Signs of Vertically Extending Mineralization in the Nizhnetaezhny Polymetallic Ore District (Northern Primorye)

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Abstract. In this work, to study the vertical extent of mineralization, determine the level of erosion, and identify signs of longitudinal placement of silver mineralization of the Nizhnetaezhny ore district (NOD) For this, the main indicator indicators Ag, Au, Cu, Zn, Pb were identified based on the maximum correlation coefficient. Then, the ratios of the linear productivities of the indicator elements for the main ore zones of the Scientific and Technological Logging were made: Kumirnoe - Sb * Ag * As / Cu * Sn, Kabaniy - Sb * Ag / Cu * Sn, SredniySukhoy - Sn * Pb * Zn / Au * As, Levoberezhnoe - Sn * Pb * Zn / W * Mo. The obtained geochemical data of changes in the multiplicative coefficients allowed us to identify areas according to their erosion: weakly eroded (Kumirny, SredniySukhoy) and significantly eroded (Kabany, Levoberezhnoe), and then divide them into upper ore, ore and under ore. At all sites (except for the SredniySukhoy), at the level of the conditionally subsided horizon, a tendency of gradual increase in productivity was revealed, which indicates the long-range placement of productive ore zones and makes it possible to suggest the presence of powerful and productive silver zones hidden at depth. The data obtained provide the prerequisites for the revaluation of the prospects of the deep horizons of the NOD silver mineralization.

1. Introduction
An objective assessment of mineralization when it extends vertically down is rather difficult without geochemical methods of prospecting. The world practice, however, knows many examples of such type of mineralization that reaches depths of from several hundreds to even thousand meters. In this connection, insufficiently explored and surveyed territories of the Russian Far East appear relevant to the purpose of further prospecting for deep mineralization. The present research is dedicated to the Nizhnetaezhny ore district (NOD) located in the near-shore area of the East Sikhote-Alin volcanic-plutonic belt. [2] The district occupies around 500 square kilometers of the Taechhnaya River basin about 25 km off the coast of the Sea of Japan, is characterized by complex geological structure [3,4] with large faults, differently oriented through-thickness fissures, vast dispersion halos, placers and geochemical aureoles. In fact, this is the largest ore district in the north of Primorsky Region.

2. Geological structure
It is consists of two stratigraphic successions: lower terrigenous (K₁) and upper volcanic (K₂). Rocks of the former are crumpled into steeply NE-dipping folds, while the latter unit comprises effusive-pyroclastic sediments of three formations: Bogopolskaya (Maastrichtian-Danian), Samarga (Maastrichtian) and Primorskaya (Turonian-Campanian).
The Primorskaya Formation is mapped in the east-southeastern portion of the NOD and has total thickness of 650-700 m. Its lower bench (K_{2pr}) with visible thickness of more than 250 m is composed of agglomerate, psephitic to psammititic lithoclastic tuffs of rhyolite containing fragments of the folded basement. The psamo-psephitic rhyolitic tuffs are overlapped by welded ignimbrite-like psephite-psammitic intermediate pyroclastic accumulations of the middle bench (K_{3pr}) which thickness reaches 250-440 m. The uppermost bench (K_{4pr}) is an integral part of the field center. The appearance of this bench is defined by ignimbrites and welded loose intermediate psammitic tuffs with fiamme of argillized volcanic glass that altogether impartsthe bench a characteristic brownish-grey tint.

The Primorskaya Formation is conformably overlapped by intermediate-to-moderately intermediate pyroclastic sediments of the Samarga Formation (K_{2sm}), which is inherent in mixed structure and a wide range of clasts’ size, right up to blocks of stone in the surrounding agglomeratic tuff matrix. There are layers of rhyolitic tuffs, psephitic and agglomeratic xenotuffs, tuffaceous sandstones and siltstones, as well as pelitic tuffswith chert appearance. The formation base contains rough pyroclastic material and xenotuff, whereas its top represents extrusive-effusive bodies of andesite and an overlying sequence of massive and bedded moderately intermediate (dacitic) siliceous tuffs and tuffites, tuffaceous sandstones and siltstones, as well as blackbedded siltstone and sandstonesof crater lake facies, in that order.

The Bogopolskaya Formation (K_{2bg}) high alkaline accumulations of pyroclastic rocks and effusive facies occupy western and northern sections of the NOD and are divided into lower (K_{2bg1}), middle (K_{2bg2}) and upper (K_{2bg3})units. The lower unit bottom is composed of blocks of rhyolitic tuff, rounded and semi-rounded boulders of rhyolite, dacite and miarolitic granite bound into a conglomerate with rarelayers of tuffites and tuffaceous siltstone; course rhyolitic ignimbrite enriched in flattened debris of argillized volcanic glass and various rock material including sediments of the lower structural level. Upwardly the unit is consisted of psephitic and pspho-psammititic lithoclastic tuffs of intermediate composition. The middle unit further up the sequenceis predominantly composed of agglomeratic (in its lower part) and psepho-psammititic siliceous (with various degrees of welding) biotite-rich rhyoliticflood tuffs. The last upper unit of the formation represents an alternation of acidic pelitic and aleurolitic tuffs, tuffites, tuff sandstones and tuff siltstones containing plant detritus.

The volcanic rock accumulations of three formations described above are comagmatic with subvolcanic intrusive bodies which are deeper members of volcanic-plutonic complexes (VPC) with the same names Primorsky, Samarga and Bogopolsky. The youngest subvolcanic bodies cutting dacite extrusions of the Bogopolsky VPC are regarded as the Miocene Kizinsky complex, representing hypersthene-andesite, andesidacite and dicite dykes.

The largest subvolcanic intrusions of the Samarga and Bogopolsky complexes have been found in the formations’ hornfelsed rocks within local dome-shape structures. The intrusions have complicated structurestheir comprising rock facies of different age. For example, the earliest facies of large Malinovsky massif are represented mainly by the Samargadioritic rocks, among which fine (rarely course)-grained biotite-hornblende-quarts acicular diorite is predominating. Porphyric biotite granites changing to granite-porphry towards the massif periphery are likely to belong already to the Bogopolsky complex [5,6]. Subvolcanic bodies of the latter are magnophyric rhyolites sometimes changing either to granite-porphry or to felsic clastic lavas, necks of dacite and trachydacitescSometimes changing to andesidacite, rhyodacite and rhyolite with tuff appearance, and explosion breccias of corresponding composition. The younger subvolcanic formations of the Kizinsky complex are fine-grained to subporphyritic (often amygdaloidal) varieties of plagioclase feldspar andesites, rarely andesibasalts and basalts. They are characterized by spheroidal jointing, high alkalinity and considerable alteration degree [7].
3. Geochemical research

Tracing the silver, lead, zinc, tin, copper, lesser arsenic dispersion haloes made it possible to reveal several complex geochemical anomalies: Kamenistaya, Osnovnaya, Levoberezhnaya, Kontrastnaya, etc. Exploration works of these areas have established ore fields named sectors Kumirnyi, Levoberezhnii, Kabaniy, etc., within which more than 30 mainly NW- (rarely near EW, near NS, and NE) trending ore zones were discovered. A diversity of the zones mineralization includes rare metal, silver-poly metallic, tin-silver-poly metallic, polymetallic-silver and silver deposits [4].

Zones of tin-polymetallic-silver and polymetallic-silver mineralization were found near the Malinovsky intrusive massif within the hornfelsed volcanic rocks of the lowermost unit of the Primorskaya Formation(zones Belembinskaya, Bortovaya, Ruslovaya, etc.). They form systems of intricately branching steep-dipping silver-quartz-sulfide veins and disseminated ore spikes along the veins. Mineralization thickness is ranging between 10 and 20 m and the length exceeds 1.5 km.

Low-sulfide silver-bearing zones (Kumirnaya, Vodorazdelnaya, Zamanchivaya, Blizhnaya, Neyasnaya, Krainyaya, Perevalnaya, Sentyabrskaya, Surpriz, etc.) do not spatially associate with the tin-polymetallic-silver mineralization. Being considerably thinner than the latter (about 3-4 m), they mainly occur within the quartz-sericite-hydromicaeous metasomatites of the uppermost unit of the Primorskaya Formation.

The necessity in understanding the genesis of anomalous concentrations of metals and regularities of their distribution within the ore nodes, fields and deposits predetermines the application of geochemistry research methods at all stages of the object’s mineral potential evaluation – from the preliminary estimation of mineralized areas till the discovery of separate ore bodies including those buried at a great depth.

4. Results and discussion

Geochemical research of the Nizhnetaezhny ore district was built on available reports of prospecting and evaluation works and personal detailed geological study of separate district’s sectors. Promises for deep mineralization have been estimated with the help of Matlab software through processing data of trenching and sampling with hammer in the preexisting trial trenches and sites of stripping. Those data represented results of five thousand analyses of sampled rocks by various analytical methods, such as spectral analysis, spectrographic aurometric surveying, activation assay, atomic absorption and chemical analyses. Computing results served as a basis for maps of primary geochemical aureoles showing spatial distribution of tracer elements in each district’s sectors. The analysis of these maps according to the methodology suggested by S.V. Grigoryam [1] has shown elements of vertical distribution of tracer elements in all objects of the district.

The Kumirny sector with silver, silver-poly metallic and, to a lesser extent, polymetallie-silver mineralization demonstrates anomalous concentrations of Ag, Sb, and Au at ~400-m hypsometric level, and S, Pb, Zn, Cu, and Moat lower levels (about 200 m). Similarly, the detected high concentrations of Zn, Mo, As, Ag and Sb at 400-m levels, and Sn, Pb, Cu, and Au at 200-m levels define the Kabaniy sector silver mineralization. The Sredniy Sukhoy sector is characterized by predominant polymetallic-silver mineralization that is corroborated by geochemical aureoles of Ag, Pb, Zn, and Cu at 300-m hypsometric horizons and concentrations of As, Sb, and Au at deeper 200-m horizon. Silver-polymetallic mineralization of the Levoberezhnii sector is confirmed by high concentrations of Ag, Sn, Pb, Zn, and As at 500-m hypometric horizon and of Mo, W, and Au at deeper 200-m levels. The revealed relief interval with an absolute lower mark of 200 m and an absolute upper mark of 600 m demonstrates complex pattern of metal elements distribution depending on the level: Ag, Au, Mo – upper and lower levels, Pb and Zn – upper and medium levels, W – medium and lower levels, and Sb – anywhere within the interval.

To detect levels of erosional truncation as well as signs of vertically extending mineralization in the sectors under study, tracer elements values per running lengths of the following geochemical aureoles have been calculated: Kumirniiy – Sb*Ar*As*/Cu*An*, Kabaniy – Sb*As*Ag*/Cu*Sn*, Sredniy Sukhoy – Sn*Pb*Zn*/Au*As*, Levoberezhnii – Sn*Pb*Zn*/W*Mo*. Plotting of values
obtained has allowed dividing the sectors on weakly eroded (Kumirny and Sredniy Sukhoy) and strongly eroded (Kabaniy and Levoberezhny) zones, with conditionally above-mineralization, mineralization, and under-mineralization horizons.

5. Conclusion
At all sectors besides the Sredniy Sukhoy, the conditionally under-mineralization horizons exhibit gradual increase of productivity that points to the possibility of vertically extending mineralization within the Nizhnetayezhny ore district. Polymetal mineralization in the district is very similar to silver deposits of Mexico, particularly to the Au-Ag deposits of Guanajuato. [8, 9] Metal elements there are concentrated according to the following order: silver – upper horizons, silver with base metals – medium horizons, copper – lower horizons. Summing up, it is suggested to renew geological research in the district to ascertain perceptivity of deeper horizons of the known sectors and to re-evaluate the scope of the Nizhnetayezhny ore district mineralization.

6. References
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