Mykert-Sanzheevka Field of Polycomponent Ores (Pb, Zn, Ag, Au, PGE): Geologic-Substance Characteristics and Formation Features of Ore-Forming System

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Abstract

The new results of geologic-structural, petrographic and mineralogic-geochemical researches of Mykert-Sanzheevka ore field—the Uda-Vitim mineragenic zone South-West ending of West Transbaikalia are given. Its main ore-controlling structure, represented by losange, consisting of rhombohedral and tetrahedral blocks-duplexes mosaic clusters, which are separated by narrow tectonic sutures, is specified. It is clarified that polycomponent ores clusters are confined with these small-block sutures, made by subvolcanic dykes of shoshonite-latite volcano-plutonic association (233 - 188 million years), apodyke dynamometamorphites (breccias, cataclasite, mylonites) and also mechanometasomatites. Four stages of the dynamometamorphites formation characterized by different species compositions of ore minerals appeared as a result of mecanochemical reactions are determined. A carbonyl model of mineral microaggregates formation with films containing noble metal nanoparticles is proposed. Ore-forming system features of Mykert-Sanzheevka field are considered.

Keywords

Polycomponent Ores, Dynamometamorphism, Mechanometasomatites, Noble Metals, Microaggregates, Nanophases, Trace Minerals, Ore-Forming System, Carbonyl Compounds, Geochemical Microanomalies

1. Introduction

Over the past 10 - 15 years, the authors of this article had carried out a minera-
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logical and geochemical study of the ore mineralization on a number of known gold and polymetal (Pb, Zn) deposits in the Baikal region, located within the Sayan-Baikal and Mongol-Okhotsk orogenic belts (Zun-Kholba, Baley, Irokinda, Kholodniy, Dovatka, etc.). The result of these researches was the identification and prediction of polycomponent noble-metal clusters (Au, Ag, Pt, Pd) and noble-metal-polymetallic (Pb, Zn, Ag, Au, Pt, Ru) ores in many ore fields, and in Mykert-Sanzheevka too [1]-[6]. Very high concentrations of Pt and Ru in noble-polymetallic ores are identified in Sanzheevka, Mykert, Dovatka, Tarbagatay fields and occurrences by variety of modern chemical analytical methods (microprobing neutron activation, test tube, atomic absorption, x-ray fluorescence using synchronous radiation, atomic emission). Small Mykert field of Sanzheevka mineral occurrence and Big Mykert form a single ore field (Figure 1). It should be noted that all attempts to find and diagnose the mineral phases of platinum group elements in all studied deposits by using the JXA-8100 microprobe and the LEO 1430 VP electron microscope were unsuccessful. The absence of PGE microphases allowed us to conclude that they are concentrated in an invisible form, most likely in the form of cluster compounds (nanoparticles) in sulfides which consist of PGE atoms groups surrounded by a dense layer of ligands (atoms H, Cl, C, S, etc.).

In the article the research results of noble-metal-polymetallic mineralization of Mykert-Sanzheevka ore field are presented. They concern poorly investigated the problem of its genesis based on the author’s new mineralogic and geochemical obtained data, additional information on lithologic-petrographic and structural-geological peculiarities of the Sanzheevka mineral occurrence and Small

Figure 1. Geological sites scheme of Mykert-Sanzheevka ore field (by A. A. Karvainov et al., 1979). Filled circles—ore sites (1—Big Mykert, 2—Small Mykert, 3—Sanzheevka).
Mykert deposits. Early publications assumed the usual hydrothermal genesis of polycomponent ores [1] [2], without discussing the mechanisms of ore genesis and components sources. From the past researches vision field, the question of ore formation processes linkage with tectonic-metamorphic transformations of host rocks fell out. We considered it recent time on the example of polycomponent noble-metal ores in Irokinda and Irba deposits to which as well as to Mykert-Sanzheevka ore field, platinoids high contents with outstanding mineral occurrence forms are inherent [4] [6]. The authors of the article proposed the deformational formation mechanism of noble metal-polymetallic ores mineral associations. Particular attention is paid to the genesis problem of so-called “oxidation zones of weathering crusts” with noble metal mineralization [7] [8], the originality of which does not fit into traditional ideas, but the prospects for high productivity are highly appreciated.

2. Research Method

The researches complex, first of all, considering the solution of those questions which are today the most poorly studied, debatable, or genetic constructions, causing doubts in its reliability, was attracted. In addition, it was aimed to obtain additional data on ore mineralization, opened with ditches and clearing, which were passed in the last 10 - 15 years by private geological organizations.

This complex included the usual standard geological and structural observations, mapping of new ore deposits uncovered by surface mining, petrographic and mineralogical-geochemical study of rock and ore samples.

Special attention was paid to the identification of carbonaceous substance and ore microaggregates micro-inclusions, first discovered in the polished sections on the ore microscope. Then the most interesting portions, polished sections fragments, containing microaggregates of poorly diagnosed ore and non-metallic mineral phases, colloidal formations (gel minerals by [9]) were investigated on microanalyzer JXA-8100, Jed Ltd. firm, equipped with three wave spectrometers and energy dispersive prefix Link Pentafet, and/or electron microscope LEO 1430 VP with energy dispersive spectrometer INCA Energy 350.

The results of the chemical elements contents, obtained using these devices at particular points of microaggregates were calculated on the normative mineral compositions.

In determining the most probable chemical compositions and forms of platinoids nanoparticles occurrence, as well as Ag and Au, data on the concentration and distribution of various elements were widely used, which were recorded on the scanograms of their characteristic radiation. On this basis, the characteristic of geochemical microfields was made, with the allocation of anomalous among them. At the qualitative level, the correlation between ore elements and fluid components (C, S, F, Cl) in anomalous geochemical microfields was estimated.

Chemical-spectral methods and x-ray fluorescence analysis were used to study the ore-rock complex. Its age was determined by rubidium-strontium iso-
tope-geochemical method.

3. Geologic-Mineragenic Characteristics of the Ore Field

According to geological surveys and prospecting of PGO “Buryatgeology”, a large part of the ore field area is composed of Bichura complex syenites and diorites of middle Paleozoic with Mesozoic diorite porphyrites dykes, microdiorites, diabases. Outside, there are widespread bodies of Ikat complex. Neoproterozoic gabbros.

On Paleozoic granitoids distribution area of Mykert-Sanzheevka ore field, in addition to the mentioned ones there are known small outcrops of amphibolites, Itantsa suite crystallo-slates, dating from the Riphean (the Neoproterozoic). In eluvial-diluvial formations, coarse fragments and boulders of intensely cataclastic scarnoids and serpentinites are observed.

Noted rocks of ultramafic-mafic association, including the Itantsa suite metabasites—there is a characteristic peculiarity of Selenga-Vitim Greenstone belt [5], composing the Precambrian crystalline basement of Dzhida-Vitim polymetallic zone [1].

The whole rocks complex that form Mykert-Sanzheevka ore field, rapidly deployed.

Ore field is located at the intersection of the Upper Orongoy and Gilbery zones of side faults bounding the Mesozoic Upper Orongoy and Ivolga depression. The ore field occupies a portion between these depressions like a small horst.

Mykert-Sanzheevka ore field area is a part of the West Transbaikalia sector of the Mongol-Transbaikalia rift zone [10], represented by volcanogenic-plutonic structure, with the age of its composing rocks (trachybasalts, volcanic trachybasalt-comendite association, arrays of alkali granites and syenites) 233 - 188 million years.

In the 70 - 90-ies of XX century on the area of the ore field (Figure 1) the exploration works on the silver were purposefully carried out. The result was the discovery of one Small Mykert field and two mineral occurrences of silver (Big Mykert and Sanzheevka). Ag total forecast resources for the three objects identified by the exploration works, made by Buryat geological department by 1988, were estimated at 2000 t. Mineragenic capacity of platinum group elements was calculated in the amount of 25 t. Au, Pb, Zn, Cu as the accompanying components, due to the small their extent, in the forecast resource estimations were not taken into account.

Presently, it is possible to state a very weak search knowledge of Mykert-Sanzheevka field as the area object with complex ores.

The noble metal-polymetallic ore formation type deposits (Novo-Shirokinsk, Bystrinsk, etc.) are known in East Transbaikalia. Their formation is associated with the functioning of latite ore magmatic systems of Jurassic-Cretaceous time (192 - 196 million years) [11] [12] [13]. In contrast to the Mykert-Sanzheevka ore field, the dominant ore component of these deposits is gold, not silver, based
on the results of exploration works.

4. Substance Composition of Ore-Bearing Rocks

Ore-bearing rocks of Mykert-Sanzheevka ore field are presented by shoshonite-latite volcano-plutonic association, which unites a plutonic series (gabbro, monzonite, syenites, subalkalic diorites) and mainly subvolcanic dyke series composed of species visually related by geologists practitioners to the diabase, the diabase and diorite porphyrites. At the same time, ore mineralization is localized in the dynamometamorphic complex resulting from two-three time tectonic-metamorphic transformations of shoshonite-latite association rocks.

As a part of the latter one, in various degrees, dynamometamorphic transformed petrotypes form a group: syenites, diorites mentioned above subvolcanic dyke rocks. They are presented by a number of petrochemical rocks of various alkalinity (Table 1): tephrite, trachybasalt and trachyandesitebasalt, alkaline syenite (trachyte).

Table 1. The chemical composition of Mykert-Sanzheevka field ore-bearing rocks.

| Components | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
|------------|----|----|----|----|----|----|----|----|
| SiO₂       | 50.29 | 50.32 | 49.96 | 53.20 | 51.96 | 52.68 | 62.70 |    |
| TiO₂       | 2.10 | 1.51 | 1.43 | 0.99 | 1.01 | 1.10 | 1.07 |    |
| Al₂O₃      | 14.37 | 17.74 | 17.73 | 18.06 | 21.94 | 22.34 | 18.15 |    |
| Fe₂O₃      | 7.28 | 5.23 | 5.05 | 3.94 | 4.01 | 4.17 | 2.49 |    |
| FeO        | 5.91 | 5.16 | 5.47 | 4.62 | 10.03 | 8.98 | 0.73 |    |
| MnO        | 0.23 | 0.19 | 0.20 | 0.18 | 0.13 | 0.013 | 0.14 |    |
| MgO        | 4.47 | 4.16 | 4.05 | 6.98 | 3.04 | 3.18 | 1.05 |    |
| CaO        | 8.50 | 8.20 | 8.68 | 5.98 | 1.64 | 1.42 | 1.81 |    |
| Na₂O       | 3.72 | 4.05 | 4.03 | 3.71 | 0.55 | 0.13 | 5.28 |    |
| K₂O        | 2.00 | 2.50 | 2.40 | 2.10 | 4.95 | 5.41 | 6.32 |    |
| P₂O₅       | 1.20 | 0.94 | 1.00 | 0.24 | 0.74 | 0.46 | 0.26 |    |
| CO₂        | 0.66 | 1.10 | 1.54 | 0.44 | 0.66 | 0.44 |    |    |
| F          | 0.09 | 0.15 | 0.11 | 0.04 | 0.25 | 0.19 | 0.07 |    |
| S          | 0.13 | 0.13 | 0.12 | 0.05 | 0.04 | 0.16 | -  |    |
| Cl         | 0.029 | 0.035 | 0.050 | 0.008 | 0.005 | 0.002 | - |    |
| Pb         | 6500 | 150 | 100 | 60 | 200 | 5200 | 1500 | 69 |
| Zn         | 168 | 110 | 84 | 110 | 63 | 4368 | 4313 | 1740 |
| Cu         | 21 | 33 | 20 | 39 | 123 | 63 | п.о |    |
| V          | 154 | 269 | 232 | 221 | 174 | 205 | 201 | п.о |
| Cr         | 18 | 21 | 17 | 16 | 89 | 42 | 50 | п.о |
| Co         | 22 | 27 | 23 | 25 | 25 | 23 | 24 | п.о |
| Ni         | 15 | 24 | 14 | 13 | 62 | 19 | 22 | п.о |

Note: Elements oxides are calculated to dry residue (wt%), CO₂, F, S, Cl—wt%, and ore elements—g/t, п.о—contents were not determined, “—“—not found, 1-8—petrochemical types of rocks on the TAS diagram (1—tephrite; 2-4—trachybasalt; 5-7—trachyandesitebasalt; 8—alkaline trachyte). Analysis of oxides, of F and S conducted laboratory of instrumental methods of analysis of GIN SO RAN Group (B.b. Lygdenovoj, etc.); The content of Cl and ore elements X-ray-fluorescent analysis VPA-90 B.i. B.J. Zhalsa-raevym (GIN SO RAN).
Below we give brief mineral-petrographic and geochemical characteristics of the main ore-bearing rocks petrochemical types.

**Tephrite.** Structure is ophite, diabase. The rock is composed of divergent *leisten* of zonal plagioclase and isometric magnetite-biotite aggregates. Biotite is characterized by a short plate shape and green color, along cleavage the rutile and ilmenite allocation is marked. The rock is for the most part carbonated, enriched with phosphorus and fluorine than other petrochemical types listed in Table 1.

**Trachybasalt (shoshonite).** The texture of the unaltered rock is diabase, microophite, grain sizes are 0.1 - 0.7 mm. Trachybasalt is composed by randomly directed *leisten* of twinned plagioclase (of andesine) and augite grains of irregular shape. The magnetite is closely associated with augite. Dykes of augite-andesine composition, during dynamometamorphism, in condition of the compression deformation, change the massive texture to the plane-oriented (trachytoid) and experience significant mineral transformations: andesine → oligoclase → sericite ± quartz ± carbonate → hydromica (“pelit”), augite → biotite or chlorite + ilmenite + rutile. Trachybasalts are characterized by higher contents of TiO₂ and P₂O₅, lower-fluorine.

**Trachyandesitebasalt (latite).** Given in Table 1 analyses 5 - 7 of dyke rocks are referred to the petrochemical group of trachyandesitebasalts, petrographically represented by amphibole, and mica-plagioclase dynamo-slates. With this, the main latite minerals—hornblende and andesine are recorded as relict isolations, preserved in the secondary minerals mass of the deformational origin (for a hornblende—actinolite with ore minerals and chlorite, for an andesine—chlorite, sericite, hydromica, ore quartz in the form of veinlets). A characteristic petrographic feature of the considered rocks is the presence of potassium feldspar rims around sericite scales. Trachyandesitebasalts differ markedly from others discussed above petrochemical types of ore-bearing rocks by lower contents of Cl, P₂O₅, and some higher ones Cr and Ni. Their main feature is the presence of potassium varieties.

Petrochemical type “**alkaline trachyte**” is presented by cataclastic syenite with inclusions of aegerine-augite. The rock is composed of relatively large (3 - 5 mm) deformed prisms of potassium feldspar filled with a dusty substance (pelite + colorless mica). Prisms deformation of the potassium feldspar is expressed in the granulation of their peripheral portions. The space between large grains is made by their small fragments, often with the correct habitus form and smooth faces of lattice microcline and newly formed short-prismatic plagioclase (albite-oligoclase). Clusters of small grains are observed in cracks that cross the rock. Large prisms deformation of feldspar is also expressed under a petrographic microscope in spindle-shaped extinction in crossed Nichols. Among the feldspar prismatic formations there are met small (up to 0.3 mm) elongated grains of relict aegirine-augite, replaced by 70% - 80% short plates of green biotite.
5. Ore Field Structure and Morphostructural Types of Ore Mineralization

The whole complex of rocks that form Mykert-Sanzheevo ore field is intensively deployed, like other ore fields of Uda-Vitim metallogenic zone that belongs to the charriage-thrust tectonotype. The main ore localizing structures of ore field are losange ones (by [14]), similar to those that are widespread in the Ilya and Dibiksa gold deposits of the Onon-Turin branch, the Mongol-Okhotsk deep fault [15].

Losange structures of Mykert-Sanzheevo fields constitute mosaic clusters of rhombohedral and tetrahedral blocks-duplexes, separated by narrow tectonic sutures. These interblock sutures, made by subvolcanic dykes and dynamometamorphites (breccias, cataclasite, mylonites) and mechanometasomatites in the form of quartz, carbonate-quartz veins and argillites, clusters of polycomponent ores are confined (Figure 2, Figure 3). Often dykes are boudinned and partly ore-bearing ones (Figure 3).

Grussy-crushed tectonoclastites we mentioned are considered as unlithified loamy tectonomixtites formed in the deformations zones during rocks mechanical destruction near the day surface [17]. They are usually referred to the group of kakirite facies dynamometamorphites. In the composition of tectonomixites in addition to the prevailing coarse fraction debris (boulders, gruss, gravel) B. M. Chikov [17] identifies milonit-slates matrix, which also includes clay component (friction clay) and powdery dispersiets. In our case, that is, within Mykert-Sanzheevo field, ore occurrence, essentially of noble-metal mineralization in kakerites are confined mainly to their matrix.

Figure 2. Geological map of the Small Mykert-Sanzheevo ore field deposits (according to V. F. Barsky, 1978 with the corrections of the article authors).
Dykes mostly create the initial (losange) frame of the ore field, fully inherited by the ore-bearing apodyke dynamometamorphites of cataclasite and mylonite facies. As show the detailed opening of ore bodies by surface mine workings and partly by drilling wells at the Small Mykert deposit, the ore-bearing ones are dynamometamorphites zones formed on the dyke bodies contacts with the syenites and presented by ore tectonobreccias with quartz-carbonate, carbonate-micaceous and galena veinlets (Figure 2).

A. L. Kowalewski with co-authors [7] [8] carried out researches on the delineation, using bio-geochemical and litho-geochemical anomalies, of Mykert-Sanzheevka field disintegrated top surface below the soil layer in the depth interval from 1 to 2.5 - 5 m. The result was the identification of platinum group elements (PGE) several morphological (“structural-formational”) types localized in syenites and monocytes field: 1) complex silver-bearing (100 - 300 m) and platinoid-bearing (up to 1000 m and more) stockworks; 2) steeply dipping (the fall angle is about 80°) platinoid-bearing local mineralized zones with a thickness of 0.2 - 2 m; 3) noble-metal mineralized zones of 2 - 20 m thickness; 4) platinoid-bearing stockwork zones with a width of 30 - 100 m; 5) platinoid-bearing xenoliths of metamorphic and metasomatic rocks; 6) manto-like deposits of secondary hydrogenic or noble metal enrichment at a depth of 1 - 3 m near alkaline syenites and monzonites; 7) expected pocket-like deposits of secondary hydrogenic enrichment in zones of crushing and fracturing up to tens of meters deep.

All given above types of near-surface structural and morphological types of ore mineralization have no distinctive from endogenous structural and geological hypergenic signs of ore formation, inherent to ore-bearing weathering crusts or hydrogenic deposits.

Intensely crushed and fractured granitoids of shoshonite-latite series, in some
areas (Figure 1) are turned into a crushed-gruss substrate.

About 110 - 120 km to North-East of Mykert-Sanzheevka ore field on the southern Ivolga depression side, Tsekhovsky J. G. with co-authors [16] studied in detail a tectonically disintegrated, sometimes silicified syenites and quartz syenites of the massif Tobhor called as tectonoclastites and are analogues to Mykert-Sanzheevka ones. The tectonoclastites grussy-crushed material of this massif is cemented by a sandy-clay matrix, often replaced by quartz, including forming veinlets.

6. Deformational and Mineral Transformations of Ore Rock Complex

Dynamometamorphic complex productive on polycomponent ores is regarded by the authors as a tectonic processing product of volcano-plutonic rocks shoshonite-latite series in the process of forming Mykert-Sanzheevka field structural frame. Primary aluminosilicate minerals composing unchanged rocks of this series, subjecting to cataclase and mineralization in the process of deformation effects under stress-metamorphism, experience solid-phase (mechanochemical) transformations, forming associations of newly formed minerals (Table 2).

The textures and structures of the initial rocks change in parallel. During diffusion mass transfer, accompanying friction sliding along the grain boundaries of the initial rocks, during crushing and abrading of the latter ones, the transition of the initial rock-forming components is performed in mineral forms that can accumulate scattered ore elements in dynamometamorphic minerals.

The most recent dynamometamorphites facies of Mykert-Sanzheevka field is represented by ore-bearing mechanometasomatites (in understanding of [17]) that finish deformational transformations of the primary initial rocks and dynamometamorphic rocks facies of the formation early stages.

### Table 2. Mineral transformations peculiar properties of shoshonite-latite series rocks during cataclasite and mylonite facies dynamometamorphism.

| Initial rocks subjected to dynamometamorphism | Initial rocks minerals and appeared on it secondary minerals of deformational genesis |
|----------------------------------------------|-----------------------------------------------------------------------------------|
| Gabbro and monzonites                        | Pyroxene → hornblende, green biotite, light mica, ilmenite, sphen                  |
|                                              | Plagioclase (andesine) → muscovite, K-feldspar                                     |
|                                              | Hornblende → actinolite, Fe-carbonate, biotite, chlorite, ilmenite                 |
| Syenites                                     | Andesine → muscovite, albite-oligoclase, K-feldspar, quartz                       |
|                                              | Aegirine-augite → green biotite                                                 |
|                                              | Biotite → muscovite, rutile                                                      |
| Diorites                                     | Andesin-oligoclase → sericite, albite, carbonate                                  |
|                                              | Pyroxene → chlorite, biotite                                                     |
| Dyke subvolcanic shoshonite-latite complex    | Andesine → oligoclase, chlorite, sericite, K-feldspar, quartz, carbonate, hydromica |
|                                              | Augite → biotite, chlorite, ilmenite, rutile                                     |
|                                              | Hornblende → actinolite, chlorite                                                |
Two types of mechanometasomatites are allocated: 1) small veins, veinlets, lenses of micaceous-carbonate-quartz composition with ore mineralization; 2) zones, areas of argillizites made mostly of clay minerals. Mechanosomatites of the first type are usually composed of zonal construction quartz veinlets. Zoning is expressed by the presence of the bands quartz and quartz-carbonate-mica composition. Quartz is of two varieties. The first makes the main vein mass and is represented by large (up to 5 - 6 mm) quartz grains of isometric and irregular shapes, dissected by parallel cracks on the plates oriented perpendicular to the banding. The second type of quartz grains is observed in the form of thin (up to 0.3 mm) strips at the border of coarse-grained quartz and strips of quartz-carbonate-mica composition. The bulk of this quartz (45% - 30%) is composed of chalcedonic gray quartz of pyramidal shape with smooth, but indistinct boundaries and unclear expressed extinction. The sizes of its grains are 0.05 - 0.15 mm. In these zones, plates relics (0.1 - 0.2 mm) of the first variety early quartz are widespread, which as a result of dissolution acquired toothed outlines. In quartz aggregates there is widespread sericite admixture.

Fine-grained micaceous-carbonate-quartz aggregates form strips of 2 - 5 mm, having clear boundaries. They do not contain any relics of early quartz. In this almost homogeneous mass, pyramidal formations (up to 0.1 mm) of rutile, apatite and veinlet separations of the latest quartz appear. There are very thin new growths of zircon, rutile, tourmaline and ore minerals of acicular form, which are located along thin parallel fractures (possibly relict cleavage) feldspars, syenites, subjected to deep deformational transformations.

At the contact of shoshonite-latite series dykes in syenites the quartz-sericite formation sometimes substantially are formed with a small admixture of potassium carbonate nanophases (calicinite), Fe hydroxides (goethite) and Mg (brucite) in total not exceeding 5%.

Ore-bearing argillizite type mechanometasomatites, composed mainly of sheet and chain silicates association (hydromuscovite, kaolinite, ferripyrophyllite, sepiolite, gibbsite), form the late separations in mechanometasomatites of micaceous-carbonate-quartz composition.

Ore accessory minerals of the aluminosilicate initial rocks listed in Table 2 and the secondary ore minerals of dynamometamorphites also experience solid-phase transformation (Table 3).

7. Isotope-Geochemical Rb-Sr Age Determination of the Dynamometamorphic Ore-Rock Complex Formation

Based on the data given in Table 4 an errorchron of 233 ± 19 million years age is obtained. It’s close to the rocks formation time (233 - 188 million years) of West Transbaikalia sector volcano plutonic structure of the Mongol-Okhotsk rift zone, which includes Mykert-Sanzheevka ore field [10]. Taking into account that the considered dynamometamorphic ore-rock complex is the result of tectonometamorphic transformations of already appeared rocks composing the mentioned volcanoplutonic structure, the interval of 233 - 214 million years can
Table 3. The deformation and mineral transformations scheme of ore minerals.

| Initial ore minerals | New-formed minerals as a result of solid-phase (mechanochemical) reactions |
|----------------------|--------------------------------------------------------------------------|
| Ilmenite             | Anatase, magnetite, sphene, pyrite                                      |
| Magnetite            | Martite, hematite, Fe-carbonate                                         |
| Titanomagnetite      | Magnetite, ilmenite, anatase, sphene                                    |
| Galena               | Sphalerite, zincite, shapbahite (AgBiS₂), bournonite, argentite,         |
|                      | cerussite, anglesite, chalcopyrite, silvana (?), geocronite, sphalerite, |
|                      | hematite, pale ore, cerussite, pyrite, galenobismutite, native Pb        |
| Sphalerite           | Hydromica Fe, chalcopyrite, zincite, sphalerite II, chalcocite,          |
|                      | hematite, alabandin, the smithsonite, bornite, bournonite               |
| Chalcopyrite         | Covellite, chalcocite                                                   |
| Bornite              | Chalcocite, covellite, eskebornite, galena, pyrite, penzhinite, plattnerite |

Table 4. Rb-Sr system isotopic characteristics of dynamometamorphic ore-rock complexes.

| Samples numbers | Rocks characteristic                                                                 | Rb   | Sr    | 87Rb/86Sr | 87Sr/86Sr |
|-----------------|---------------------------------------------------------------------------------------|------|-------|-----------|-----------|
| T-28A (6)       | Weakly cataclastic trachyandesitebasalt (Pb = 0.52 wt%, Zn = 0.49 wt%)                  | 219.6| 42.0  | 15.214    | 0.756315  |
|                 | Sericite-chlorite dynamoslate on trachyandesitebasalt with thin veinlets of galena-quartz composition (Pb = 1.5 wt%, Zn = 0.43 wt%) | 224.7| 51.3  | 12.728    | 0.749498  |
| T-29A (7)       | Tectonobreccia on diorites with weak sulphide mineralization                             | 12.3 | 60.0  | 0.592     | 0.709840  |
| CJK-9           | Hematite ore with galena (wt%)                                                          | 4.6  | 35.3  | 0.379     | 0.707716  |
| T-23 (4)        | Chlorite-amphibole dynamoslate on trachyandesitebasalt                                  | 45.8 | 1252  | 0.106     | 0.705866  |

Note: in parentheses—number of analyses given in Table 1. Definitions were made on the mass—spectrometer MU 1201T V.F. Posokhov.

be considered the most probable dating of such transformations. It is assumed that the dynamometamorphism and ore genesis processes, occurred in several temporal stages are within the range of 19 million years.

8. Mineralogical-Geochemical Peculiar Properties of Dynamometamorphic Origin Ore Mineralization

Ore mineralization is represented by continuous and nest-disseminated sulfide separations, usually with a galena prevailing. The species composition of ore minerals is given in Table 4. Note that besides visual individuals of galena, sphalerite, magnetite, sometimes chalcopyrite, argentite, pyrite, native gold, other ore minerals have micro- and nanosizes.

There are distinguished 4 time formation stages of dynamometamorphites characterized by different species compositions of forming ore minerals (Table 5).
Table 5. Ore minerals in dynamometamorphic genesis ore-bearing rocks of different stages formation.

| Stages of dynamometamorphism | Typical ore minerals                                                                 |
|------------------------------|--------------------------------------------------------------------------------------|
| I Stage. Mainly cataclastic facies. Deformational transformations of initial rocks minerals | Ilmenite (FeTiO₃), geiklomite (MgTiO₃), rutile (TiO₂), magnetite (Fe₃O₄), pyrite (FeS₂), |
| II Stage. Cataclastic and mylonit facies. Deformational transformation of initial rocks minerals and I stage cataclasites | Hematite (Fe₂O₃), ilocite (FeO), tenorite (CuO), zincite (ZnO), plattnerite (PbO₂), magnetoplumbite (PbFe₁₂₄O₁₉), anatase (TiO₂), galena (PbS), sphalerite (ZnS), boulangerite (Pb₃Sb₄S₁₁), bournonite (CuPbSbS₃), covellite (CuS), chalcocite (CuS), empclectite (CuBiS₃), bornite (CuFeS₄), tetrahedrite (Cu₅FeS₄S₉), antimonite (Sb₂S₃), bismuthine (Bi₂S₃), argentite (Ag₂S), stroymerite (AgCuS), penzhinite (AgS), pyrargyrite (Ag₃SbS₃), matildite (AgBiS₃), native Pb, Ag, Au |
| III Stage. Mylonite facies with the mechanometasomatites formation of quartz, carbonate-quartz, and sulfide composition | Plattnerite, massicot (PbO), galena (PbS), sphalerite (ZnS), pyrite (FeS₂), chalcopyrite (CuFeS₂), bornite, eskebornite (CuFeSe₂), covellite (CuS), chalcocite, penzhinite, cencosite (ZnSO₄), smithsonite (ZnCO₃), cerussite (PbCO₃), native Pb, Ag, Au, intermetallics, Ag-Mo, Ag-Pb-Mo |
| IV stage. Mechanometasomatites mainly with aqueous minerals | Volborrhitite (Cu₃O₄•3H₂O), tangeite (CaCuVO₄OH), motramite (PbCuVO₄OH), chlorargyrite (cerargyrite) (AgCl), Ag₂SO₄•5H₂O, Ag(OH)₃, szomolnokite (Fe₃O₄•H₂O), goethite (HFeO₂), anglesite (PbSO₄), zicoside, nanophases of native noble metals |

Among these minerals, the main role in the composition of ore clusters belongs to galena, sphalerite and pyrite. As shown in Table 3, galena is the primary matrix for the various groups of minerals represented mostly by sulfides and oxides. Ore sulphates, carbonates, native metals were also diagnosed.

Galena is mostly represented by fine-grained aggregates with small (0.08 - 0.12 mm) isometric, slightly flattened, grains with uneven curved boundaries. Fine-grained structure is found in the galena by etching with concentrated hydrochloric acid. When etching galena for 7 minutes, its dark gray short and white plates appear in accretion with white-gray smaller ones, forming a intersecting lattice microstructure and presented by sulfides of different composition (Cu, Bi, Sb, Zn, Ag, Fe). These sulfides are grouped into separate microinclusions (10 - 20 µm) not only in the form of short plates, but also isometric grains tending to cleavage cracks. Small (0.01 - 0.05 mm) inclusions of chalcopyrite and pyrite are relatively widespread in galena. Pyrite forms skeleton porphyroblasts containing microinclusions of galena and chalcopyrite. In zones of intense foliation the pyrulite, covellite, chalcocite, cerussite, anglesite appear. Covellite and chalcocite occur in small amounts, together forming thin scales in cerussite.

The authors studied in detail the ore minerals microaggregates with size from 5.0 × 2.5 µm to 2.5 × 1.3 µm in some galena ore samples that concentrate “invisible” Au in a wide range of contents from 0.07 to 0.69 wt% (Table 6). The data analysis showed that there is no direct correlation between the values of Au and most other ore elements. Only positive correlation for Au-Cu concentra-
tions is found.

At the same time, between the contents in Au-Pb and Au-Ag pairs, a possible relationship is seen, which is approximated by the sinusoid \( y = \sin x \) (\( y = \text{Au} \), and \( x = \text{Pb} \) and \( \text{Ag} \)). An adequate reflection of the marked stochastic geochemical relations is the variability nature of the mineral associations species composition making microinclusions in galena ores (Table 6) as the content of “invisible” gold increases. It should be noted that the maximum content of Au (0.69 wt%), is identified in micro-inclusion containing nanoparticles of native Ag and oxides.

**Sphalerite**, which is the second by the prevalence (5 - 20 vol%) ore mineral of Mykert-Sanzheevka field, forms two generations. I—dark gray, with a smooth surface, without the characteristic sphalerite twins and decay structures. It forms polygonal aggregates extended along quartz veinlets, often bordering larger galena aggregates. In the contact zones of these two ore minerals, their mutual penetration into each other is sometimes observed. More often, these zones are made by late minerals that replace both galena and sphalerite from the periphery and along cleavage cracks. The sphalerite I reflectance is low, the color is gray

| Contents of “invisible” Au wt% | Ore mineral associations |
|-------------------------------|-------------------------|
| Galena, tetrahedrite (Cu₇Sb₄S₁₉) | Penzhinite (AgS), antimonite (Sb₂S₃) |
| Goethite (HFeO₂), native Ag, melanterite (FeSO₄·7H₂O) | Anglesite (PbSO₄) |
| Galena, argentite (AgS) | Hematite (Fe₃O₄) |
| Tetrahedrite, galena | Argentite, antimonite |
| Tetrahedrite, galena | Argentite, antimonite |
| Argentite, stroymerite (AgCuS) | Galena |
| Tetrahedrite, galena, penzhinite | Antimonite |
| Tetrahedrite, penzhinite | Antimonite, galena |
| Galena | Iocite (FeO) native Ag, plattnerite (PbO₂) |

Note: The content of Au and the elemental composition of minerals are determined by I.G. Bystrov (VIMS) on the JXA-8100 microanalyzer of Jed Ltd, equipped with three wave spectrometers and energy dispersal console Link Pentafet.
with a brownish tint. Isotropic, by portions, a weak anisotropy is observed, the solid solutions decay structures were not observed, galena inclusions (0.01 - 0.1 mm) are marked. Sphalerite is later and replaces sphalerite-I in the form of borders from the grain boundaries to the center and by cleavage. Sometimes it replaces the grain completely. It is characterized by higher reflectance and bluish tint, isotropic, internal reflexes are typical. Iron hydroxides develop on sphalerite-II. No decay structures were found in it.

Sphalerite, as galena, was subjected to dynamometamorphism with oxidation. The total content of the resulting minerals varies within 5 - 47 vol%. The most common of them are cerussite, limonite, chalcocite. In smaller quantities, but everywhere anglesite and smithsonite are observed.

**Pyrite** is the third, in occurrence, ore mineral in ores with noble metals. The physical properties of pyrite are close to standard ones. It forms mainly small (0.02 - 0.1 mm) inclusions in galena and is in close accretion with it, associating with chalcopyrite. The shape of pyrite grains is cubic, the largest (0.15 - 0.4 mm) of them are porphyroblasts and have a cribiform microstructure due to the inclusions of galena, sphalerite and quartz. Pyrite as well as galena and sphalerite in zones of intense dynamometamorphism are replaced by limonite.

**Chalcopyrite** associating with pyrite was found as microinclusions (0.01 - 0.05 mm) in galena. In some galena specimens chalcopyrite inclusions partially (50%) are replaced by chalcocite.

**Silver mineral form** represent a particular interest for the study because the high content of this element in ore-rock complex was allowed to consider it as a major industrial component in prospecting and exploration of Mykert-Sanzheevka field ore zones and deposits. The identified Ag minerals do not form, as Pb, Zn, Cu or Fe, as well as part of the native Au visible by the naked eye individual minerals or their clusters. They are found in the form of micro- and nanophases not only in visually distinct galena ores (argentite, stroymerite, penzhinite, cerargyrite, native Ag), but also in clayey formations of argillize mechanometsomstites not having other ore elements mineralization (Figure 4). Only here they are represented by sulphates (Ag₂SO₄∙2H₂O, Ag₂SO₄∙5H₂O) and hydroxide Ag(OH)₂ emissions with sizes from 200 × 200 nm to worm-like separations with thickness of 200 - 650 nm, length from 1.2 to 13 microns or more.

9. On the Occurrence Forms of Platinum Group Elements in Dynamometamorphic Complex Rocks and Ores

Substance composition detailed researches of the ore-bearing complexes in noble metal deposits significant number in order to develop the ore enrichment and technologies effective methods for the most complete extraction of Au, Ag and PGE allowed to establish a wide development of these elements cluster forms, concentrating the bulk of these elements [18]. It is assumed that the primary metal-organic clusters with the outer carbon shells, named by V. N. Mat-vienko with co-authors the proto-clusters are the metal-extracting paleo-bacteria.
Figure 4. Nano-silver trace minerals in argillizite mechanometasomatites of Mykert-Sanzheevka ore field.

These proto-clusters after transforming themselves in noble metals native phase, i.e. after their metallization, resulted in ore material accumulations, including platinoids in occurrences of the auriferous deposits various types (Bakyrchik, Baley, Kumtor, Nezhdaninsk, etc.) [18]. At the same time, an important, if not decisive role is established in the destruction of primary organometallic clusters—the dynamometamorphism processes accompanied by oxidation. The paragenesis of noble metals metastable phases evolving in time, but combined in space is shown against the background of tectonic-metamorphic transformations increasing intensity. It looks like: metastable protocluster organometallic (chlorides, sulfates) → (sulfuric sulfides, tellurides, selenites) → colloidal forms (MenOHb) → aggregative native forms. The given idealized evolutionary scheme can be violated because of multiple deformational transformations acts of ore-rock complexes and the mechanochemical reactions intensity.

A large role in ore formation, including noble metal and complex mineralization, is given to organoelement compounds represented by metal carbonils and related to the compounds (carbonyl hydrides, carbonyl halides, carbonils organic derivatives etc.) [19] [20]. It is assumed that the primary associations evolution of platinum group mantle minerals in ultrabasites took place in the form of carbonyl compounds under the action of strongly recovered fluids [21]. According to [22] data, the formation of ore-forming carbonyl complexes, their involvement in the field of ore genesis, greatly stimulate the processes of dynamometamorphism. Herewith, thermal dissociation, hydrolysis, oxidation of carbonils, leading to the formation of oxides, hydroxides and native metals are the result of their molecules strong deformations.
We propose carbonyl model of noble metals nano- and microparticles formation in polycomponent ores of Mykert-Sanzeveka field that is substantiated by a number of signs, characteristic to chemical technologies for producing metal films and coatings [23] [24] [25].

1) Wide distribution of metal polyelement oxide microfilms (Table 7, Figure 5) containing nanophases of noble metals. Microfilms have substrates with graphite, graphite oxides. The existing methods and mechanisms of low-temperature carbonyl metal films and coatings formation cannot be implemented without substrates with a heated surface. In our case, the considered conditions of carbonyl compounds metallization and/or their clusters (friction heating, oxidation) are created by a deformation (tribochemical) mechanism.

![Figure 5](image_url)

Figure 5. Ore microfilm (20 × 12 µm) with nanophases of noble metals (piece of polished section T-29A).
Table 7. The elemental composition of the ore microfilm with noble metals, appeared on a mechanometasomatites substrate.

| Analysis points in Figure 5 | C     | O     | Na    | K     | Si    | Al    | Ca    | Mg    | Mn    | Fe    | Zn    | Pb    |
|----------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| 1                          | -     | 29.46 | -     | 1.55  | 5.20  | 2.98  | 2.57  | -     | 22.18 | 2.13  | 3.58  | 29.60 |
| 2                          | -     | 30.67 | -     | 1.22  | 5.77  | 2.92  | 5.02  | -     | 21.12 | 2.31  | 3.87  | 27.60 |
| 3                          | -     | 25.49 | -     | 1.34  | 5.58  | 3.13  | 1.94  | -     | 24.82 | 2.00  | 4.01  | 31.69 |
| 4                          | -     | 31.96 | -     | 1.29  | 6.53  | 3.39  | 3.17  | -     | 19.71 | 3.66  | 4.21  | 26.08 |
| 5                          | 14.32 | 41.63 | 0.68  | 5.73  | 17.12 | 11.36 | -     | 0.93  | 3.64  | 4.59  | -     | -     |

Note: 1 - 4—ore microfilm with nanophases of noble metals fixed in energy spectra; 5—carbonaceous mechanometasomatites substrate. The tests were performed on the scanning electron microscope LEO 1430 VP E.A. Khromova (GIN SO RAS).

2) Mineralogic and geochemical signs of oxidative mineral microaggregates decarbonylation and formation with discrete noble metals nanoparticles fixed on energy spectra shown in Table 8 and Table 9. There were identified 7 types of mineral microaggregates. Herewith, in six of them, Pb-plattnerite oxide is present in the composition of ore oxide associations. Thus, this mineral can be considered as platinoid mineralization indicator of Mykert-Sanzheevka ore field.

All seven identified mineral types are enriched to the greatest extent with nanoparticles of native Pt, and six of them with Pd. Spectral energy peaks are also found for ruthenium microphases. These facts are consistent with the previously established platinum-ruthenium ore-geochemical specialization of the Mykert-Sanzheevka field polymetallic ores [1].

3) The structure and composition of PGE geochemical microfields in those ore microaggregates, where there are no their peaks in the energy spectra (Table 10). The characteristic morphostructural surface relief, peculiar to metal coatings is not only adequately reflected in the components geochemical microfields usually intrinsic to carbonyl compounds (volatile hydrocarbons, S, Cl, F, H₂O pairs), but is also emphasized by the uniformly discrete distribution of Pt mineral nanoparticles.

10. The Results Discussion: Geologic-Genetic Peculiar Properties of Mykert-Sanzheevka Field Ore-Forming System Formation

Structural-geological and mineralogic-geochemical data obtained by the authors, in total with predecessors published materials allow to consider the proposed evolutionary model main traits of the Mykert-Sanzheevka field ore-forming system (OFS) formation (Table 11). Below we give a description of such OFS important elements as of fluids sources and ore substance, the concentration mechanisms of the latter one.

**Fluids sources.** Proposed above organometallic carbonyl model of ore genesis assumes as the ore elements migration and accumulation main agents—volatile compounds represented by hydrocarbons (methane, ethane, etc.) CO, CO₂, and by S, Cl, F, H₂O vapors. From our point of view, they are formed in the processes of dynamometamorphism due to the deformational (mechanochemical) mechanism.
Table 8. The composition of mineral microaggregates of mechanometasomatites characterized by the presence of energy spectra with noble metals.

| Numbers of polished sections | Sites (analysis points in parentheses) | S   | O   | Pb  | Zn  | Fe  | Mg  | Mn  | Ti  | Si  | K   | Ca  | Al  |
|-----------------------------|---------------------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1                           | S.1-1 (1)                             | 12.50 | 2.29 | 82.89 | -   | 1.16 | -   | -   | -   | 1.16 | -   | -   | -   |
| 2                           | S.2 (4)                               | 9.41 | 12.92 | 66.32 | 1.11 | 2.10 | -   | -   | -   | 5.98 | 0.72 | 0.31 | 0.93 |
| 3                           | S.3 (3)                               | 5.93 | 32.02 | 38.02 | -   | 3.16 | -   | -   | -   | 18.32 | 0.93 | -   | 1.62 |
| 4                           | S.1-1-1 (1)                           | -   | 29.47 | 29.64 | 3.58 | 2.13 | -   | 22.88 | -   | 5.20 | 1.55 | 2.57 | 2.98 |
| 5                           | S.4 (2)                               | -   | 24.33 | 63.50 | -   | 3.52 | 0.58 | -   | -   | 4.57 | 0.94 | -   | 2.56 |
| 6                           | S.3 (2)                               | -   | 35.79 | 14.73 | 1.33 | 32.85 | -   | -   | -   | 10.81 | 1.09 | 0.51 | 2.89 |
| 7                           | S.3 (6)                               | -   | 39.15 | 4.38 | 2.84 | 34.90 | 0.65 | -   | 0.39 | 11.48 | 1.42 | -   | 4.79 |

Note: polished sections: 1—sample K-12, 2 - 7—sample T-29A. Samples are represented by mechanometasomatites on the apodyke ore-bearing dynamometamorphites. The gross chemical composition of the T-29A sample is given in Table 1 (analysis 7). Associations composition (in parentheses-percentages of micro- and nanophases contents): 1—galena (93.3), quartz (2.5), plattnerite (1.7), hematite (1.7); 2—galena (50.2), anglesite (25.5), quartz (7.6), native Pb (5.6), K-feldspar (5.2), anorite (2.2), native Fe (2.1) and Zn (1.1); 3—quartz (34.8), plattnerite (26.7), anglesite (21.8), muscovite (9.5), pyrite (6.8), kaolinite (0.3); 4—plattnerite (34.2), manganite (33.3), muscovite (14.8), portlandite (4.8), zircon (4.5), goethite (3.4); 5—plattnerite (73.4), muscovite (9.6), ferrhydrite Fe(OH)₃·3H₂O (8.6), quartz (3.2), kaolinite (3.2), Mg-chlorite (2.2), 6—goethite (31.9), hematite (18.8), plattnerite (17.0), quartz (16.2), muscovite (11.1), anorite (3.4), zircon (1.7); 7—goethite (26.0), hematite (25.8), muscovite (14.5), quartz (13.0), kaolinite (8.5), massicot (4.7), zircon (3.5), Mg-chlorite (2.5), ilmenite (1.2). The tests were performed on the scanning electron microscope LEO 1430 VP E.A.Khromova (GIN SO RAS).

Table 9. The most feasible compositions of noble metal nanophases in various mineral types of ore microaggregates.

| Energy spectra of noble metals | Mineral types of ore microaggregates (numbers of polished sections in Table 8) | Impurities of ore minerals nanophases | Characteristics of the studied polished sections portions and geochemical micro anomalies | The most feasible compositions of noble metal nanoparticles |
|-------------------------------|---------------------------------------------------------------------------------|--------------------------------------|----------------------------------------------------------------------------------------|-----------------------------------------------------|
| Pt, Pd                        | Anglesite-plattnerite (3)                                                        | Platyrite                           | Grain 4.2 × 2.9 μm. Point anomaly Ru, Pb, S and F                                     | Pt, Pd, RuFe₅, RuO₂                                    |
|                               |                                                                                  | Pyrite                              | Late ore veinlet of 80 × 200 μm crosses muscovite-quartz with FeSi (3.9%) and siderite-hematite-kaolinite with graphite (2.9%) formations. Geochemical fields were not studied | Pt, Pd                                               |
| Pt, Pd                        | Ferrhydrite-plattnerite (5)                                                       | Not identified                      | In the area of 25 × 8 μm – anomalous fields of K, Al, F on the background of uniformly distributed values of Pt, Pd, Au, Ag over the ore grain entire area of the size 124 × 90 μm. The edgel part of this grain consists of pyrite (67.8%), graphite (9.8%), C₂O (3.3%). The boundaries of the geochemical anomalies Ru, Pb, Zn, Fe, S, F, Cl are determined by the grain outline | Pt, Pd, Au, Ag, their oxides and hydroxides. Ruthenium is in the form of Ru(CO)₁₂, RuF₅, RuO₂ |
| Pt, Pd, Ru                    | Hematite-goethite (7)                                                            | Platynerite, zinite, massicote, ilmenite | The coincidence of Pt, Ru, Au, Cl geochemical anomalies with the boundaries of the galena grain (1.5 × 0.5 mm), superimposed on the graphite-pyrite mineralization (pyrite – 80.5%, graphite – 15.2%) | Pt, Pd, Ru, chlorides Pt, Ru, Au and Cl               |
| Pt, Pd, Ru, Au, Ag            | Galena (1)                                                                       | Platyanerite hematite               | Ore film 32 × 20 μm on a quartz substrate containing native Al (0.2%) and culcite FeSi (1.3%) | Pt, Pd, Ru and Ag                                     |

Pt, Pd, Ru, Au, Ag Anglesite-galena (2) Native Pb, Fe and Zn
Continued

| Pt, Ru, Au, Ag | Manganese-plattnerite (Point 4, on Figure 5) | Manganeseosite, zincite, goethite | Ore film 20 × 12 μm on a quartz-muscovite carbonaceous substrate. Ru, Mn, Zn and S anomalies coincide with it boundaries | Pt, Ru, Au, Ag and their oxides, sulphates of Ag₂SO₄ type |

Table 10. Carbonyl genesis mineralogic and geochemical signs of noble metals ore nanominerals.

| Poly-elemental geochemical microfields of carbonyl type | Characteristic micro- and nanominerals and chemical compounds appeared from the decay of the carbons and their derivatives as a result of dynamometamorphism |
| --- | --- |
| Pb-Zn-Mn-Ru-Pd- Pt-Au- Ag-C-Cl-F | Native Fe, Pb, Zn, Al, silicide FeSi, moissanite, graphite, iocite, hematite, goethite, manganosite, zincite, plattnerite, massicot, ferrihydrite, portlandite, calcinite, naccolite, losite, carobiite, williamite, silica gel SiO₂·nH₂O, gelgraphite |
| Pb-Fe-Ru-S-F | C₂H₂O, oxides C₆O₅, C₆O |
| Pb-Pd-Pt-O-C | Pb-Pd-Pt-O-C |
| Zn-Ru-Au-Ag-S-Cl | Zn-Ru-Au-Ag-S-Cl |
| Pb-Cu-Ni-Au-Pt-S | Pb-Cu-Ni-Au-Pt-S |

Note: the structure of geochemical microfields is similar to the surfaces structures of carbonyl nickel coatings obtained at a substrate temperature of 500°C, and is very similar to the discrete distribution pattern of nanoparticles in carbonyl metal powders W and Mo [Syrkin, Babin, 1986], mechnochemically synthesized powders (hematite + Fe-Al intermetalld) [Lyakhov et al., 2005], hydroxylapatite [Petrakova et al., 2018].

Table 11. The formation and evolution sequence of the ore-forming system (OFS), the main factors of ore substance mobilization and.

| OFS formation stages (time intervals) | Sources of fluids and ore components | Mobilization and concentration factors of ore elements |
| --- | --- | --- |
| Ore preparative I—magmatic (Riphean–Vend) | Mantle | Fluid-magmatic. Ore-geochemical specialization of the volcano-plutonic ultrabasite-basite association |
| Ore preparative II—mud-volcanic (Cambrian) | Crustal | Hydrothermal-sedimentary with the participation of microorganisms during thermal sources functioning and the formation of travertines (“limestone”, “calcareaous siltstones”). |
| Ore preparative III—dynamometamorphic (medium? Paleozoic) | Crustal | Tectonic-metamorphic. Inheritance with amphibolites, crystalloslates and, serpentinites of ore-geochemical specialization of the ore preparative rocks stages I and II. |
| Break. The granitoids formation of the Angara-Vitim areal-Pluton (upper Paleozoic) | |
| Ore preparative IV—magmatic (lower Mesozoic) | Mantle-crustal | Fluid-magmatic, inherited ore-geochemical specialization of ore preparative stages I-III. |
| Ore stages I-IV—dynamometamorphic (Triassic) | Crustal | Tectonic-metamorphic. Deformational transformations of volcano-plutonic shoshonite-latite series rocks. |
| OFS biogenic transformation (Jurassic?—Cenozoic) | Crustal | Biogenic inheritance of ore stages geochemical specialization with partial conservation of noble metal high concentrations. |

Note: the structure of geochemical microfields is similar to the surfaces structures of carbonyl nickel coatings obtained at a substrate temperature of 500°C, and is very similar to the discrete distribution pattern of nanoparticles in carbonyl metal powders W and Mo [Syrkin, Babin, 1986], mechnochemically synthesized powders (hematite + Fe-Al intermetalld) [Lyakhov et al., 2005], hydroxylapatite [Petrakova et al., 2018].

This conclusion is confirmed by the experiments results [26] on mechnochemical synthesis from inorganic minerals (magnetite, siderite, quartz, calcite, pyrite)—hydrocarbons, which include N₂, CO₂, H₂, O₂.

**Ore substance source** From the submitted above sections it follows that the
leading element of Mykert-Sanzheevka field polycomponent ores is a lead. The overwhelming number of detected ore minerals appeared as a result of galena multiple deformational transformations. Lead in the form of plattnerite basically determines the ore mineralization productivity on the platinum-group metals. Therefore, knowing the sources of lead, we can judge about the sources of the most ore elements associating with it. Using the Pb-isotope galena characteristics (Table 12) we will determine the source of lead and respectively paragenic with it ore elements.

For this purpose, from carefully selected galenas of lead-silver ores four representative samples of the North Sanzheevka site for isotope analysis, lead was separated by the method [27]. The Pb isotope analysis was performed on the multichannel mass spectrometer Finnigam MAT-261, belonging to the Irkutsk center of collective use, in the simultaneous registration mode of different isotopes ion currents. The fractionation factor was established by multiple measurements of the NBS-SRM-982 isotope standard. According to the obtained Pb isotope composition data (Table 12) on two-stage model [28] the model age datings were obtained determining the time of lead separation from the source, if after that leads isotopic compositions were not changed as a result of mixing with variable amounts of radiogenic lead. And also this model is not applicable to those leads, which were consequently in rock systems with different ratios of U/Pb and TH/Pb.

The age limit for four samples was 558 - 649 million years, with values of µ(238U/204Pb) in the range of 8.8 - 9.1. The obtained value of µ is slightly lower than that of the Stacy-Kramers model (9.735), which indicates the involvement of a substance originating from the lower crust.

The obtained data indicate that the ore substabc primary sources of the Mykert-Sanzheevka OFS are mantle-crustal rock complexes of the earth crust lower part, composing the Vend-Riphean Greenstone belt (Selenga-Vitim South-West ending [5].

OFS evolution had an inherited multistage nature, with a tendency to be changed in time of ore-generating and ore-concentrating processes.

The uniqueness of Mykert-Sanzheevka OFS is that, that in the final stage of its evolutionary development, it goes into the biogenic regeneration phase, characterized by the change of the mobilization rock forms and ore substance concentration—biological (woody vegetation, microorganisms) [29].

Table 12. Pb-isotope galenas data of North Sanzheevka site.

| No. | Sample  | 206/204 | 207/204 | 208/204 | T (m. years) | 238U/204Pb |
|-----|---------|---------|---------|---------|-------------|------------|
| 1   | K-2012  | 17.222  | 15.344  | 37.217  | 556         | 8.86       |
| 2   | 4062    | 17.243  | 15.389  | 37.368  | 633         | 9.06       |
| 3   | 4081    | 17.263  | 15.404  | 37.417  | 648         | 9.13       |
| 4   | 4071    | 17.243  | 15.383  | 37.349  | 621         | 9.03       |

Note: The analyses were obtained using the method of La-ISP-MS V.F. Posokhov (GIN SO PAS).
11. Conclusions

The main implemented new research results of polycomponent noble-metal-polymetallic mineralization of Mykert-Sanzheevka ore field are:

- Its geological structure is specified to belong to the *charriage* thrust tectonic type presented by the ore-controlling *losange* consisting of rhombohedral and tetrahedral blocks-duplexes set, separated by narrow tectonic sutures made by ore dynamometamorphites;

- A number of ore-bearing rocks petrochemical types of shoshonite-latite volcano-plutonic association is selected, mainly consisting of dyke series (te-froite, trachybasalt, trachyandesite-basalt) and syenite rocks;

- Dynamometamorphic ore-bearing complex of rocks is divided into breccias, cataclasite, mylonites and mechanometasomatites of two varieties (mica-ceous-carbonate-quartz and argillite). The crushed-debris tectonites are referred to kakirites group;

- Deformational (mechanochemical) mineral new formations in rock-forming, secondary, and also accessory ore minerals of the primary rocks subjected to dynamometamorphism are revealed;

- 4 short-term stages of dynamometamorphites formation, characterized by the various associations formation of ore minerals are selected;

- A carbonyl model of the mineral microaggregates formation with films containing MPG nanoparticles, less often Ag and Au, is proposed;

- The most feasible mineral occurrence forms in ores of noble metals nanophases are identified;

- The age of 233 ± 19 million years of the ore-rock dynamometamorphic complex was determined by the isotope-geochemical Rb-Sr method;

- The evolutionary model of the Mykert-Sanzheevka field ore-forming system is proposed.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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