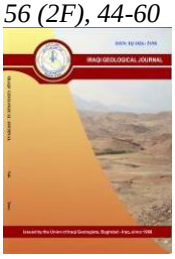
Iraqi Geological Journal

Journal homepage: https://www.igj-iraq.org



Features of the Geological Structure and Polymetallic Mineralization of the Uspensky (Central Kazakhstan) and Dalnegorsky (Far East) Ore Districts

Ainel Yessendossova[1], Volodymyr Mykhailov[2], Aliya Maussymbayeva[1], Vassilii Portnov[1] and Medet Mynbaev[3,*]

[1] Department of Geology and Exploration of Mineral Deposits, Abylkas Saginov Karaganda Technical University, Karaganda, Kazakhstan
[2] Petroleum Geology Department, Taras Shevchenko National University of Kyiv, Kyiv, Ukraine
[3] Department of Geology, Geotek LLP, Karaganda, Kazakhstan
* **Correspondence**: ainelkin@gmail.com

Received:
3 July 2023

Accepted:
29 August 2023

Published:
31 December 2023

Abstract

Polymetallic deposits of lead and zinc are of great importance in the economy of the developed countries of the world. Kazakhstan is among the world leading countries in terms of reserves and production of lead and zinc. There are large ore regions with polymetallic mineralization; these are the deposits of the Atasu and Uspensky ore regions in Central Kazakhstan. The former are genetically related to the final (taphrogenic) phase of the development of the large orogenic structure in the Central Kazakhstan (the Devonian volcano-plutonic belt), with the period of Late Frasnian-Famenian-Early Carboniferous formations of thick carbonate and carbonate-terrigenous sediments, including significant reserves of stratiform lead-zinc ores. Polymetallic mineralization of the Uspensky zone is singled out as an independent genetic Alaygyr type, and the tectonic nature of the ore-bearing Uspensky zone, as well as mineralization of this type, is still the subject of constant discussions. In this regard, the comparative characteristics of the Dalnegorsky and Uspensky ore regions, which have certain similarities in geodynamics, magmatism and metallogeny, are of great importance not only for solving the issues of the general patterns of formation, factors and criteria for controlling lead-zinc mineralization but also for an objective assessment of the ore potential of these and similar areas with polymetallic mineralization. Research methods: comparative analysis of the results of petrographic, chemical and mineralogical studies of ores enclosing near-ore metasomatically altered rocks and intrusions of different age and composition.

Keywords: Lead; Zinc; Factors and criteria of mineralization; Magmatic and metasomatic factors; Volcanic belt

1. Introduction

The main ore-controlling factors of polymetallic mineralization were established, including structural, lithological-stratigraphic, magmatic and metasomatic factors manifested at different stages of the ore matter formation and in different geological and structural conditions. scientific and methodological bases for forecasting and prospecting for lead-zinc deposits in volcanic belts were developed on the basis of established factors and criteria, regularities in the distribution of polymetallic mineralization. the revealed regularities in the formation of polymetallic deposits show their genetic connection with both volcanism and magmatic activity, which makes it possible to use them in geological exploration within the Uspensky belt (Central Kazakhstan) and the Berchogur volcanic-tectonic depression (Western Kazakhstan), volcanogenic-hydrothermal deposits of Subcarpathia (Ukraine). Analyzing the previous studies. For comparison, the Dalnegorsky ore region was selected. It is characterized by a high degree of geological exploration, where an extensive complex of geological surveying, prospecting and exploration and thematic work was carried out. The work of the 1973–1986

DOI: 10.46717/igj.56.2F.3ms-2023-12-9

period was the most productive; based on its materials the State geological maps were prepared for publication with the ore district scale 1:50000 – 1:200000 (Mykhailov and Kostin, 2006; Mykhailov and Feoktistov, 1987). As a result, the main features of the geological structure of the ore region, the patterns of distribution of mineral deposits, the main factors and criteria for endogenous mineralization were clarified. From the point of view of terrane tectonics, the geotectonic position of the DOD (Dalnegorsky ore district) was substantiated in the major monograph. A significant number of works were dealing with consideration of the features of lead-zinc mineralization and characteristics of specific deposits (Ratkin et al., 2016 and 2018; Simanenko and Ratkin, 2008).

The first researchers of the Uspensky ore region (UOD) (Yagovkina and Rusakov 1928–1933) established-the presence of a tectonic zone with which polymetallic mineralization was associated. Comprehensive work in this area began in 1962 under the leadership of K.I. Satpayev, as a result of which the main features of its geological structure and metallogeny were revealed (Shcherba et al., 1968). The conclusions of these authors are based on a huge factual material and have not lost their relevance at the present time.

In the 60-80s of the last century, the entire area of the Uspensky zone was covered by geological surveys with the scale of 1:200,000 - 1:50,000. Huge factual material was collected, but it was considered from the point of view of the geosynclinal theory therefore, the theoretical postulates of those works have currently only historical significance. The study aims to establish the factors and criteria, patterns of placement, formation and localization of polymetallic mineralization based on the comparative analysis of the Dalnegorsky (Far East) and Uspensky (Central Kazakhstan) ore regions.

2. Materials and Methods

The comparative analysis of the results of petrographic, chemical and mineralogical studies of ores enclosing near-ore metasomatically altered rocks and intrusions of different age and composition.

3. Results

Dalnegorsky ore district. Here there are known 15 deposits of polymetallic ores, some of which are being developed. The deposits of the skarn formation predominate (Nikolaevsky, Verkhnee, Svetly Otvod, 1st Sovetsky, Sentyabrsky Otvod, 2nd Sovetsky, Vostochny Partizan, etc.), hydrothermal vein deposits (Malyshevsky, Lidovsky, Novo-Monastyrsky, etc.). The ores contain silver, bismuth, copper, cadmium, indium, sulfur.

The district is located in the Coastal metallogenic zone of the Early Cretaceous Sikhote-Alin orogenic belt of East Asia (Primorye) (Fig. 1), within the Taukha terrane, on which structures of the post-accretionary East Sikhote-Alin volcanic belt (ESAVB) are superimposed.

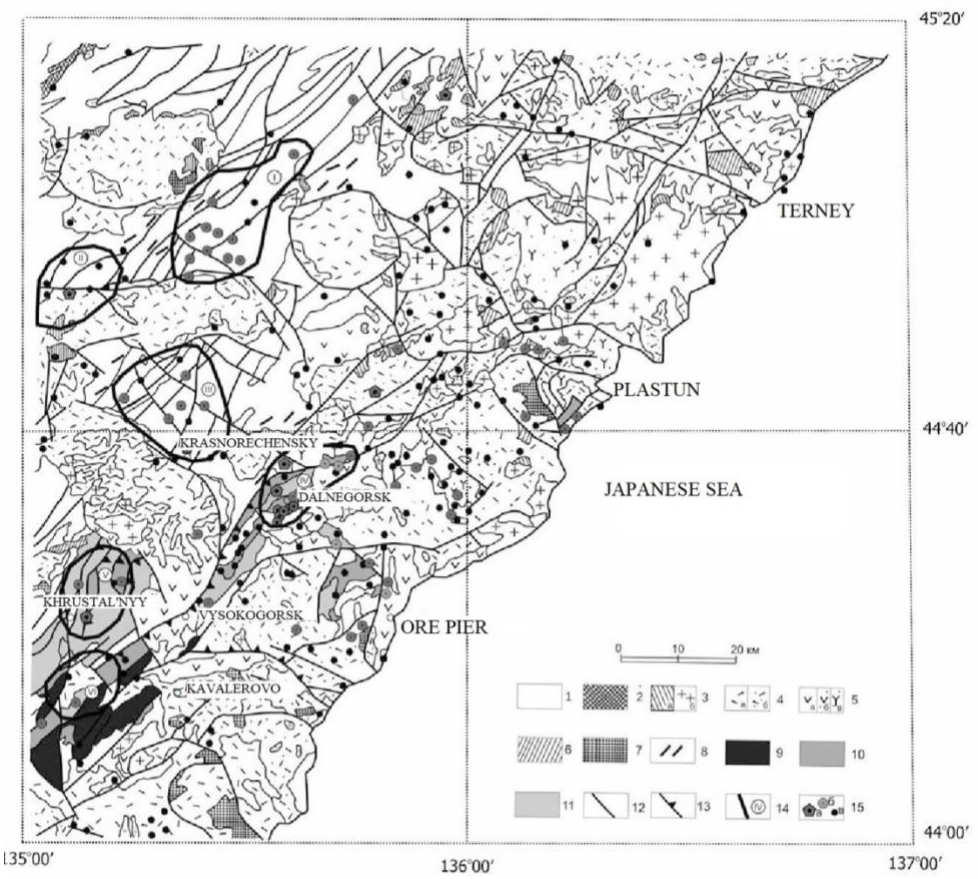


Fig. 1. Scheme of the geological structure of the Dalnegorsky region and adjacent territories (with changes according to (Brezhneva)), 1) Terrigenous rocks of the ESAVB basement; 2–3 – intrusive rocks of the Upper Cretaceous: 2) gabbro of the Bachelaz complex, 3) Primorsky complex (a – quartz diorites, monzonites, diorites; b – granites); 4) Upper Cretaceous rhyolites (a) and rhyolite tuffs (b); 5) subvolcanic and volcanic rocks of the Lower and Upper Cretaceous (a - andesites of the Samarga and Sinancha formations, b - their tuffs, c - volcanic rocks of different composition); 6) Upper Cretaceous subvolcanic andesites and basaltic andesites; 7) Paleogene andesites, dacites, basaltic andesites; 8) Rhyolite dikes (Paleogene); 9–11, accretionary terrigenous-carbonate and siliceous complexes: 9) Permian, 10) Triassic, 11) Jurassic; 12) Discontinuous violations; 13 - Thrusts; 14 - Ore clusters

(I - Oktyabrsky, II - Dalninsky, III - Krasnorechensky, IV - Dalnegorsky, V - Khrustalnensky, VI - Deciduous); 15 - ore objects according to the VSEGEI classification: a - medium deposit, b - small deposit, c - ore occurrence

The lower structural stage is composed of flysch formations of the Lower Cretaceous (Berriasian-Valanginian-Albian) with olistostrome horizons (Berriasian-Valanginian) containing olistoliths and olistoplaks of different sizes (from 1-2 m to 2-3 km) of Permian and Triassic limestones (Tetyukhinskaya series), Triassic–Early Cretaceous siliceous–terrigenous rocks (Gorbushin Group) in the Early Cretaceous flysch matrix (Mykhailov, 1997). These deposits are folded into steep, often isoclinal and overturned folds of northeast strike, broken by numerous multidirectional faults. The formations of the lower structural stage are exposed in the erosion windows among the ESAVB rocks.

The upper structural stage, which lies sharply unconformably on the structures of the lower one, is represented by volcanogenic and volcanogenic-sedimentary formations of the ESAVB, among which tuffs and ignimbrites of rhyolites, rhyodacites, and dacites predominate, andesites are less common. They form a series of volcanic structures (ignimbrite fields, calderas, volcanic depressions). Subvolcanic

and intrusive complexes are developed that cut through stratified formations, among which the most important are the intrusions of the multiphase Dalnegorsky complex (quartz monzonites, diorites, gabbrodiorites, granodiorites, quartz diorites, granites, granite-porphyries, aplites), with which the main processes of hydrothermal metasomatism of the DOD are associated: sericitization, greisenization, propilitization, formation of secondary quartzites, argillization, and formation of polymetallic mineralization (Mykhailov, 1989).

The DOD is broken by a network of faults of different ranks, among which submeridional and north-northeast left-hand strike slips prevail, which are components of the global East Asian strike-slip zone (Central Sikhote-Alin, Coastal, East, etc.). They form a complex dynamic system in which the main compressive stress is realized not only in the form of shears, but is also accompanied by thrusts, reverse faults and extensional structures in the form of normal faults and parting systems, weakened zones. The latter are often associated with intrusive massifs, volcanotectonic depressions, zones of increased fracturing, which are structures favorable for the localization of dike belts, zones of metasomatic processing, and endogenous mineralization. It is these structures that determine the structural features of the ore region.

A typical representative of a skarn polymetallic formation can be considered the Nikolaevsky deposit, and of a vein formation the Lidovsky deposit.

The Nikolaevsky deposit is located in the northern part of the Dalnegorsky horst, on its border with the Nikolaevsky volcanogenic structure (Rogulina and Sveshnikova, 2008). The ore bodies of the deposit are controlled by the olistostroma sequence of the Berrias-Valanginian Monomakhovskaya suite with blocks and landslide plates (up to 700 × 1800 m in size) of Triassic limestones, partially in the overlying tuffs of rhyolites of the Arzamazovsky suite of the Primorsky series (Turonian-early Cognac), which also contains limestone blocks Triassic (up to 100-200 m in size), in the exocontact of the multiphase intrusion of the Dalnegorsky complex, in the junction zone of large fault structures of the northeast and northwest directions. The main ore deposits (Vostok-I, Nizhnyaya) are localized along the contacts of limestones with polymictic sedimentary breccias or volcanics, and are also confined to limestone blocks in volcanic rocks.

The main Vostok-1 deposit occurs at the depths of 700–1500 m. It is a cloak-like body with branches (Fig. 2). The deposits are composed of hedenbergite skarns with vein-disseminated sulfide mineralization. The skarn minerals include granite, axinite, and ilvaite. The main ore minerals are sphalerite and galena; minor: pyrrhotite, arsenopyrite, pyrite and chalcopyrite; non-metallic (except skarn): quartz, calcite, chlorite, epidote. Ore mineralization is distributed in the form of nests, veinlets and dissemination, forming vein-disseminated, less often massive ores. The content of lead and zinc varies from fractions to 20-30 %. In addition to them, silver, bismuth, cadmium, indium, sulfur, as well as selenium, tellurium, and germanium are present in increased quantities.

The Nizhnyaya deposit, in the form of a pasty body, is connected with the Vostok-1 deposit and is localized from the side of the lying block of the limestone plate at depths of more than 900 m. In terms of material composition, it is similar to the Vostok-1 deposit but differs in lower concentrations of lead, zinc and tin.

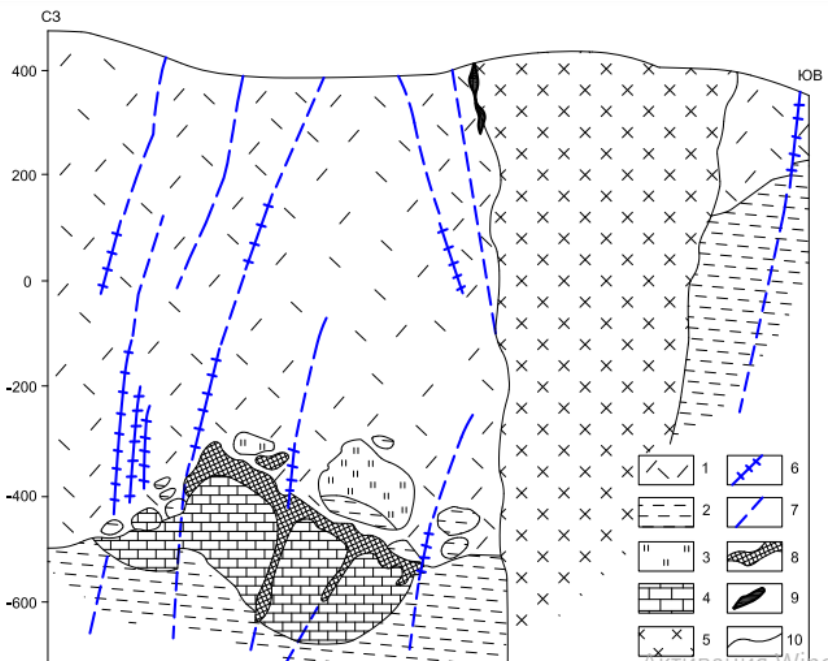


Fig. 2. Scheme of the structure of the Nikolaevsky deposit (Ore deposits…, 1978, as amended by the authors): 1) Rhyolite tuffs of the Arzamazov Formation; 2). Olistostromic unit of the Monomakh Formation; 3) Siliceous-terrigenous rocks of the Gorbushinskaya series; 4) limestones of the Tetyukhinskaya series; 5) granodiorites of the Dalnegorsky complex; 6) diabase dikes; 7) faults; 8) skarn-polymetallic ore bodies; 9) quartz-sulfide vein bodies; 10) geological boundaries

Five ore bodies 100–500 m in size are known in limestone blocks in volcanic rocks transformed by metasomatism into mineralized hedenbergite skarns. Their mineral composition is similar to the ores of the main deposit. The ores of the deposit are characterized by disseminated, spotty (nested), massive, less often breccia texture, crystalline-granular structure, sometimes there are structures of substitution, cataclasis, and decomposition of solid solutions. The deposit belongs to the skarn lead-zinc formation, infiltration type (Awadh and Nejbert, 2016); Nikolaevsky field, 2021).

The Lidovsky deposit is located in the northeastern part of the Monomakhovsky horst. It is localized in Early Cretaceous terrigenous rocks overlain in the north and east by Upper Cretaceous volcanics. In the central part of the ore field, a stock-like intrusion of granodiorites is localized, surrounded by a zonal halo: cordierite-bearing hornfelses – biotitized – propylitized rocks. Ore bodies are localized in the field of hornfelsed and biotitized rocks in the junction zone of the submeridional strike-slip and northwest strike-slip fault within the anticlinal fold of northeast orientation, spreading into granodiorites.

There are known more than 50 veins and mineralized zones. Ore bodies are represented by veins of variable thickness, which are replaced by crushing zones in some areas. They are confined to gently dipping (20–45°) to the south-southeast cracks, which opened slightly under conditions of northwestern compression and left-lateral displacements. They are often complicated by steeply dipping submeridional strike-slips and overthrusts.

The veins are composed of banded, massive and disseminated ores, the main minerals of which are sphalerite, galena, pyrrhotite, quartz, calcite; pyrite, chalcopyrite, stannin, cassiterite, fahlore, and chlorite are noted. The content of metals in rich ores in terms of the sum of lead and zinc reaches 40–48 %, the ores contain silver, indium, bismuth, cadmium, sometimes with a high content of tin (up to 1 %), and disseminated molybdenite is noted in granodiorites. The deposit belongs to the hydrothermal type, vein polymetallic formation.

Mineralization control factors of *DOD*. The intensive ore load of the DOD is caused by a favorable combination of the multilevel system of metallogenic factors controlling mineralization: structural, igneous, metasomatic, lithological and stratigraphic ones.

Regional factors include the ore region position in the general tectonic structure of the region, geodynamic, paleotectonic and paleovolcanological conditions for the formation of metallogenic igneous associations, volcanic and deformation tectonic structures. The DOD is located in the Coastal (Taukha) metallogenic zone that coincides with the terrane of the same name, which includes large limestone olistoliths and olistoplacs, favorable for the widespread manifestation of skarning processes. The basement structures are overlain by the ESAVB structures, which consist of complexly built volcanic and intrusive complexes, among which the Dalnegorsk multiphase intrusive complex has the most important metallogenic significance. An important role is also played by the presence of a surface of structural unconformity at the base of the ESAVB, which often determines localization and structural and morphological types of ore bodies close to the reservoir ones. The location of the DOD within the East Asian shear zone determined the leading role of the dynamics of shear formation in the formation of both the general structure of the region and specific, including ore-controlling, deformation structures of all the ranks.

Structural factors that control mineralization are manifested at all the levels of the ore-magmatic process organization. The most important of them are ore-controlling faults of the highest, the I, II rank and the ore-bearing faults of the III rank. The faults of the highest rank include structural sutures (Coastal, Eastern, Central faults) limiting terranes and metallogenic zones. The faults of rank I control the placement of ore zones and nodes, horst-like protrusions and anticlinor structures of the basement, volcanic structures and intrusions of the ESAVB. These include submeridional and northeastern shears and transverse extensional structures, the occurrence of which is due to the dynamics of shear formation. The ore-controlling faults of rank II include faults, in the zones of influence of which there are located ore fields of deposits. Among them, the zones of intersection of differently directed faults are especially favorable. The ore-bearing faults of rank III directly control the placement of ore bodies.

Among the magmatic factors, the most important is the ore-bearing Dalnegorsky complex, with which a genetic relationship has been established for both skarn-polymetallic and vein mineralization. The role of metasomatic factors is manifested in the confinement of endogenous mineralization to fields of metasomatically altered rocks: skarns, propylites, quartzites, quartz-sericite-hydromicaceous facies, greisens. Lithological and stratigraphic factors are of the key importance for the control of skarn-type polymetallic mineralization. The close connection of skarn deposits with limestone bodies is caused by the favorable chemical properties of the latter, namely, high reactivity to separation of ore-bearing solutions and precipitation of useful components. All the deposits of this type in the DOD are associated with carbonate and carbonate-bearing deposits of the Triassic and Berriasian-Valanginian age.

In Ukraine, lead-zinc ores are known in the southeastern part of the Dnieper-Donetsk depression and in Transcarpathia, where the State balance of mineral reserves of Ukraine takes into account the reserves of Beregovsky, Muzheevsky, Bigansky complex deposits, as of 01.01.2020, the extraction of barite ores with associated extraction of polymetals and silver).

The Carpathian metallogenic province includes the Transcarpathian inner trough, the folded Carpathians, and the Carpathian foredeep. Within its limits, the bulk of hydrothermal deposits and promising ore occurrences of lead and zinc are localized in the Transcarpathian inner trough and are associated with alpine volcanism of andesite-rhyolite formation.

Complex gold-polymetallic deposits associated with Neogene volcanism are known in the frame of the Pannonian massif not only in Ukraine, but also in Romania (ore areas of Baia de Aries, Sekarimb and Brad) and in Slovakia (ore areas of Kremnica and Pukanets). All objects have a number of similar features (Fig. 3): a two-tier structure with an effusive-sedimentary or carbonate-terrigenous pre-Neogene basement overlain by Neogene andesite-rhyolite volcanic rocks, with numerous extrusions,

necks, vents, subvolcanic often control the placement of ore bodies (Mazari, Ha-nesh, Baia-Sprie, Herzha, Valnia-Roshie, Nagiag in Romania); regurgitation zonality with internal zones with Cu-Pb-Zn mineralization and external zones with Au-Ag; vertical length of the structure up to 500-800 m (Apusene, Baia-Sprie, Rochea-Montana); ore bodies are represented by low-sulfide quartz and quartz-adular veins, quartz breccias, kaolinite-quartz vein-disseminated zones located in systems of ore-bearing cracks in detached, propylitized and pyritized rocks. They belong to the gold-adularia-quartz-chalcedony shallow formation, characterized by high silver content (Au:Ag - 1:3) and relatively low fineness of gold (600–800).

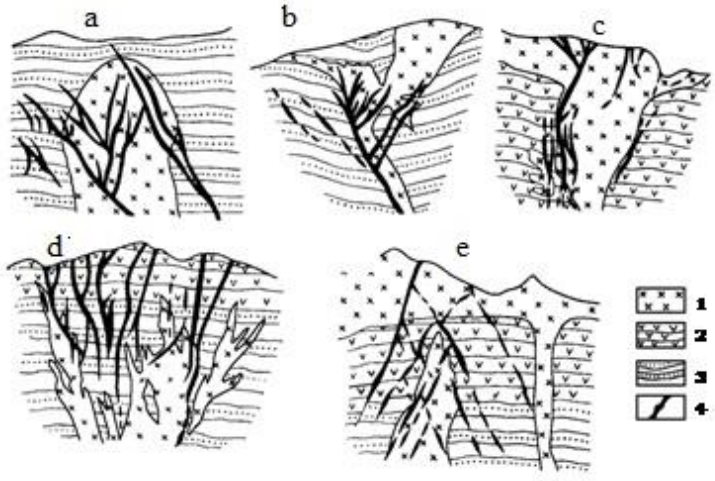


Fig. 3. Schemes of the structure of gold-polymetallic deposits in Romania (Mykhailov, Fedchuk, 2008)
Deposits: a - Mazari, b - Hanesh, c - Baia-Sprie, d - Kherzha, e - Valeya-Roche
1 - Subvolcanic bodies of acidic and intermediate composition; 2 – containing volcanic (a) and sedimentary (b) rocks; 3 - ore bodies

Thus, in the Stiavnica-Godrush ore field in Central Slovakia, the inner zone (Stiavnica) is represented by veins of a polymetallic (Cu, Pb, Zn) formation located in Neogene andesites, as well as vein-disseminated hydrothermal-metasomatic ore ore zones, and the outer zone (Godrush) - silver-gold zone. Gold-bearing, often with silver and stibnite, quartz veins are also widespread in the ore fields of Kremnica, Novaya Banya, Pukanec in Central Slovakia.

The Beregovsky ore district is located in the southern part of the Transcarpathian region in the northeast of the Danube lowland (Fig. 4). The area of the ore region coincides with the Beregovsky highlands, which are low volcanic insular mountains in the middle of the plain. The modern structure of the area is due to tectonic movements that took place in the Pliocene during the formation of the Great Hungarian Basin and the horst zone. In the region, the rocks of the pre-Neogene basement (Paleozoic phylites, limestones and Triassurian limestones, diabases, jaspers) were discovered by drilling. The Neogene is represented by a sedimentary-volcanogenic stratum, consisting of alternating horizons of rhyolitic tuffs and sandy-argillaceous rocks.

Factors of control of the mining of the Beregovsky ore district. The ore load of the Beregovsky ore district is due to a favorable combination of a multilevel system of metallogenic factors controlling the mineralization: structural, lithological-stratigraphic, igneous, metasomatic, manifested at different levels of organization of the ore substance. General metallogenic factors include the position of the ore region in the general tectonic structure of the region, geodynamic, paleotectonic and paleovolcanological settings for the formation of metallogenic igneous associations, volcanic and deformation tectonic structures.

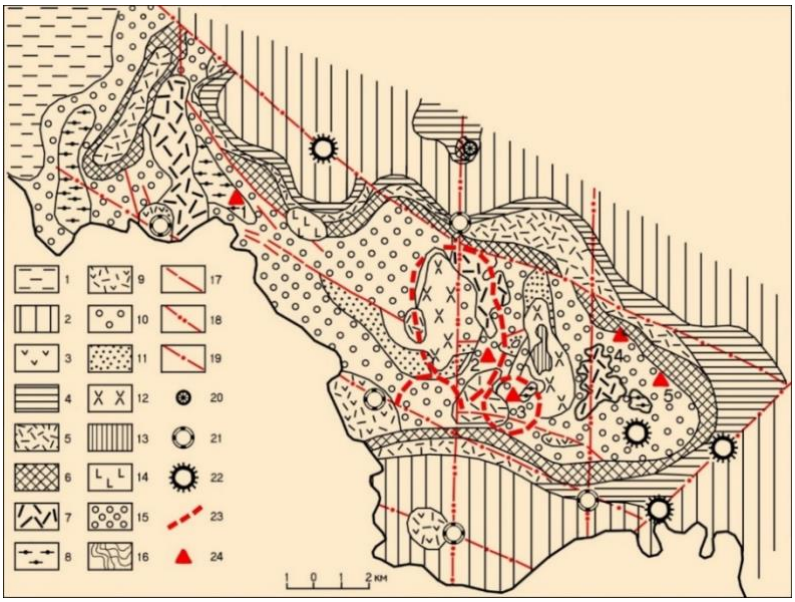


Fig. 4. Geological map of the Beregovsky ore region (1) Clays, sands of the L'nitskaya Formation of the Levantin; 2) Clays with i nterlayers of sandstones of the Kozhelevskaya and Izovskaya worlds of the Pannonian; 3) Pliocene andesites; 4) Clays, sands, marls of the Almas Formation of the Middle Sarmatian; (5–6) tuffs (5) and mudstones (6) of the Lukovo Formation of the Lower Sarmatian; 7) Rhyolites; 8) Ignimbrites; 9) Benches and tuffs of andesites and rhyolites; 10) upper tuff horizon of the Lower Sarmatian; 11) Upper sedimentary sequence of the Lower Sarmatian; 12) Medium tuff horizon of medium baden; 13) Lower sedimentary sequence of the Helvetian and lower badenia; 14) Lower tuff horizon of the Carpathian; 15) Conglomerates and gravelstones of the Burkalovskaya Formation; 16) Folds; 17–19) faults controlling manifestations of rhyolitic volcanism (17) Andesitic volcanism (18) Through (19); 20–22 – andesitic 20) Mixed composition 21) Rhyolitic 22) Volcanoes; 23(Calderas; 24) Deposits and ore occurrences (1 - Biganskoe, 2 - Beregovskoe, 3 - Muzheevskoe, 4 - Loposskoe, 5 - Kvasovskoe)

The Beregovsky ore region is located on the outskirts of the Pannonian median massif, on the border with the Folded Carpathians, from which it is separated by a deep Transcarpathian fault. Its activation in the Neogene led to the formation of two large volcanic structures: the Beregovo Upland, composed mainly of felsic volcanic rocks, and the Vygorlato-Gutinskaya ridge, composed predominantly of intermediate and basic volcanic rocks.

Structural factors of equipment control are manifested at all levels of the organization of the ore-magmatic process. The most important of them are the ore-controlling faults of the highest, I, II rank and the ore-bearing faults of the III rank. The faults of the highest rank include the Transcarpathian deep fault, which separates the Folded Carpathians and the Pannonian massif. Faults of the 1st rank control the location of the volcano-structures of the Beregovsky Highlands and the Vygorlat-Gutinskaya ridge. Ore-controlling faults of rank II include faults, in the impact zones of which ore fields of deposits are located. Among them, the zones of intersection of differently directed faults are especially favorable. Ore-bearing faults of III rank directly control the placement of ore bodies.

Lithological-stratigraphic and magmatic factors are manifested in the confinement of subsidence to the volcano-structures of the Beregovsky Highlands, composed of Neogene volcanic rocks of acid composition.

The role of metasomatic factors is manifested in the confinement of endogenous subsidence to fields of metasomatically altered rocks, among which the formation of low-temperature secondary quartzites and argilizites of zonal structure predominates, which determines the zonal distribution of ore

formations with confinement of gold tools. personal - to the lower zones of albite-quartz and adularia-quartz metasomatites.

The Uspensky ore district is located in the eastern part of Central Kazakhstan, within the Altai and Transbaikal-Mongolian orogenic collage or the Central Asian Orogenic Belt (CAOB) (Fig. 5). According to modern concepts, this giant structure is a long-lived accretionary orogenic collage that developed from the end of the Mesoproterozoic to the Mesozoic through the accretion of magmatic arcs, ophiolite plates, microcontinents, and accretionary wedges (Seltmann and Porter, 2005).

The collage consists of fragments of sedimentary basins, island arcs, accretionary wedges, and tectonically bounded terranes composed of Neoproterozoic and Paleozoic rocks that arose as a result of subduction, collision, transcurant movements, and other tectonic processes.

The UOD is located within the Balkhash-Ili belt of the Middle-Late Paleozoic Kazakh-Mongolian arc of the CAOB, which includes sedimentary sequences, arc volcanic and intrusive rocks of predominantly Devonian and Carboniferous age, deformed during the Permian Hercynian orogeny.

Structurally, the region belongs to the system of the Central Kazakhstan Hercynian folded belt of east-northeast strike. The main regional structures here are large anticlinoria Tekturmasky in the north, which is a ledge of the oceanic type of crust, and Zhaman-Sarysusky in the south, composed mainly of green-colored Silurian-Middle Devonian deposits. Between them there is a narrow and strongly compressed Uspensky synclinorium, which contains mainly Late Devonian and Early Carboniferous terrigenous and volcanogenic-sedimentary deposits, overlying Silurian-Middle Devonian terrigenous formations similar to those developed in the Zhaman-Sarysu anticlinorium, which emphasizes the structural and facies unity of the existing on them the place of a single trough with a submarine character of sedimentation. The Givetian stage is facies variable, in some sections it is variegated and red-colored conglomerates, sandstones and siltstones, at the base of which horizons of volcanic conglomerates, lavas and ignimbrites of felsic composition are isolated, in others green-colored terrigenous formations. The overlying volcanogenic formations of the Frankian Stage, the Ortau Formation are composed of andesites, andesite-basalts, dacites and their tuffs, 200 to 600 m thick, and the Tastau Formation is represented by tuffs, ignimbrites, rhyolite tuffs, red-colored conglomerates, tuff sandstones, 350 to 1200 m thick. They compose an arcuate band, which is considered as “a structure of the type of secondary island arcs (Lyapichev and Shuzhanov et al., 1977). The overlying Famennian-Early Tournaian marine volcanogenic-carbonate formation plays a decisive role in the metallogeny of polymetals. The formation is characterized by a correlation in folded dislocations between the thicknesses of the Frank Famennian volcanic formations and the Famen-Tournaisian volcanic-carbonate ones. So, if the former in synclines have the thickness of 2000–3000 m, then they correspond to the increased thicknesses (up to 1000–1300 m) of the latter. In the horst anticlines, the Zhite-Franca thicknesses are reduced to 700–1600 m, and the corresponding thicknesses of the Famenna-Turnais are reduced to 300–400 m. Analyzing the thicknesses indicates the unity of their accumulation areas. Deep faults of the pre-Givet origin predetermined the tectonic plan of the territory, dividing it into stable areas of uplifts (horst anticlines) and subsidence (graben synclines). This suggests that the Uspensky zone as a tectonic structure of long development was formed in the Givetian time (Shcherba et al., 1968).

Early-Middle Visean formations are represented by a sequence of carbonaceous siltstones, sandstones and tuffs, occurring conformably on Tournaisian limestones.

The Upper Visean-Serpukhov deposits are identified as the Karkaraly Formation (C1 v3-s), which unconformably rests on older rocks. It is composed of terrestrial volcanic rocks of basalt, andesitic, dunite and rhyolite compositions, with horizons of conglomerates and sandstones, fills paleorelief depressions and marks the beginning of volcanic activity within the Kainda volcanic arc located to the east.

.

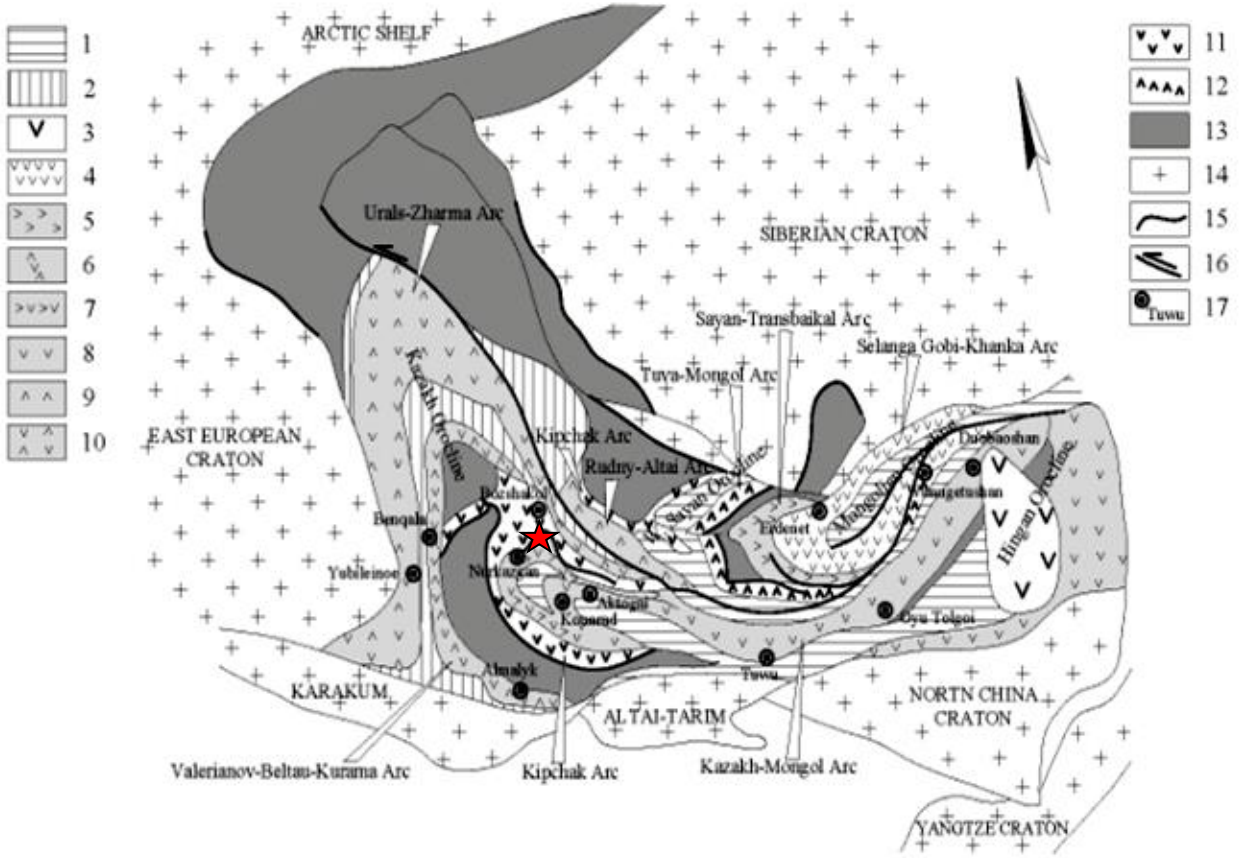


Fig. 5. Schematic tectonic map of the Altai and Trans-Baikal-Mongolian orogenic collage (Seltmann and Porter, 2005): 1) Undifferentiated Proterozoic to Mesozoic accretionary complexes, 2) Accretionary complexes in sutured back- arc and intr-arc basins, 3) Late-Mesozoic Yanshanian magmatism, 4) Late-Palaeozoic to Middle-Mesozoic Selanga-Gobi-Khanka magmatic arc, 5) Mid-to Late-Palaeozoic Sayan-Transbaikal arc, 6) Mid-to Late-Palaeozoic Valerianov- Beltau-Kurama arc, 7) Mid-to Late-Palaeozoic Kazakh-Mongol Arc-Silurian to Devonian segment, 8) Mid-to Late-Palaeozoic Kazakh-Mongol Arc–undifferentiated, 9) Mid-Palaeozoic Rudny-Altai Arc, 10) Mid-Palaeozoic Urals-Zharma Arc, 11) Late Neoproterozoic to Lower-Palaeozoic Kipchak Arc, 12) Late Neoproterozoic to Lower-Palaeozoic Tuva-Mongol arc, 13) Proterozoic pre-Uralides and pre-Baikalides, 14) Precambrian cratons and micro-continents, 15) Suture zone,16) Major strike-slip fault, 17) Porphyry Cu-Au/Mo deposit, The red asterisk indicates the Alaigyr field

The northern part of the Uspensky synclinorium and the adjacent southern part of the Tekturmas anticlinorium are intruded by numerous granitoid intrusions, among which the Middle Carboniferous intrusions of the Topar complex predominate, forming the Kaldyrma intrusive belt in the form of a strip more than 200 km long and about 30 km wide. The absolute age (K/Ar) is from 325 to 340 Ma, which corresponds to the middle section of the Carboniferous system. The complex is represented by a series of gabbro-gabbro-diorites-diorites-granodiorites-granites. Granites (third phase according to (Bekzhanov et al., 2000) are porphyritic, medium-grained with porphyroblasts of potassium feldspar (up to 5 cm) and plagioclase (up to 3 cm). They have a distinct geochemical specialization in lead (Shcherba et al., 1968), and some increase in the content of lead during magma crystallization is noted. Chemical analyzes of 32 samples show that lead is permanently fixed in granites, its content is 0.01–0.03 %, less often 0.03–0.04 %.

The complex plays the decisive role in the polymetallic metallogeny of the structure. In the south, parallel to the granite belt, within the Uspensky synclinorium in the east-northeast direction, there is a

regional zone of dislocations and metamorphism known as the Uspensky zone of deep faults, which determines the structural plan of the region. It divides it into stable linear graben synclines and horst anticlines. The formation of this structure occurred in the Givetian time, it was repeatedly updated in the subsequent stages of tectogenesis, which allows us to consider it as a structure of long development.

In terms of quantity, diversity and industrial value of deposits, the UOD is one of the most important ore districts of Kazakhstan (Baibatsha, 2008; Parilov, 2012). It is known that one of the important structural elements of the earth's crust are deep mobile zones that are manifested as activation zones, which determine the development of sedimentary facies, folded belts, control the placement of magmatism and associated mineralization. Among such zones in Central Kazakhstan there is the Uspensky zone that is confined to the UOD. It is traced in the northeast direction from the Atasu ore region in the west. Its eastern continuation (Shcherba et al., 1968) is the Kainda zone traced along thick shear zones to the Karagaily deposit. The authors consider the Kainda zone as the rear part of a fragment of the Carboniferous–Permian volcanic arc that moved along the systems of regional meridional subparallel faults to the north. In this regard, the paper considers only the Uspensky zone, conditionally limited in the east by the area of allochthonous volcanic facies of the Carboniferous-Permian period of volcanism.

In the UOD, the most important ore-controlling role is played by cracks associated with deep faults, which in the upper horizons correspond to the boundaries of local horst anticlines and graben synclines, flexural folds, and other plicative structures. The linear nature of the cracks determined the ribbon-like shape of the ore deposits located above them. The ore bodies are confined to linearly elongated folded elements: fold limbs, flexure bend, etc.

The maximum number of ore occurrences was recorded in sedimentary and volcanic-sedimentary rocks of the Famennian-Early Tournaisian formation. Below and above the section, there are mainly small ore occurrences, mainly of the quartz-vein type.

In the Uspensky ore district, numerous ore objects of the same ore formations as within the DOD are widely developed, namely, of the lead-zinc skarn and lead volcanogenic-hydrothermal vein polymetallic formation. Stratiform (sedimentary) objects (Alabuga) are developed in the Famennian-Tournaisian volcanogenic-carbonate formation in the form of small manifestations and do not form industrial objects.

Polymetallic deposits of the skarn formation: Samombet Yuzhny, and others are controlled by the areas of developing carbonate-terrigenous stratified Famennian-tourne facies cut through by bodies of granitoids of the Topar intrusive complex. Usually they form a series of manifestations, small in terms of reserves, and their industrial significance is not great.

Lead volcanogenic-hydrothermal vein polymetallic formation that includes 11 deposits, among them the Alaigyr deposit, which is large. They are localized mainly in rhyolites and their tuffs of the Givetian-Frankian stage, controlled by steeply dipping crushing zones in the crests of anticlinal or volcano-dome folds of II and III orders. The presence of zones of silicified and sericitized rocks is typical. The shape of the ore bodies is steeply dipping, less often gently sloping lenses in crushing zones. A widespread ore mineral is galena associated with quartz. The other sulfides (sphalerite, chalcopyrite, pyrite) occur in sharply subordinate amounts.

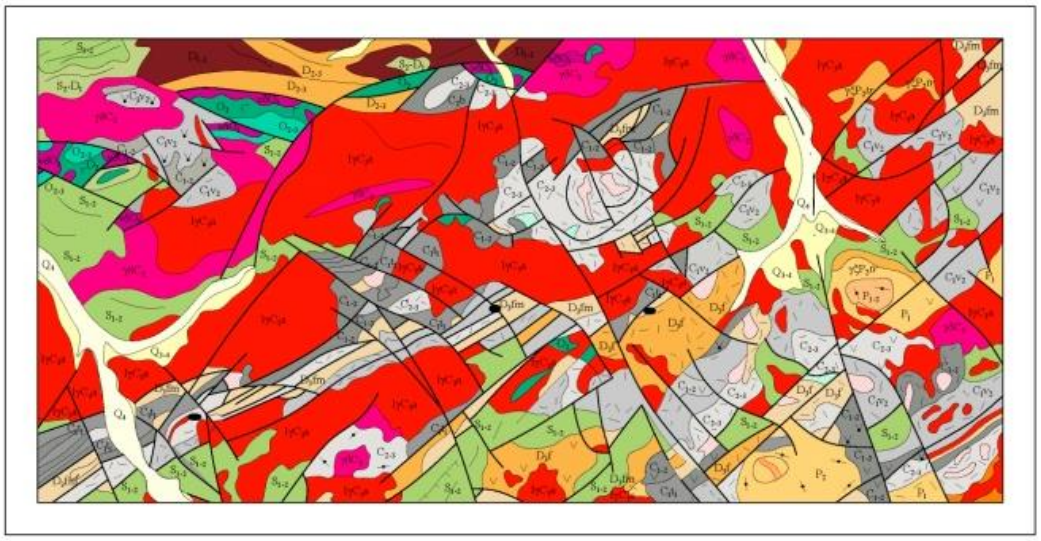


Fig. 6. Overview geological map of the work area, scale 1:1,000,000 (Bekzhanov, 2000)

The Alaigyr deposit is the largest polymetallic object within the Uspenskaya tectonic zone. The main structure of the ore field is a compressed sublatitudinal brachi-anticlinal fold. The subvolcanic rhyolite body, which controls lead mineralization, is located in the northern flank of this structure. Within the deposit, the rocks have a monoclinal occurrence with a dip to the north and northwest, complicated by folds of a higher order.

The ore field of the deposit is composed of the Devonian effusive-pyroclastic sequence (D2-D3). In the complex of volcanic-sedimentary rocks of the Famenn, dike-like bodies of subvolcanic rhyolites are distinguished, occupying a conformable and secant position. Small dikes of porphyrites are known. In the immediate vicinity of the deposit there are two large granite massifs. The deposit is localized in a subvolcanic body of rhyolites. Since ore mineralization has breaks along the strike, the deposit is conditionally divided into three sections: Western, Middle, and East ones (Fig. 7).

The most ancient faults complicating the folded structure are concordant longitudinal (sublatitudinal) faults such as overthrusts or interstratal failures. Close to them in type are the systems of longitudinal in-situ zones of crushing and fracturing in the subvolcanic body of rhyolites. The younger are fault-slip faults of northeastern and northwestern strike, which are associated with diorite and diabase dikes.

Intrusive formations are represented by Hercynian granitoids with subordinate development of intermediate and mafic intrusions. There are three stages of intrusive magmatism. Early Hercynian intrusions are represented by small mafic massifs in the southwestern part of the deposit, composed of coarse- and medium-grained gabbro-diorites, granodiorites, and quartz diorites; Middle Hercynian intrusions include diorites, quartz porphyries, and granodiorites forming small stock-like massifs. The most widely developed in the area are massifs of leucocratic fine- and medium-grained granites and granite-porphyries, biotite and biotite-hornblende granites of the Topar complex, which cut through the entire Paleozoic volcanogenic-sedimentary sequence, often they are confined to the zone of the submeridional Uspensky fault.

Formation of the deposit is conventionally divided into three stages (Parilov, 2012). In the first, pre-ore stage there were widely manifested near-ore metasomatic changes in effusive rocks: sericitization, silicification, carbonatization, chloritization, baritization and albitization. The process of pre-ore alteration was carried out due to autometasomatization of subvolcanic facies rhyolites occurring in the form of a continuous strip along the zones of tectonic faults. Sericitization, silicification,

pyritization, K-feldspathization, chloritization, and carbonatization manifested themselves in the pre-ore stage. Of main interest are the changes associated with the pre-ore and ore stages since they characterize the specifics of the ore formation process at the deposit. On the surface, these rocks were still subjected to hypergene alteration, which was reduced mainly to their clarification in the immediate vicinity of the ore bodies, with the formation of light gray, whitish gray and yellowish gray rocks.

Changes in the pre-ore stage. The nature of the neoformations, the high degree of their crushing (during the period of intense deformation), the absence of low-temperature vein minerals in their composition, etc. made it possible to attribute this group of alterations to the early, pre-ore, stage of the hydrothermal stage.

Sericitization is one of the most common processes and is controlled by tectonic faults in the northwest and northeast directions. Due to the homogeneity of the original rocks, sericitization areas acquire a vein-like shape, being located in the form of more or less symmetrical bands along the ore bodies. The width of these bands depends on the degree of fracturing and ranges from 8-10 to 80–100 m. At the same time, rather abrupt transitions along the strike of intensely sericitized areas into slightly altered ones are noted.

The intensity of the process decreased in the immediate vicinity of the ore bodies, and thus the confinement of mineralization to areas of relatively weak sericitization is noted. This is due to the subsequent metasomatic replacement of part of the sericite by later minerals (quartz, sulfides, etc.).

The silicification has a metasomatic and veinlet character with rather irregular thickness along the strike, from 7–10 to 60–80 m. The degree of silicification of the rocks is very different, from weak, imperceptible macroscopically, to the formation of quartzite-like rocks. The most silicified areas clearly reflect the contours of the ore zones.

Chloritization is closely related to the processes of sericitization and silicification and is poorly developed at the deposit. Areas of chlorite-bearing rocks (mainly tuffs) are isolated in the form of narrow discontinuous bands at a considerable distance from the ore bodies, confined to areas of sericitization. In places, the development of rare chlorite veinlets is noted in close proximity to the ore bodies.

Orthoclasization. Among the bulk of quartz porphyries there are small (0.5 mm and rarely more) lenticular areas with a clear spherulitic structure. Measurements of optical constants showed that these formations belong to the orthoclase subgroup (Ng = 1.528, Np = 1.520, Ng - Np = 0.008, 2V = 60°).

Pyritization of 1 into the pre-ore stage manifested itself relatively weakly (about 1.5-2% of the rock volume), but over a large area. Pyrite of this stage forms a finely dispersed dissemination of the smallest euhedral and cubic grains ranging in size from 0.005 to 0.1 mm, rarely 1-2 mm. Occasionally, pyrite forms small nest-like accumulations, developing mainly along the groundmass of the rock, sometimes in the form of a rim around quartz and feldspar phenocrysts. Areas of development of pre-ore pyritization approximately coincide with areas of pre-ore silicification of host rocks.

The extremely fine dispersion of pyrite at this stage suggests that it was formed in situ due to ilmenite and magnetite, which pigment quartz porphyries and their tuffs (pyrite is closely associated with rutile and leucoxene everywhere).

Carbonatization is most intense in quartz porphyry tuffs. It is also widely developed in the quartz porphyries themselves. Areas of carbonatized rocks can be traced for considerable distances along the vertical, while along the strike such rocks quickly wedge out already over 30–40 m. The main newly formed mineral is calcite, which metasomatically developed along the groundmass of the rocks and less often in the form of veinlets.

Thus, pre-ore changes are characterized by the widest development and intensity of manifestation. They proceeded in close connection with each other and in a certain sequence. This is due to the appearance of zoning in the distribution of altered rocks.

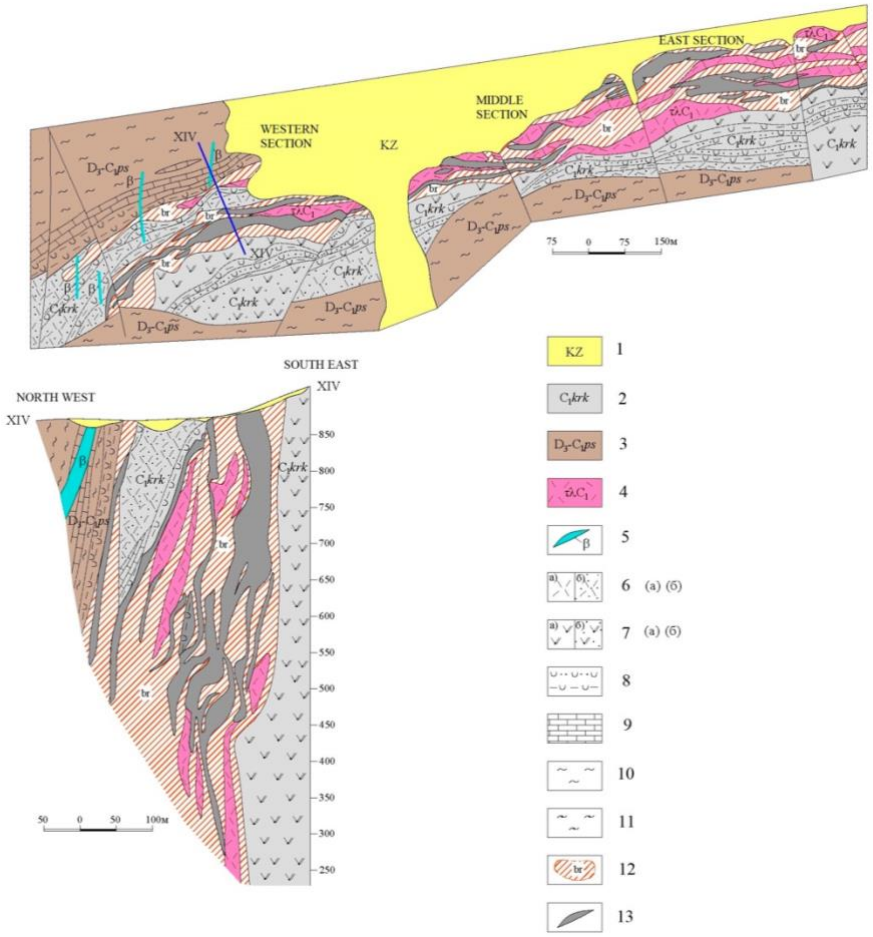


Fig. 7. Schematic geological plan of the Alaigyr field and the geological section of the western area (according to Medvedev)

1) Undivided Cenozoic deposits: loam with rubble; 2) Karkaraly Formation: trachyandesidacites, rhyodacites, rhyolites and their tuffs, volcanomictic sandstones and siltstones; 3) posidonian formation: calcareous shales, pelitomorphic limestones, 4) Subvolcanic formations: trachyorhyolites; 5) Diabase and rhyolite dikes; 6) Rhyolites (a) Rhyolite tuffs (b) 7) Trachyandesidacites (a), their tuffs (b); 8) Volcanic sandstones and siltstones; 9) Limestones, siltstones, calcareous sandstones; 10) Calcareous-argillaceous and carbonaceous-argillaceous shales; 11) Carbonaceous shales; 12) Metasomatites, sericite-quartz beresites after felsic volcanics, predominantly subvolcanic; 13) Ore bodies

Ores of the second stage are vein-disseminated and disseminated, have all the signs of a typical hydrothermal metasomatic formation. Ore deposition, according to decriptation data (Parilov, 2012), originated from hydrothermal fluids at the temperature of 470–490 °C. The main mineral, galena, is present as inclusions, less often as thin veins in cracks. In places, together with sphalerite, pyrite, calcite, and barite, galena forms small clusters of solid ores.

At the third, final stage of the ore process, there occur pyrite-sericite, carbonate and barite veinlets, forming a continuous strip along the ore bodies and cataclase zones with the thickness of 15–20 to 80–100 m. The processes differ in the widest development and intensity. sericitization, silicification, pyritization and K-feldspathization, to a lesser extent in chloritization, baritization and albitization; the last three occur locally, near ore bodies, crushing and shearing zones.

The main ore minerals are sphalerite and galena, of non-metallic minerals there is calcite, barite and quartz. Pyrite is a minor mineral and occurs mainly in the quartz-carbonate association. The most

common impurity elements are cadmium and silver, there are mercury, antimony, arsenic, gold, germanium, thallium, etc.

The main zone gravitates toward the footwall of the rhyolites. Closer to the hanging side, parallel to it, there is the Northern ore zone. It is separated from the Southern lenticular layers of tuffs and carbonate rocks. Near the lying side, especially at deep horizons, there are noted unseasoned, often blind ore bodies (Western site). Throughout the entire length, the ore bodies are arranged in the echelon-like manner, grouped into parallel zones, in some places contiguous, in the other places diverging. The ore-bearing band in rhyolites is about 3 km long.

Oxidized ores (25.5 % of reserves) are mainly composed of cerussite. The depth of the oxidation zone varies from 50 m to 220 m, reaching maximum values in the central part of the deposit. The oxidized zone is characterized by intensive development of cerusite and a subordinate amount of anglesite. Galena occurs as relic segregations and small particles in cerussite.

The genetic link of mineralization with a certain igneous complex was convincingly substantiated (Puchkov, 1986). According to his data, the time of mineralization is close to the time of intrusion of "ore-bearing" rhyolites, so, according to the lead-isotope studies, the modal age of ore lead is 250–300 Ma. According to K/Ar dating of biotites and sericites, the age of rhyolites is 320 Ma, which corresponds to the middle section of the Carboniferous system. Based on this, the age of the ores corresponds to the interval from the Middle Age of the Carboniferous system to the Late Permian. Thus, the formation of the deposit is close in modal age to the granitoids of the Topar intrusive complex. Mineral formation at the deposit was high-temperature hydrothermal-metasomatic (Parilov, 2012).

5. Conclusions

Despite general similarity of the geodynamic development of the Dalnegorsky and Uspensky ore districts, lithofacies, folded and disjunctive dislocations, the evolution of magmatism and the development of similar ore formations, the structures differ in the degree of ore saturation. Thus, the DOD contains a significantly larger number of skarn-type deposits than the UOD, where this formation is expressed only by small scattered manifestations. In this case, for the purposes of forecasting, it is not the fixation of signs of their similarity (search signs and criteria) that matters but the establishment of their differences in the structure, tectonics, magmatism, which determine the scale of ore accumulations.

The main defining difference in the structure of the ore districts lies in the different lithofacies characters of the volcanic belt base structure. Thus, in the Dalnegorsky ore district, volcanogenic formations are underlain by flysch formations of the Early Cretaceous (Berrias-Valanginian - Albian) with horizons of olistostrome (Berrias-Valanginian), Permian and Triassic limestones (Tetyukhinskaya series), to which deposits of skarn polymetals are associated at contacts with intrusive type formations. This ensures a deeper, longer and larger-scale thermal impact on the enclosing limestones.

In contrast to the DOD, at the UOD the basement complex is represented by exclusively monotonous terrigenous facies of the shallow-water marginal marine basin of the Silurian-Middle Devonian, containing only thin layers and rare reef banks. This environment is not favorable for the manifestation of skarning processes, and the introduction of intrusions leads only to the formation of hornfelses. In this case, the "favorable environment" arose only during the Famennian-Tournaisian transgression, which led to the formation of a volcanogenic-carbonate formation overlying the volcanogenic formations of the Givetian-Frankish volcanic arc. Thus, extremely unfavorable conditions for the skarning process were formed, since intrusions developed mainly in the underlying structural complexes either outside the UOD (Kaldyrma belt) or in the form of small near-fault bodies along meridional faults.

Deposits of the hydrothermal type of the vein polymetallic formation have similar structural features, structural and tectonic confinement, however, there are a number of differences. So, if the DOD

deposits are complex (lead-zinc), then the Alaigyr deposit is lead-silver, practically without zinc; in addition, there are no significant tin contents in the ores, which are present at the DOD objects. The vein mineralization of the DOD is developed in Early Cretaceous terrigenous rocks overlain in the north and east by Upper Cretaceous volcanic rocks. In the central part of the ore field, a stock-like intrusion of granodiorites is localized; the ore bodies are controlled by fields of hornfelsed and biotitized rocks in the junction zone of the submeridional strike-slip and northwestern strike-slip. At the Alaigyr deposit, mineralization is controlled by a body of subvolcanic intrusion of rhyolites and their tuffs, where it is confined to zones of crushing and increased fracturing. Near-ore hydrothermal-metasomatic changes include sericitization, silicification, carbonatization, chloritization, baritization and albitization. Structural factors of deposit control are deep-seated ore-controlling faults associated with deep active magmatism chambers (possibly plumes) that determine the development of folded belts and associated mineralization.

Thus, for ore districts, the main factors controlling mineralization are structural, igneous, metasomatic and lithological-stratigraphic ones.

The prospects of the Uspensky ore district for the discovery of new industrially significant polymetallic objects are far from being exhausted. Based on the foregoing, further prospecting and metallogenic studies should be focused primarily on the study of the Famen-Tournaisian volcanogenic-carbonate facies in order to identify the most subsided linear synclinal structures, especially those occurring in the supra-perforated zones of the massifs of the Topar complex, or in the development zones of regional submeridional faults that control "near-fault" bodies of granitoids. Particular attention should be paid to the eastern flank of the structure, the area of developing Early-Middle Visean carbonaceous siltstones, sandstones, and Upper Visean-Serpukhov deposits of the Karkaraly Formation (C1 v3-s) composed of an allochthonous sequence of volcanic rocks of basalt, andesitic, dunite and rhyolite compositions, overlying the Famen-Tournaisian volcanogenic-carbonate formation, which makes it very similar to the DOD. In this case, outcrops of carbonate-terrigenous formations in erosion windows among volcanic rocks of the Karkaralinskaya suite with apical protrusions of the Topar complex intrusions will have the greatest prospects.

It is recommended to use the established regularities based on the ore-formational typification of lead-zinc deposits in carbonate deposits of volcano-plutonic belts as scientific and methodological bases for predicting the prospecting of deposits, identifying spatio-temporal and genetic relationships of mineralization with certain formations, facies and rock lithotypes, creation of a geological and genetic model, as a basis for forecasting in other volcanogenic-plutonic belts, for example, the Subcarpathian volcanogenic-hydrothermal deposits (Ukraine), the Zhaksytau caldera of the Berchogur volcanogenic-tectonic depression (Western Kazakhstan), where these predictive criteria were used in assessing the reserves of a series polymetallic manifestations (Tasbulak, Geophysical, South-West).

The recommended conclusions regarding the factors and criteria of polymetallic mineralization can be used as scientific and methodological foundations for forecasting and prospecting for lead-zinc deposits in the other regions of the world. New data of the Alaigyr type of deposits in Kazakhstan make it possible to resolve successfully the issues of the genesis of similar polymetallic deposits in the Uspensky ore district, to show their relationship and patterns of formation in connection with volcanogenic-plutonic activity. These data are undoubtedly important for exploration in the territory of Central Kazakhstan and polymetallic deposits of the world within volcano-plutonic belts of the Devonian and the other age.

Acknowledgements

We present our thanks to the Department of Geology and Exploration of Mineral Deposits of KSTU, JV Alaigyr LLP for supporting our research, data and links.

References

Awadh, S.M. and Nejbert, K., 2016. Polymetallic sulfide ores hosted in Late Permian carbonate at the Alanish locality, northern Iraq: petrography and mineral chemistry. Arabian Journal of Geosciences, 9, 1-15.

Baibatsha, A.B., 2008. Geology of mineral deposits: Textbook. Almaty: KazNTU. 368.

Bekzhanov, G.R., Gilmutdinov G.Kh., 1974. Geology, patterns of placement and localization conditions for non-ferrous metal deposits in Kazakhstan Alma-Ata, 216.

Lyapichev, G.F., Shuzhanov V.M., 1977. Geology of the USSR. Volume XX. Central Kazakhstan. Geological description. Book 1. M., "Nedra". 532.

Mineral Commodity Summaries, 2020. USGS. 200.

Mykhailov, V.A., 1989. Magmatism of volcano-tectonic structures of the East Sikhote-Alin volcanic belt. Vladivostok: FEB AN USSR. 172.

Mykhailov, V.A., 1997. Correlation of tectono-stratigraphic complexes of the southeastern Sikhote-Alin. Stratigraphy. geological correlation. 5(4), 85–94.

Mykhailov, V.A., Feoktistov Yu.M., 1987. State geological map of the USSR, scale 1:50,000. Dalnegorskaya series. Explanatory note. St. Petersburg: VSEGEI.

Mykhailov, V.A., Kostin A.Ya., 2006. State geological map of the Russian Federation, scale 1:200000. Sikhote-Alinskaya series. Sheet L-53-XXVIII (Cheremshany). St. Petersburg: VSEGEI.

Nikolaevskoye field, 2021. The site of the mining and metallurgical complex "Dalpolimetall".

Ore deposits of the USSR, 1978. In 3 volumes. Ed. acad. V. I. Smirnova. Ed. 2nd, rev. and add. V. 2. M.: Nedra. 399.

Parilov, Yu.S., 2012. Genesis of the main types of non-ferrous metal deposits in Kazakhstan (according to the results of the study of fluid inclusions). Almaty. 266.

Puchkov, E.V., Naidenov B.M., 1984. Formirovanie stratiformnykh svintsovo tsinkovykh rud, mestorozhdenii atasuiskogo tipa (Forming stratiform lead-zinc ore deposits of the Atasu type). Sovetskaya geologiya. 1, 33-41.

Ratkin, V.V., Simanenko L.F., Eliseeva O.A., 2018. Microfacies and mineral associations of silver-polymetallic ores of the Maiminovsky vein deposit (Sikhote-Alin, Dalnegorsky ore district). Pacific geology. 36(37), 76–94.

Ratkin, V.V., Simanenko L.F., Eliseyeva O.A., 2016. Typification of deposits and resource potential of lead-zinc and borosilicate ores of the Dalnegorsky ore region (Sikhote-Alin). Fatherland geology. 4, 1–13.

Rogulina, L.I., Sveshnikova O.L., 2008. Nikolaevskoye skarn-polymetallic deposit (Primorye, Russia). Geology of ore deposits. 50(1), 67–82.

Rusakov, M.P., Yagovkina I.S., 1928–1933. The Uspensk-Spasski district in the Kazakian Steppe and its mineral resource, Proceedings of the All-Union Geological Prospecting Association of the NKTP of the USSR-Leningrad; Moscow: NKTP: State. scientific and technical geological exploration publishing house.

Seltmann, R., Porter M.T., 2005. PGS Publishing, Linden Park. 46.

Shcherba, G.N., Patalakha E.I., 1968. Geology and metallogeny of the Uspenskaya tectonic zone (Central Kazakhstan). V.6. Metallogeny. Alma-Ata: Nauka. 180.

Simanenko, L.F., Ratkin V.V., 2008. Partizanskoye skarn-polymetallic deposit. M.: Nauka. 158.