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Geochemical Aureoles of Ore-Bearing Areas of Nizhne-Taezhnyi Ore Node (East Sikhote-Alin)

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Abstract. Nizhne-Taezhnyi ore node of Northern Primorye is a complex object containing tin-polymetal-silver, polymetal-silver, and proper silver mineralization silver-porphyry mineralization is possible to be found also. Analysis geogimicl element distribution showed that Ag and Sb with good correlation between each other manifested a weak tendency to decrease with depth. The highest concentrations of Sn, Pb, and Zn are fixed at a depth of about 250 m and decrease upwards and downwards from this level, but Mo and Cu contents essentially increase at low levels (Fig. The revealed tendencies of variability of the chalcophile element concentration both laterally and vertically can be explained by the availability of a vertical mineralogical-geochemical zonality of the mineralization.

1. Introduction

The Nizhne-Taezhnyi ore node occupies 500 km² in the Coastal zone of the East-Sikhote-Alin volcano-plutonic belt (the Taezhnaya River basin, about 25 km of the Japan Sea coast). The Nizhne-Taezhnyi ore node shows a rather complicated geological structure: large rupture dislocations, differently oriented through faults, large magmatic centers, major spray fluxes, and concentrate and geochemical aureoles [5,7].

2. Geological structure

The stratified formations participating in the node structure and composing the node are belong to two structural stages: a lower terrigenous stage whose rocks (K₁) are crushed into dip folds of the northeast trend and an upper volcanogenic stage involving the effusive-pyroclastic accumulations of the Bogopol'skaya (Maastrichtian-Danian), Samarginskaya (Maastrichtian), and Primorskaya (Turonian-Campanian) strata [9]. The Late-Cretaceous volcanic accumulations are distributed irregularly on the node area and reach 3 km in thickness.

The Primorskaya strata of 650-700 m in total thickness is mapped in the east-south-east part of the area. Its lower bench (K_{2pr1}) with visible thickness of more than 250 m is represented by agglomerate, psephitic, and psammitic lithocrystalloclastic tuffs of rhyolites containing the fragments of the rocks of the folded basement. The psammitic-psephitic tuffs are overlapped by the welded ignimbrite-like psephitic-psammitic pyroclastics of acid composition of the second bench (K_{2pr2}) 250-440 m thick containing rare interbeds of ignimbrites, tuffites, and ash and coarse-fragmented tuffs. This bench is characterized by a facial variability of accumulations and their mottled color. The upper bench (K_{2pr3}) of the strata has a distinctive brownish-brown-grey color and occurs in the central part of the node. Appearance of this bench is defined by ignimbrites, loose sintered psammitic tuffs of acid composition



with welded tuffs of the argillized volcanic glass. The bench contains rare interbeds of tuffs of rhyodacites, tuffites, tuff-sandstones, and tuff-siltstones [4].

Extrusive bodies mapped among the volcanites of the Primorskaya strata are composed of ignispummites, magnaphyric rhyolites, sometimes surrounded by agglomerate mantle.

The deposits of the Primorskaya strata are conformably overlapped by pyroclastic accumulations of intermediate and moderate-acid composition of the Samarginskaya (K_2sm) suite characterized by mottled appearance and a wide variability of the fragment sizes up to blocks of rocks in the agglomerate tuffs. The interbeds of rhyolite tuffs, psephitic and agglomerate xenotuffs, tuff-sandstones, tuff-siltstones, as well as pelitic silica-like tuffs are found. The lowers of the strata section contain coarse pyroclastics and xenotuffs, the upper parts – extrusive-effusive bodies of andesites that are successively overlapped by massive and bedded siliceous tuffs of moderate-acid (dacite) composition, siliceous tuffites, tuff-sandstones, tuff-siltstones, and black bedded siltstones and sandstones of the facies of crater lakes [6,8]. The extrusive bodies of the Samarga time are divided into two groups by composition and sequence of formation: early (acid and moderate-acid composition) – spherulitic and fluidal-spherulitic rhyolites and rhyodacites and their porphyric varieties, sometimes of breccia-like appearance, and late (intermediate composition) – andesites and andesi-dacites.

The effusive-pyroclastic accumulations of the Bogopol'skaya strata (K_2bg) of high alkalinity occur in the western and northern sectors of the node. The lowers of the section of the strata first bench (K_2bg_1) are composed of block tuffs of rhyolites and tuff-conglomerates (with rounded and semi-rounded blocks of rhyolites, dacites, and miarolic granites) with rare interbeds of tuffites and tuff-siltstones and of coarse-fragmented rhyolitoid ignimbrites with abundant flattened fragments of the argillized volcanic glass and different rocks including sedimentary deposits of the lower structural stage. The upper parts of this bench section are represented by the psephitic and psephitic-psammitic lithovicroystalloclastic tuffs of acid composition. The middle bench (K_2bg_2) is dominated by agglomerate (lowers) and psephitic-psammitic siliceous (welded to a different degree) ignimbrite-like biotite tuffs of rhyolites. The upper bench (K_2bg_3) is composed of widespread light-colored bedded pyroclastites and rarer tuffogene-sedimentary rocks. Its lowers consist of aleuropsammitic and pelite-aleurite tuffs of rhyolites with interbeds of ignimbrites and ignimbrite-like psephite-psammitic, sometimes ash, tuffs. The middle part of the bench includes a significant portion of pelite massive and bedded opal-like tuffites and siliceous rocks with lenses and interbeds of black opalites. The upper part (K_2bg_3) is an alternation of pelite and aleurite tuffs of acid composition, tuffites, tuff-sandstones, and tuff-siltstones containing plant detritus. The extrusive bodies of the Bogopol'sky time belong to three groups. The early ones are rhyodacites, dacites, trachydacites grading sometimes into andesites, and their breccia varieties that in some cases have tuff appearance. Later extrusive bodies are composed of porphyric, often amygdaloidal, hornblende-plagioclase andesites. The youngest ones compose the extrusive bodies of rhyolite ignispummites surrounded by agglomerate mantles.

Subvolcanic and intrusive bodies, that are deeper parts of the volcano-plutonic complexes (VPC) (named as strata), are comagmatic to the extrusive-effusive-pyroclastic accumulations of the three described strata. The youngest subvolcanic formations crossing the dacite extrusions of the Bogopol'sky VPC on the node area are attributed to the Kizinsky (Miocene) complex. These are the dikes of hypersthene andesites, andesidacites and dacites breaking the bodies of explosive breccias of the Bogopol'sky complex.

The largest intrusive and subvolcanic bodies of the Primorsky VPC were found among the hornstoned rocks of a corresponding strata. Together with younger formations they occur in the local focus structures of the intrusive-dome type. The intrusive bodies show a complicated structure as they are composed of rocks of different phases. The largest Malinovsky massif (Fig. 1) is dominated by Samarginsky granitoids [10]. Among the latter, both fine (rarely coarse)-grained biotite-hornblende quartz ("needle-shaped") diorites and biotite porphyry granites, grading into granite-porphyries in the marginal parts of the massif, are distinguished. The subvolcanic bodies of the VPC under study are

represented by magnophyric rhyolites grading sometimes into granite-porphyrries or clastolavas of acid composition.

A spectacular representative of the intrusive bodies of the Samarginsky VPC is the Zavodskoy massif where 2 phase of injection are observed. The early phase is composed of fine-grained miarole alaskite granites that take the aplite-like appearance in the endocontact zone; the late phase consists of pyroxene-hornblende coarse-grained diorites (grading sometimes into gabbro-diorites) that in the endocontact and apical zones of the massif are changed by strongly porphyry-like varieties with gradation into typical diorite porphyrites of the pyroxene-hornblende-biotite composition. The Samarginsky VPC volume is dominated by subvolcanic bodies: dikes, stocks, and necks. Among them, like among the stratified accumulations, we fixed the antidromeness of evolution of the Samarginsky magmatism: from rhyolites to dacites of the porphyry and magnophyric appearance at the early stage to andesi-dacites and plagioclase-hornblende (rarely biotite) andesites at the late stage. Small contiguous domes of andesites have a complicated inner structure and are well pronounced in the relief. The space between them sometimes is filled with explosive breccias containing blocks of andesites, granites, and diorites and tuffs of rhyolites cemented with lava of andesi-dacite composition.

The subvolcanic bodies of the Bogopol'sky VPC are represented by the necks of dacites and trachydacites grading sometimes into andesi-dacites, rhyodacites, and rhyolites of tuff-like appearance as well as by bodies of explosive breccias of a corresponding composition. The later – Kizinsky – formations, as noted above, are composed of fine- and subporphyry (often amygdaloidal) varieties of hornblende-plagioclase andesites and more rarely andesi-basalts and basalts. They are characterized by spheroidal jointing, significant modification, and high alkalinity.

3. Mineralogy and mineralogical-geochemical types of ore zones

In the ore node, several complex geochemical anomalies have been revealed from the spray fluxes of silver, lead, zinc, copper, and to a lesser degree arsenic: Kamenistaya, Osnovnaya, Levoberezhnaya, Kontrastnaya, and others. On their area the ore fields, in searching practice named as plots, were recognized: Kumirnyi, Levoberezhnyi, Kabaniy, and so on (Fig. 1). Within them, the ore zones (more than 30) of north-west (more rarely sublatitudinal, submeridional, and rarely northeast) orientation occur with rare-metal, polymetal, polymetal-silver, and silver mineralization. Elements of zonality are outlined in the ore zone distribution [11]. There is evidence that the endogenous mineralization was formed in two stages: post-Samarginsky and post-Bogopol'sky. However, accurate determinations of the relative and absolute ages of mineralization are not available as yet. In the intrusive massifs, the polymetal, poor-bismuth, molybdenum, and tin mineralization associated with quartz-muscovite greisens has been found. With distance from intrusive bodies, the aureoles of greisenization and hornfels development are changed by the aureoles of propilitization and quartz-sericite-hydromicaceous metasomatites. The vein-streaky zones with tin-polymetal-silver and polymetal-silver mineralization are localized near the Malinovskaya intrusion and the stocks of the Samarginsky diorites among the hornstoned volcanites of the lower bench (K_2pr_1) of the Primorskaya strata (Belembinskaya, Bortovaya, Ruslovaya, and others). The thickness of such zones reaches 10-20 m and extension – 1.5 and more kilometers. They are composed of multiple-branched steeply dipping silver-bearing quartz-sulfide veins accompanied by streaky-impregnated mineralization (including quartz-fluorite one). Their common feature is the presence of SnO_2 (in tin-polymetal-silver to 1% and more and in polymetal-silver to 0.1%). They contain about 1% and more of Pb, Zn, and Cu and about 200g/t Ag and are considered as facial varieties of a single ore formation. Differences between them are possibly caused by different truncation: a more significant for the tin-polymetal-silver mineralization. This is supported also by its lower silver content as compared with the polymetal-silver one. The latter is divided into two mineral-geochemical types: lead-silver quartz-sulfide with silver-bearing galena and copper-silver sulfide-carbonate-quartz with the limited volume of sulfides among which silver-bearing chalcopyrite dominates (Dorozhnaya, Osennyaya, and other zones). As a whole, the productivity of such zones for Ag is determined by occurrence in them of pyrite-

chalcopyrite and especially late galena mineral associations [1]. In the first zone, native silver and stephanite predominate and in the second one – freibergite and (or) argentite.

The poor-sulfide silver-bearing zones (Kumirnaya, Vodorazdel'naya, Zamanchivaya, Blizhnyaya, Neyasnaya, Krainyaya, Pereval'naya, Sentyabr'skaya, Syurpriz, and others) are spatially separated from the tin-polymetal-silver mineralization. They have a significantly less thickness (3-4 m) and are localized predominantly among the volcanites of the third bench of the Primorskaya strata (K_2pr_3) transformed into quartz-sericite-hydromicaceous metasomatites. Such zones are characterized by coarse-banded structure. Their axial parts are usually composed of combed, medium-grained semitransparent quartz of breccia-like appearance, surrounded symmetrically or only on one side by quartz vein-streaky "bands" containing nests, streaks, and impregnation of fine-grained and dispersed arsenopyrite and simple sulfides of Fe, Zn, Pb, Cu as well as sulfides of Ag and its sulfosalts (acanthite, pyrrargyrite, polybasite, argentite, stephanite, freibergite, stromeyerite, and others). In some zones, pyrrargyrite prevails

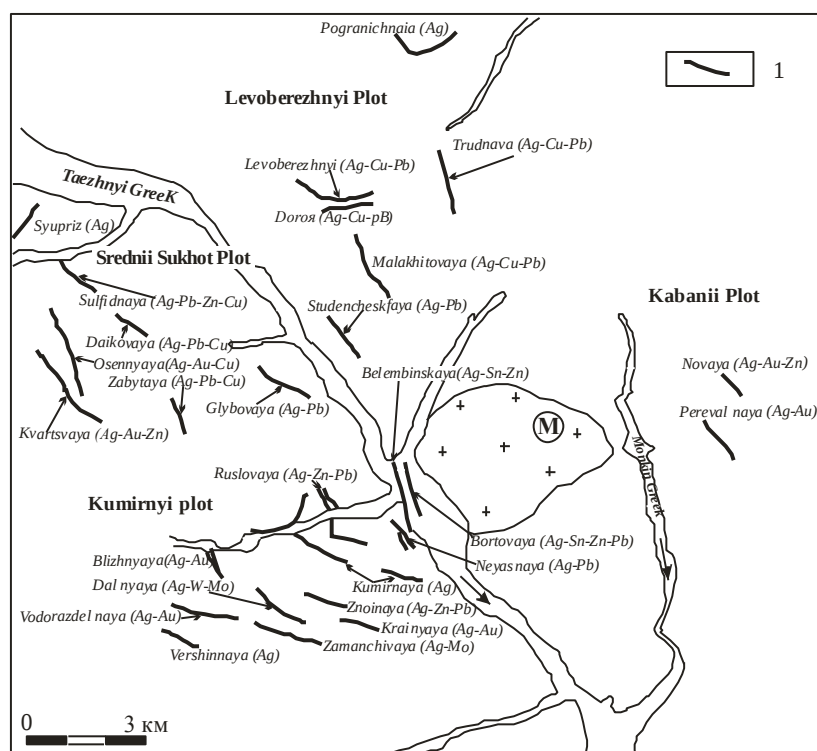


Figure 1. Scheme of distribution of mineralized zones on the area of the Nizhne-Taezhnyi ore node. 1 – mineralized zones and their ore-geochemical signature (Au, Ag, Pb, Zn, Cu, Sn). M – Malinovsky massif of granitoids. See the text for other explanations.

over acanthite and other minerals of Ag (for example, Zamanchivaya zone), in other zones ratios of the mentioned minerals are inverse (Sentyabr'skaya, Pereval'naya, and other zones).

The possibility that silver-porphyry mineralization also occurs on the node area is not excluded.

Data on the geological structure, metasomatic alterations of rocks and mineral associations and geochemical features of the silver-bearing zones of the Nizhne-Taezhnyi ore node and their zonal distribution testify, in the authors' opinion, to significant scales of mineralization within the nodes and its certain unique character. Reason for such inclusion is not only the silver content in ore zones but also the presence of marked amounts of copper, lead, zinc, and tin as well as the evidence of zonal distribution of different types of mineralization at the level of the today truncation.

The mineral types revealed at the Nizhne-Taezhnyi node area may be conditionally combined into a successive row according to the Ag concentrations in them and position relatively to the Malinovsky intrusive massif with which silver and silver-bearing mineralization associates. The ore deposits recognized on the area of the Nizhne-Taezhnyi ore node are controlled mainly by tectonic elements and the deep-seated faults are deciding among them. Associated fractured zones are responsible for distribution of magmatic formations and metasomatites. Along such zones and on their intersections, abundant ore occurrences gravitating to the tectono-magmatic structures composed of the rock complexes of the basement and intrusive, subvolcanic, extrusive-effusive, and volcanogene-sedimentary formations occur.

4. Features of distribution of precious metals, siderophile and chalcophile elements in the geochemical aureoles of ore zone

A set of siderophile and chalcophile elements and precious metals (Au, Ag), participating in the formation of geochemical anomalies of the Nizhne-Taezhnyi node, was determined using different methods: spectral quantitative, in part spectrographometric, atom-absorption, and selectively chemical analyses. The greatest number of determinations was done by the spectral analysis; other analyses comprise about 10%.

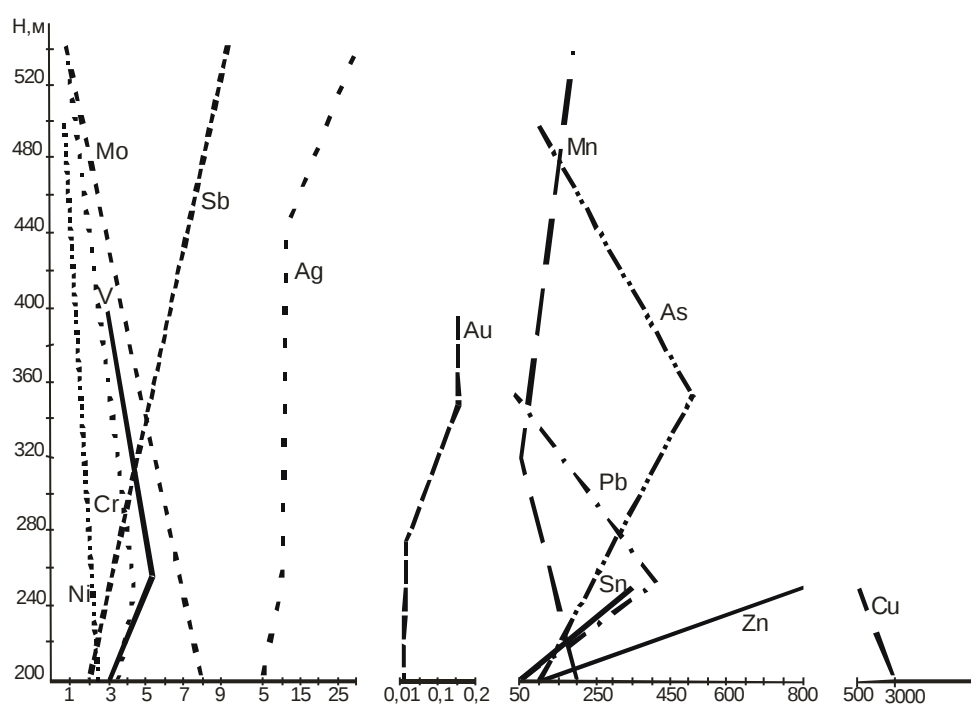


Figure 2. Lateral distribution (isolines) of precious metals and chalcophile elements at the Kumirnyi plot.

Further analysis of the spatial distribution of elements using Matlab Program showed their differentiated occurrences practically at each of the plots both laterally and vertically [2,3]. For example, at the Kumirnyi plot, the highest concentrations of Ag and Sb were found on its western flank, As and Au – in the center, and Mo, Cu, and Sn – on the eastern flank (Fig. 2). Analysis of the same element distribution (with regard to the modern surface hypsometry) showed that Ag and Sb with good correlation between each other manifested a weak tendency to decrease with depth. The highest concentrations of Sn, Pb, and Zn are fixed at a depth of about 250 m and decrease upwards and downwards from this level, but Mo and Cu contents essentially increase at low levels (Fig. 3). The revealed tendencies of variability of the chalcophile element concentration both laterally and vertically

can be explained by the availability of a vertical mineralogical-geochemical zonality of the mineralization. Cases of such distribution of elements have been studied in detail at the deeply stripped deposits of the Mexico chain of the Pacific segment of the Earth (Guanokhuato and others) [12,13].

5. Conclusion

On their area, silver ores are changed with depth by gold-silver and then by silver-polymetallic and copper ores. The mineralogical-geochemical zonality is accompanied by zonality of metasomatic alterations of rocks. Silver mineralization is usually localized at the level of argillizites of the hydromicaceous, montmorillonite-hydromicaceous, and chlorite-hydromicaceous composition and adularia-bearing metasomatites. At deeper levels (lead-zinc, bismuth, tin-polymetal, copper, and copper-molybdenum mineralization), sericite, chlorite-sericite, chlorite-carbonate, orthoclase, and albite metasomatites are fixed.

On the basis of the foreign and home experience the evidence of lateral changeability in the distribution of elements on the study area can be logically explained by different truncation of the western (small truncation) and eastern (essential truncation) flanks of the Kumirnyi plot. This conclusion suggests that further geological investigations of the Nizhne-Taezhnyi ore node will help to evaluate objectively the scales of the complex mineralization revealed there.

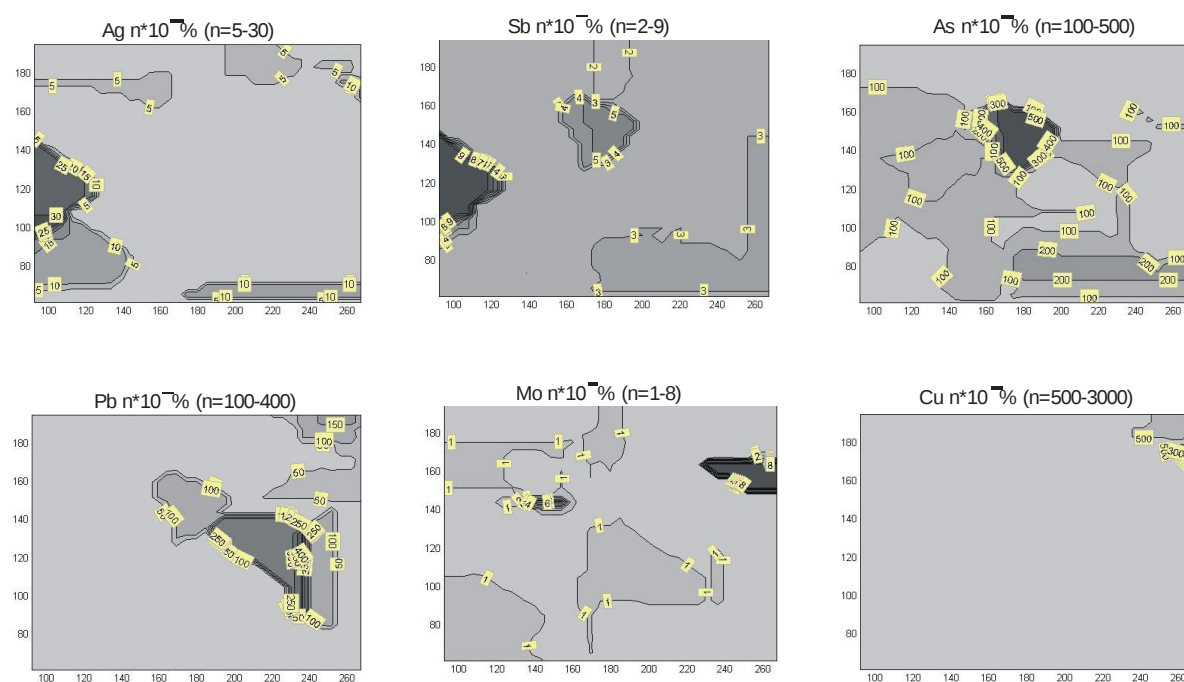


Figure 3. Distribution (relative to modern surface) of precious metals and chalcophile elements at the Kumirnyi plot.

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