite, gudmundite) | Tin-silver-polymetallic | Polysulphide | Quartz-Arsenopyrite |
| | Chalcopyrite stannite-sphalerite | | | Sphalerite (pyrrhotite) -chalcopyrite |
| | Boulangerite galena with freibergite, pyrargyrite | | | Cassiterite-galena with Ag minerals |
| | | | | (Marcasite-pyrite) |
| (Ag sulphostibnites) | (Freibergite-diaphorite-miargyrite) | | (Carbonate) | (Hydromuscovite-quartz) |
| | (Pyrargyrite-stephanite) | | | (Calcite-Fe-dolomite) |
| Quartz-carbonate | Quartz-calcite | | | |
| | (aragonite, siderite Mn-siderite, ankerite) | | | |
| | | Selenocanfieldite-quartz | Drusy quartz | (Adularia-quartz) |
| | | | | Stannite-selenocanfieldite-quartz |
| | | | Carbonate | Quartz-calcite (Mn-calcite) |

The hydrothermal mineral occurrences of the Omsukchan metallogenic zone have six to eight successive paragenetic mineral assemblages that developed during three or four main stages (Table 1). The processes of telescoping and periods of intrastage crush resulted in several mineral generations. The total sulphide content of ore averages not more than 30%. Iron sulphides are replaced by copper sulphides and then by lead and zinc sulphides, which co-occur and are followed by lead and silver sulphostibnites. It is noteworthy, that small quantities of cassiterite begin to occur in parageneses of arsenopyrite-chlorite-quartz stage, and silver concentrations become highly increased by the end of mineralization. This increase is already evident from the early parageneses of polysulphide stage with its chalcopyrite irregularly enriched with silver (the example is the Mechta deposit) and having local contents to 2.8 wt% Ag.

The Tenka metallogenic zone is somewhat different, and this is primarily due to that ore bodies formed at different ore genesis stages are interrelated here. This mineralization is evidently younger that Au quartz mineralization and features occurrences of three different developmental stages (Table 1), which may be separate (the example is the Tigrets-Industriya ore field, Fig. 4) or combined (the example is the Tokichan or field, Fig. 5). The early are cassiterite-silicate-sulphide veinlets and veinlet zones occurring in a subvolcanic body of the Tigrets-Industriya deposit. Ore composition of tin-silver-polymetallic stage (the western Tigrets-Industriya ore field, the central Tokichan ore field, the Kochevoi occurrence) includes 3 to 5 mineral paragenesis of polysulphide stage and calcite-Fe-dolomite assemblage of carbonate stage, that is wide-spread in the Tigrets-Industriya deposit. The total sulphide amount may be more than 50%. Veins and veinlets related to this stage are cut by drusy quartz veins featuring a particular stannite-selenocanfieldite mineralization (the Tokichan occurrence). This stage represents the youngest mineralization in this area and is also evident from the eastern Tigrets-Industriya ore field and at the Kochevoi occurrence.

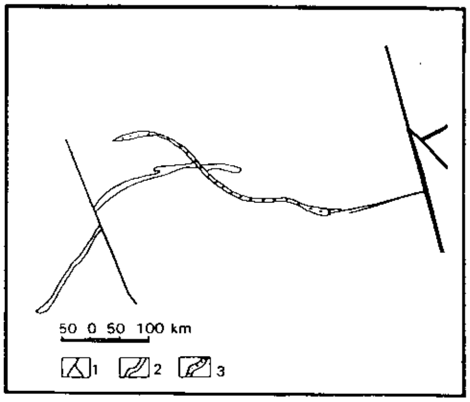



Fig. 5. Ore bodies of two stages of silver mineralization in the middle of the Tokichan ore field (according to Yu.P. Karelin and A.I. Beltsov). 1 - tectonic deformations; 2 - tin-silver-polymetallic stage veins $K_2$; 3 - selenocanfieldite-quartz stage veins $K_2$-P?

The Tenka and Omsukchan metallogenic zones feature approximately the same succession of formation of main minerals of polysulphide stage and ore texture and structure properties including the general veinlet character and abundant brecciated structures. Nevertheless, they differ for the position of tin in the general schematic succession of mineralization and for main silver minerals (Table 2). According to the dominating type of silver mineralization, the Omsukchan mineral deposits are defined as mostly sulphostibnite ones, and those of the Tenka mineral zone as sulphostannate ones.

Both ore types are similar by their Au, Sn and Ag concentrations. According to atomic absorption analysis, the content of gold is not higher than several tenth of g/t, tin $n \times 10^{-10}$g/t (spectrum analysis) and silver content ranges from tens of grams to several kilograms per ton (fire assay analysis).

Table 2. Tin and silver minerals of tin-silver-polymetallic deposits of NE Russia

| Minerals | Metallogenic zones | |
|---|---|---|
| | Omsukchan | Tenka |
| Established on all deposits of group | cassiterite<br>stannite<br>tetrahedrite (Ag-bearing)<br>pyrargirite<br>acantchite<br>myargirite<br>polybasite<br>stefanite<br>owyheete<br>Ag native | cassiterite<br>stannite<br>tetrahedrite (Ag-bearing)<br>pyrargirite<br>canfildite<br>hokartite<br>canfildite (Ag-bearing) |
| Established on some deposits | freieslebenite<br>raındorite<br>dyscrasite<br>dyaphorite<br>Sb native (Ag- or Bi-bearing) | acanthite |

## THE COMPOSITION OF MAIN SULPHIDES AND SILVER MINERALS

The similarities and differences of both ore types become more evident, when changes in the composition of main sulphide and silver minerals are considered. This study involved extensive micro-x-ray-spectrum analyses of arsenopyrite, sphalerite, chalcopyrite, pyrite, galena, fahlore minerals, canfieldite and selenocanfieldite, hokartite, pyrargyrite and some other silver sulpho-stibnites. It is possible to ignore pyrite and galena, as the changes in their composition and the concentrations of silver do not usually exceed the calculation errors. It is actually impossible to establish how the changing compositions of minerals depend upon the depth of their formation, as the mineral deposits occur at shallow depths and the exposed intervals are relatively small by vertical; nevertheless, different mineral type belongings are identified clearly.

In all mineral deposits under consideration, arsenopyrite is typical of early paragenesis of polysulphide stages, and one mineral generation is predominant due to the process of mineralization compressed in time. The Omsukchan mineral deposits are dominated by arsenopyrite of the initial arsenopyrite-quartz paragenesis, that is distinguished for a well-defined inner inhomogeneity mostly expressed by a thin zoning (the Mechta deposit). This zoning is caused by rather significant changes in As and S concentrations, i.e., to 3-5 wt. %. Mineral deposits of the Tenka zone feature a standard arsenopyrite-pyrite paragenesis. The average arsenopyrite composition is distinguished into two groups (Fig. 6).

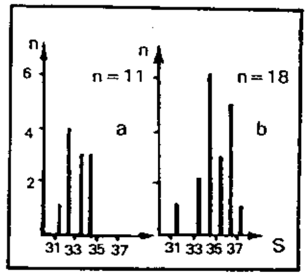



Fig 6. The sulfur content (at.%) of arsenopyrite in: a - the Tigrets-Industriya and Tokichan deposits, b - the Mechta deposit, n - the number of examined rock samples.

The first group consists of arsenopyrite typical of the Mechta deposit, the composition of which is nearly normal and changes for about 1.5 at.% in "sulphur" and "arsenic" areas. The second group consists of arsenopyrites, which are typical of mineral deposits of the Tenka zone and occur in the "sulphur" area, i.e., they contain more than 33.3 at.% S. This group is not completely uniform and contains somewhat separate high-sulphur samples of $Fe_1As_{0.9}S_{1.1}$ composition area and, probably 34.8-35.3 at.% concentration area. It is noteworthy, that arsenopyrites from the Mechta sulphostibnite deposit and the Ircha cassiterite-silicate-sulphide deposit in the southern Omsukchan metallogenic zone (Figs. 1 and 6) are close by their composition. The composition of arsenopyrite from sulphostannate deposits of the Tenka metallogenic zone represents the general tendency for an increase of $As_2$ content of solutions resulting in a high-sulphide content of ore, which may sometimes become massive, as it is exemplified by the Tigrets-Industriya deposit. It is also close to arsenopyrite from polymetallic deposits in Yakutiya (Flerov et. al., 1985) and seems to be in general similar to tin-silver-polymetallic mineralization. It is also very close to arsenopyrite from the late silver-bearing assemblage of gold lode deposits of the Pionersky ore district (Voroshin et. al., 1989).

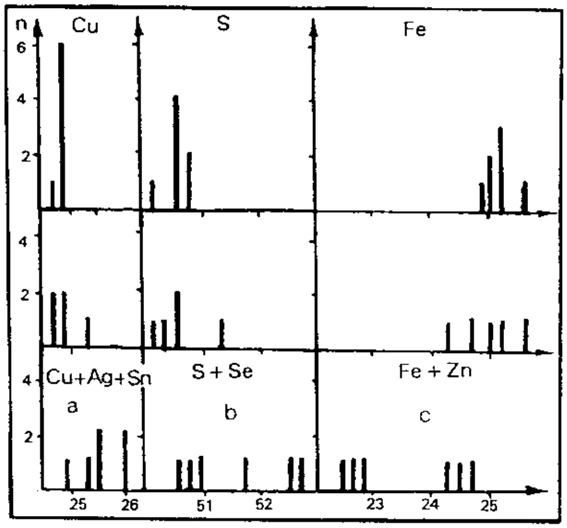



Fig. 7. Different chalcopyrite compositions (at.%, n - the number of rock samples): a - the Mechta deposit, b - the Tigrets-Industriya deposit, c - the Tokichan deposit, the second stage veins.

Chalcopyrite is a main mineral of polysulphide stages pertinent to all mineral deposits under consideration. It is mostly present in paragenesis with sphalerite, stannite and pyrrhotite. It usually occurs as emulsion disseminations in sphalerite and, to a lesser extent, in pyrrhotite and fahlore. In the Mechta mineral deposit, it doesn't contain emulsion sphalerite and the concentration of Zn isomorphous admixture is not higher than 0.6 wt.%, which testifies to low initial concentrations of ZnS, i.e., not more than 3 mol.%. The silver isomorphous admixture, that is typical of chalcopyrite from the Mechta mineral deposit, is quite irregularly distributed, and its local content can be as high as several percent. The chalcopyrite content of ore is somewhat lower in the Tenka metallogenic zone, and the emulsion sphalerite is usually present there. The initial ZnS concentrations could range from 3 to 10 mol.% there (Vorobjev, 1975). The examination of changing mineral compositions (Fig. 7) proves to a significant similarity between chalcopyrite from the Mechta sulphostibnite deposit and the Ircha cassiterite-silicate-sulphide deposit of the Omsukchan metallogenic zone, i.e., there is some deficiency of S and the excess of Fe, whereas the concentrations of Cu are close to normal values. The composition of chalcopyrite from the Tigrets-Industriya sulphostannate deposit is approximately the same. Chalcopyrite occurring in late selenocanfieldite-quartz veins of the Tokichan deposit is abundant with Ag, Sn, Zn and Se admixtures and changes by its composition in the area having an excess of Cu and deficiency of Fe.

Sphalerite of this paragenesis is usually abundant with emulsion disseminations of chalcopyrite, often stannite and only in the Tenka metallogenic zone, pyrrhotite. Changing concentrations of Mn, Cd, Sn, Cu and Fe macroadmixtures were analyzed. The reliable concentrations of the first four elements determined through micro-X-ray-spectrum analysis, i.e., exceeding 0.1 wt.%, are found in 65-70% of examined grains and usually equal several tenths of at.%, seldom 1-2 at.%. High Fe concentrations are pertinent to actually all examined samples, and their distribution is different for different deposit types (Fig. 8).

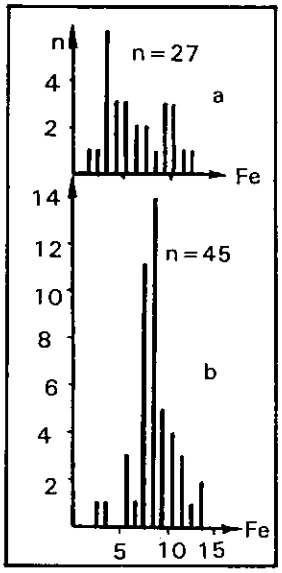
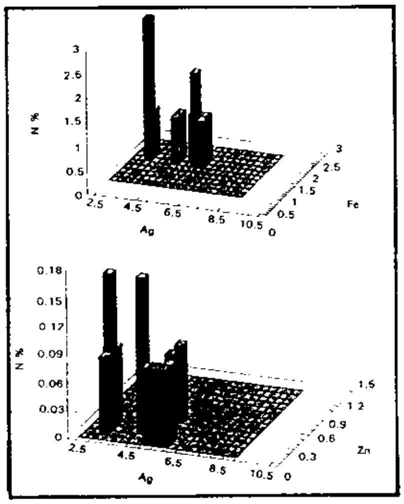



Fig. 8. The iron content of sphalerite (at.%, n - the number of rock samples): a - sulphostibnite deposit type, b - sulphostannate deposit type.

The sulphostibnite deposit type has two well-defined and approximately equal groups of mineral compositions with their maxima in areas 3-6 and 9-11 at.% (light colored cores and dark colored sphalerite periphery). The sulphostannate deposit type is generally dominated by high ferruginous varieties with an expressed maximum in area 7-10 at.%. Sphalerite occurring in late selenocanfieldite-quartz veins contains admixtures of Ag, Se (0.2-0.5) and Fe (3-4 at.%).

Silver-bearing fahlore is the main silver mineral of most silver-bearing ores of volcanogenic deposit type. It always consists of Fe and Ag bearing tetrahedrite that usually also contains Zn admixture. The contents of sporadic As and Se equal several tenths of wt.%. There are three ore varieties including Fe-freibergite, Ag-Fe-tetrahedrite and Ag-tetrahedrite (according to classification by Mozgova and Tsepin, 1983), with the predominance of the first two. Silver bearing tetrahedrite is heterogeneous in both deposit types, but it is more heterogeneous in sulphostibnite deposit type. According to the established changes of the mineral composition (Fig. 9), Fe concentrations are predominant for 1-2 k.f., Zn mostly to 1 at.%; three main Ag bearing groups are distinguished with their maxima in areas 2.3-4, 4.5-6 and 7.5-8 k.f. The last group of high silver Fe freibergite is pertinent only to sulphostibnite deposit type having two or three known mineral generations (Sakharova et. al., 1985) and serves as an indicator for high silver ore.

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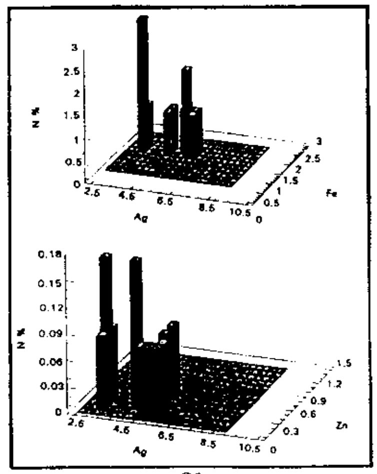


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Fig. 9. Different silver-bearing tetrahedrite compositions (formula coefficient, n - the amount of analyses): a - sulphostibnite deposit type, b - sulphostannate deposit type.

Galena hosted canfieldite from tin-silver-polymetallic deposit type and selenocanfieldite from the youngest mineral occurrences are the most widespread silver minerals in the Tenka metallogenic zone and typical of tin and polymetallic volcanogenic deposit types in Yakutiya and Russian Far East. The changes of mineral compositions are significant especially by silver and sulfur (Fig. 10), i.e. for 3-4 at.% for one sample. The deficiency of silver can be greater than it was earlier assumed (Nekrasova et. al., 1981) and is compensated by increased concentrations of anion group elements.

Hokartite occurs in galena in paragenesis with canfieldite, stannite and sphalerite, and its composition is relatively persistent and close to normal. The decay structures of selenocanfieldite-stannite solid solutions in late veins are of a particular interest. In this case, stannite may contain an admixture of Ag and Se equalling several tenths of wt.% and a constant admixture of Zn (1.8-4.1 wt.%).

Pyrargyrite is known from both deposit types and usually contains an admixture of Cu (0.1-0.9 wt.%) and sometimes Fe, Zn and Se (0.1-0.4 wt.%). It has some excess of silver, i.e., 0.01-0.31 in mineral deposits of the Omsukchan metallogenic zone.

## CONCLUSIONS

Such factors as different geologic environments, the position of tin in mineralization processes and the character of silver mineralization may serve as a sufficient basis to distinguish the mineral deposits under consideration into sulphostibnite and sulphostannate mineral types.

The sulphostibnite deposit type of the Omsukchan metallogenic zone features diverse silver sulphostibnites, small quantities of initial cassiterite, constant presence of stannite in polysulphide ore and a high-antimony content of ore resulting in gudmundite-native antimony paragenesis in the Tidid deposit. The main silver minerals include Fe-freibergite and pyrargyrite; a high silver Fe-freibergite variety, i.e., up to 46 wt.% Ag, is characteristic of this mineral type.

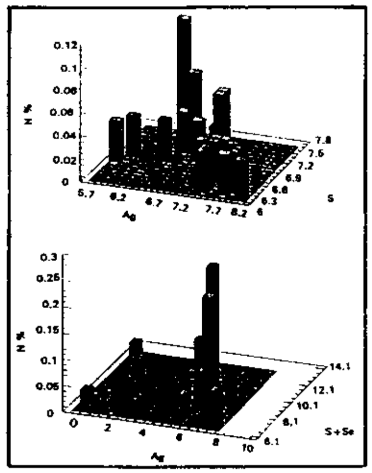

Fig. 10. Different canfieldite (a) and selenocanfieldite (b) compositions in the Tenka metallogenic zone (formula coefficient, n - the amount of analyses).

The sulphostannate deposit type of the Tenka metallogenic zone features even a wider occurrence of main sulphides and ferruginous carbonates, with the predominance of silver sulphostannates including canfieldite and hokartite among silver-bearing phases. Fine needle cassiterite occurs only in galena and seems to be a result of the decay of initial teallite under increased Ph conditions of solutions (Nekrasov, 1976). This deposit type is close to cassiterite-sulphide occurrences in the Russian Far East (the Sinancha deposit).

Both deposit types under consideration are characterized by heterogeneous properties of main minerals and especially silver bearing minerals due to a fast site evolution of ore forming fluids under the gradient conditions of the near surface zone. Relatively small mineral deposits may have high silver and tin concentrations.

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