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Notes

Previous studies on the Erdenetiin ovoo porphyry copper-molybdenum deposit, Mongolia

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Abstract: The Erdenetiin ovoo deposit in the Bulgan Aimag of Mongolia is the largest copper producer of the nation. According to the information available, the deposit is of porphyry type and controlled by complicated combination of structure, magmatic and geochemical factors. In the mineralized area widely outcropped are two types pf porhyryies: (1) Selenge Comple of Permian time (270-240 Ma) and (2) Triassic Erdenet Complex. The mineralization is related genetically and spatially to the Erdenet Complex. Sericite alteration of the deposit shows the K-Ar age between 210 and 190 Ma. The ore-bearing porphyries intruded rhythmically into the Selenge Complex. Sulfur isotopic compositions of sulfides exhibit bimodal distribution but satisfactory explanation for this phenomenon has not proposed yet.

1. Introduction

The literatures available on the Erdenetiin ovoo deposit for western researchers are scarce although the deposit has been famous as largest copper producer in Mongolia (Fig. 1). One of the reason for this is that they appear in Russian in local publications. Thus the authors have listed up the information on this deposit mainly from Russian text books. The summary of these articles are stated in this note. As ore genesis of Erdenetin ovoo is complex and no data of high quality are available at present, this note aims only to show representative view on the deposit and does not necessarily discuss the detail of the mineralization and alteration.

The Erdenet area is located in the northern part of central Mongolia (Fig. 2). Many ancient pits were seen before the open-pit mining, from there native copper and turquoise were exploited possibly by small-scale miners. The first survey of the Erdenetiin

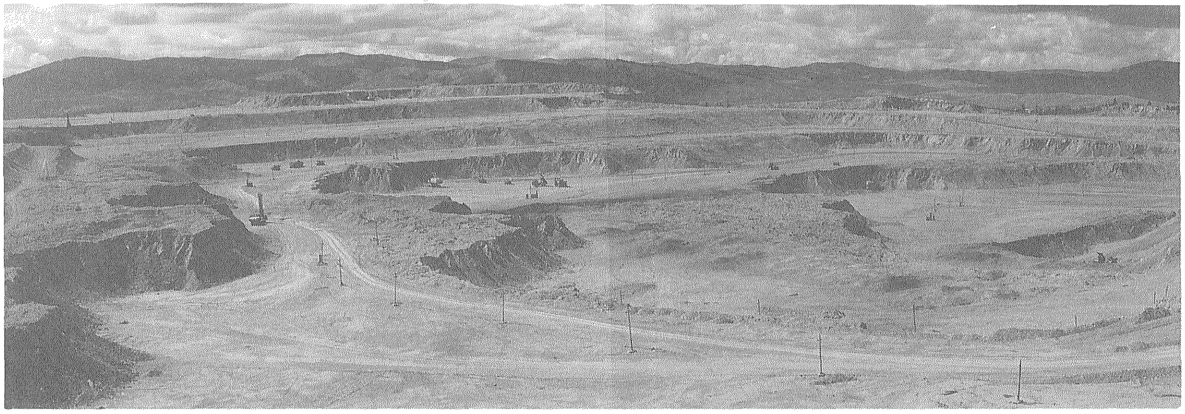

Fig. 1 Open-pit of the Erdenet mine.

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Keywords: Erdenetiin ovoo deposit, Erdenet Complex, porphyry copper, Selenge Complex, Mongolia

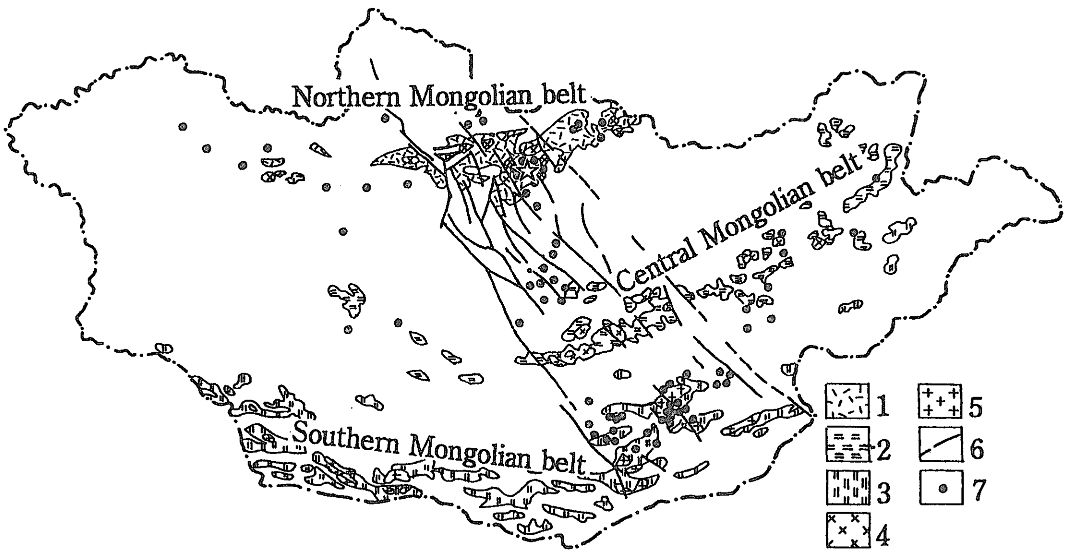

Fig. 2 Copper-molybdenum metallogenic belts of Mongolia (Sotnikov *et al.*, 1984).
Star indicates the location of Erdenetiin ovoo.

1-3 : Upper Paleozoic orogenic belts (1 : Northern Mongolia volcanic belt, 2 : Central Mongolia volcanic belt, 3 : Southern Mongolia volcanic belt), 4 : Intrusions of adamellite-granodiorite, 5 : Intrusions of gabbro-monzonite, 6 : Erdenet-Tsagaan Subarga ore concentrating zone, 7 : Copper-molybdenum deposits and occurrences.

ovoo field was done by Ushakov and Agomalyan in 1963 but they did not publish the result. They pointed out a possibility of existence of stockwork type copper deposit, and recommended for farther exploration. In 1977, the exploitation of the Erdenetiin ovoo deposit was started by open-pit mining. Recently, the oxidized and leached zone has been taken out, and the secondary sulfide enrichment zone is being recovered. After 1977, the information of the Erdenetiin ovoo can be found in many literatures: Sotnikov and Berzina (1985) and Sotnikov *et al.* (1979), Sotnikov *et al.* (1981), Sotnikov *et al.* (1984), Sotnikov and Berzina (1985), Gerel *et al.* (1984) and Gerel *et al.* (1985), Koval and Gerel (1986), Gerel (1989), Gavrilova *et al.*, (1984), Gavrilova *et al.*, (1988), Gavrilova *et al.*, (1989). Among these literatures, Gavrilova *et al* (1984), Gavrilova *et al* (1988), and Gavrilova *et al* (1989), are important. Because these researches were done by scientist including resident geologists, and the attention was paid on ore mineralogy and hydrothermal alteration of the deposit. These studies lead to the publication of a book "Porphyry Molybdenum-Copper Deposit of Erdenetiin ovoo", in 1989.

2. Regional setting and geology

Sotnikov *et al.* (1984) considered that a volcano-plutonic belt which designates Mongolian-Vitim Volcanic Belt in northern Mongolia hosts copper mineralization, and the Erdenetiin ovoo[*1] ore deposit is found at the intersection of this belt and the Tsagaan Subarga-Erdenet belt of NW-SE direction (Fig. 2). Volchanskaya *et al.* (1978) and Volchanskaya (1980) considered that the Erdenet ore-bearing area is situated at the intersection of faults with three different directions: E-W trending Erdenetiin fault, N-S trending Central Mongolian fault and N-W trending Khar-Airgiin fault.

The Erdenet area is located in the Orkhon-Selenge Depression which is a part of the northern Mongolian-Vitim Volcanic Belt where Upper Paleozoic to Mesozoic volcanism are recorded. The basement of the depression consists of Precambrian and Cambrian formations with Devonian volcano-sedimentary rocks. In the southern part of the depression, the Carboniferous marine sedimentary rocks and Triassic sedimentary and volcanic rocks are distributed. Permian intrusive rocks of the Orkhon-Selenge Depression was named the "Selenge Complex" by Mikhalov and Shabalovskii (1971). Inside the complex, three phases are noticed: first phase/gabbro, gabbro-diorite, diorite, monzonite, rarely monzodiorite; second (main) phase/subalkaline granite, granodiorite, granosyenite, syenite, quartz-syenite; third phase/two groups of igneous rocks, which occur separately. In the Erdenet area third phase of the complex includes stocks and dikes of granodiorite porphyry and granite porphyry, but in other places, the rocks are fine granular leucocratic granite, granite-aplite and microgranite (Mikhalov, 1971). Yashima and

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[*1] "Erdenetiin ovoo" is the name of the porphyry Cu-Mo deposit, while "Erdenet" is the name of the mining company.

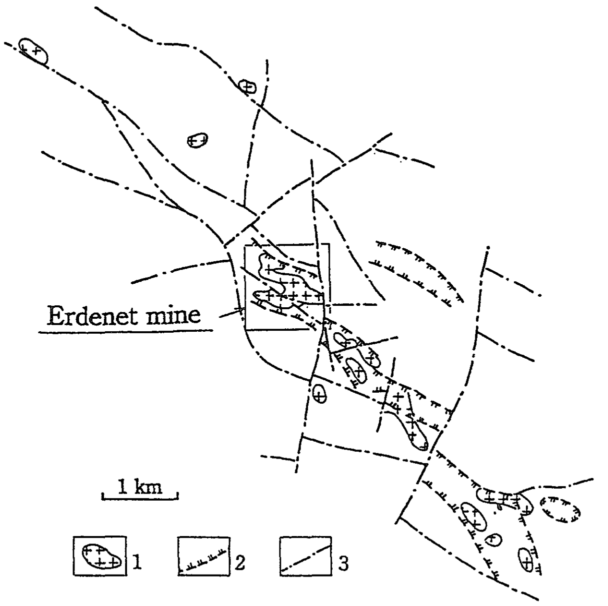

Fig. 3 Scheme of structure of the Erdenet ore bearing zone (after Sotnikov *et al.* 1984)

1 : granodiorite porphyry, plagio-granite porphyry of ore bearing complex, 2 : zones of ore-metasomatitic formations, 3 : faults.

Matrenitskii (1978), Yashima and Matrenitskii (1979), Matrenitskii (1977) and Matrenitskii (1981) clarified the following three independent associations in the Selenge Complex : 1/Gabbro syenite (P_{22}) ; 2/Syenite, granosyenite, granite (P_2-T_1); 3/Monzogabbro-diorite, syenite, granite porphyry (Erdenet type : P_2-T_1).

Gavrilova *et al.* (1984) summarized results of these studies and established following sequences of constituent rocks of the Orkhon-Selenge Depression :

1) Granite-granosyenite, T_3-J_1
2) Trachyandesite (Mogod suite), T_3-J_1
3) Molasse (Abzoga suite), T_2-T_3
4) Granite-granosyenite, P_2-T_1, 256-226 Ma (K-Ar)
5) Gabbro-syenite, P_{22}, 268-242 Ma (K-Ar)
6) Basalt-trachybasalt (suite of basic effusion), P_2
7) Sedimentary volcanogenic rocks (tuffaceous suite), P_{12}-P_{21}
8) Alkaline granosyenite and granite, 234 Ma (K-Ar)
9) Rhyolite-trachyrhyolite (suite of acidic effusions), P_1
10) Trachybasalt-trachyandesite (suite of basic and intermediate effusions), P_1
11) Interval for sedimentation
12) Gray color molasse, C_1-C_2
13) Sandy siltstone, marine, C_1

3. Geology of mineralized area

3.1 Geology

Mossakovskii and Tomortogeo (1976) divided the Orkhon-Selenge Depression into western and eastern blocks, and stated that the boundary between these blocks is the Bukhaingolyn fault. In the western block, the basement is deeper than that of eastern block. In the eastern margin of the Erdenet cross structure, the mass of alkaline basalt, trachybasalt, trachyandesite of the Upper Permian to Early Triassic age is lying with disconformity on the Permian rocks being intruded by gabbro-syenite and granosyenite-granite associations. In western side and in the southern part of the cross structure, the Permian rocks is covered with the sandy conglomerate of the middle to Upper Triassic age (Abzoga suite) and the trachyandesite mass with rhyolite and trachyrhyolite of the Upper Triassic to Early Jurassic age.

The mineralized zone of the Erdenet area is found in the "Erdenet cross structure" that is located in the northeastern part of the western block of the Orkhon-Selenge Depression. The area is widely occupied by Permian volcanic rocks (Hanyi Series) and felsic intrusions. The Upper Triassic to Lower Jurassic formation is also seen in the block and this formation consists of trachyandesite, trachybasalt-porphyry and trachyandesite-basalt with high sodium content (Kepejinskas and Luchitskii, 1974). The stratigraphy of volcanogenic and sedimentary rocks, and petrochemistry were reported by Kepejinskas and Luchitskii (1973) ; Kepejinskas and Luchitskii (1974); Mossakovskii and Tomortogeo (1972); Mossakovskii (1975); Mossakovskii and Tomortogeo (1976) ; Saltykovskii and Orolmaa (1977) and Gavrilova *et al.* (1984). The Hanyi series in the western block is characterized by a combination of pyroclastic rocks and bimodal calc-alkaline lava. The volcanic rocks of the Hanyi Series with lower Al_2O_3 content, subalkaline and alkaline composition are commonly developed in the western block.

The mineralized zone of the Erdenet area with 20-25 km length is located in the center of a narrow dome structure, which consists of granodiorite and monzogranite of main second phase of the Selenge Complex. Around the dome structure, the Permian volcanic rocks and the basement of the Orkhon-Selenge Depression are distributed. In the northern part of the mineralized zone, Precambrian metamorphic rocks are also distributed. Dikes and the porphyritic plutons intrude into the center of the mineralized zone. Mikhalov (1971), Khasin *et al*. (1977), Pavlenko *et al*. (1974) considered these porphyritic intrusions as members of the Selenge Complex. Yashina and Matrenitskii (1978) described that so-called Selenge Complex includes two groups : Upper Permian rocks and Lower Triassic rocks. The former is the general type of syenite-granosyenite-granite, and the latter includes porphyritic intrusions of monzogabbro-diorite-syenite-granite porphyry. Sotnikov *et al.* (1984) stated that Erdenet-type porphyritic intrusions are younger than Selenge Complex and have different origin from the Selenge Complex. Based on such studies, these intrusions are separated from the Selenge

Complex and are now called as "Erdenet Complex" (Sotnikov *et al.*, 1985). According to Gavrilova *et al.*, (1989) the chemical composition of the complex belongs to high alumina, potassium-sodium, calc-alkaline series. The Na_2O content is as high as 4.02–5.9 wt.% in all stages. Low Rb (40–68 ppm) and high Sr (800–1100 ppm) and Ba (1000–1100 ppm) are also typical feature of this complex. Based on the information stated above, the intrusive rocks within the Erdenet cross structure area could be divided into four groups:

1) Lower Paleozoic complex in the Precambrian basement
2) Upper Permian Selenge gabbro-granosyenite-granite complex
3) Erdenet Porphyry Complex
4) Upper Triassic to Early Jurassic leucogranite

Recent Mongolian geological kingdom tend to accept the distinction between Upper Permian Selenge Complex and Upper Triassic to Early Jurassic Erdenet Complex.

The sequence of all porphyritic phase is as follows:

1) diorite porphyry and microdiorite
2) granodiorite porphyry (main part), plagio-granite porphyry
3) fine grained, middle grained granodiorite in association with breccia
4) fine granular aplite with increase of alkaline

Being different from these description, Professor Gerel's group at Mongolian Technical University have an unique idea on the genesis of Erdenetiin ovoo. Gerel *et al.*, (1984), Koval *et al.*, (1985), Koval and Gerel (1986), and Gerel (1990) thought that the Erdenet type intrusions were formed as a series of magma with trachyte and trachyandesite and considered that the Early Mesozoic trachyte and trachyandesite to be genetically related to the mineralization.

In the following paragraphs we use Selenge and Erdenet classification to describe the mineralization at Erdenet. Based on this concept, it can be stated that most part of the Cu-Mo deposits occur within the Erdenet Complex.

3.2 Structure of the mineral deposit

The deposit is located in the intersection of faults of NE–SW, NW–SE, N–S and E–W trends. Southwestern and northeastern side of the Erdenetiin ovoo area have steep boundaries into which magma ascended. The mineralized zone includes a cupola of granodiorite of the Selenge Complex and stocks and dikes of the Erdenet Complex. The Erdenet Complex rocks are distributed as dome-like bodies and satellites in the cupola mentioned above. The porphyries of third phase have mostly E–W direction and steep falling, and the porphyries of fourth and fifth phase have NE–SW direction.

The Erdenet Complex is roughly divided into southeastern and northwestern stocks, and contains gigantic breccia body (Gavrilova *et al.*, 1989) due to explosive processes and complicated tectonics of the zone (Fig. 4). In the brecciated body, fragments of granodiorite-porphyry are cemented with dacite of several phases. An explosive pipe, possible neck of the volcanism, is seen in the complex. Granodiorite fragments in this pipe are cemented by plagioclase-porphyry, dacite and their autochthonous breccia. The southeastern stock has pear-like shape. The stock has 60 to 70° contact against the wall illustrating the upper part of dome-like shape, and vertical contact in deeper part and the contacts fall toward center of stock in the 950–1000m depth. The northwestern stock has horseshoe-like shape in surface with complicated steep boundaries. In deeper portion, the stock consists of two steep fallen bodies that are connected in upper horizons of flat-lying part with 300–400 m thickness. The northern contact of the stock with complicated shape fall steeply and vertically into southward.

The structure of hydrothermal system of the deposit can be outlined based on the distribution of SiO_2 anomaly. The distribution can be traced down to 1600 m, which implies that the hydrothermal system had at least about 1.6 km extension. Such situation is also suggested by the distribution of Na, K and Rb anomalies.

Quartz metasomatite and quartz breccia are widely distributed in the southeastern part of the southwestern stock. The quartz-sericite metasomatite has a two-layer structure. The lower layer (900–1100 m above sea level) corresponds to a root zone of hydrothermal system. It consists of separated pillar-like and steep fractured bodies. The upper layer (1100–1600 m above sea level) surrounds all stocks and satellites intrusions. The thickness of the upper layer are 650–700m in the southwestern part, 500–550m in the center and 300–400 m in northwestern part.

Gavrilova *et al.* (1989) considered that the lower layer of the deposit corresponds to a zone of vertical/steep-angle channel where ore bearing hydrothermal solution was focused. The upper layer of the deposit behaved as a chamber where the mineralizing fluid precipitated minerals. The contour of elemental concentration in the lower horizon suggests vertical channel of migration of elements, but horizontal shape of the contour line is common in the upper horizons. An important structural factor of the deposit is fault of N–S, NW–SE, E–W and NE–SW directions. The intersection of these faults determined the high level of fracturing-ability and of permeability. All these faults are older and have been active during the formation of the deposit, and after formation of the deposit some of them played an important role. Sotnikov *et al.* (1984) noted that faults of NW–SE, NE–SW and N–S directions give the structural control of the mineralized zone and the deposits (Fig. 3). The faults of NW–SE direction controlled the mineralization, the

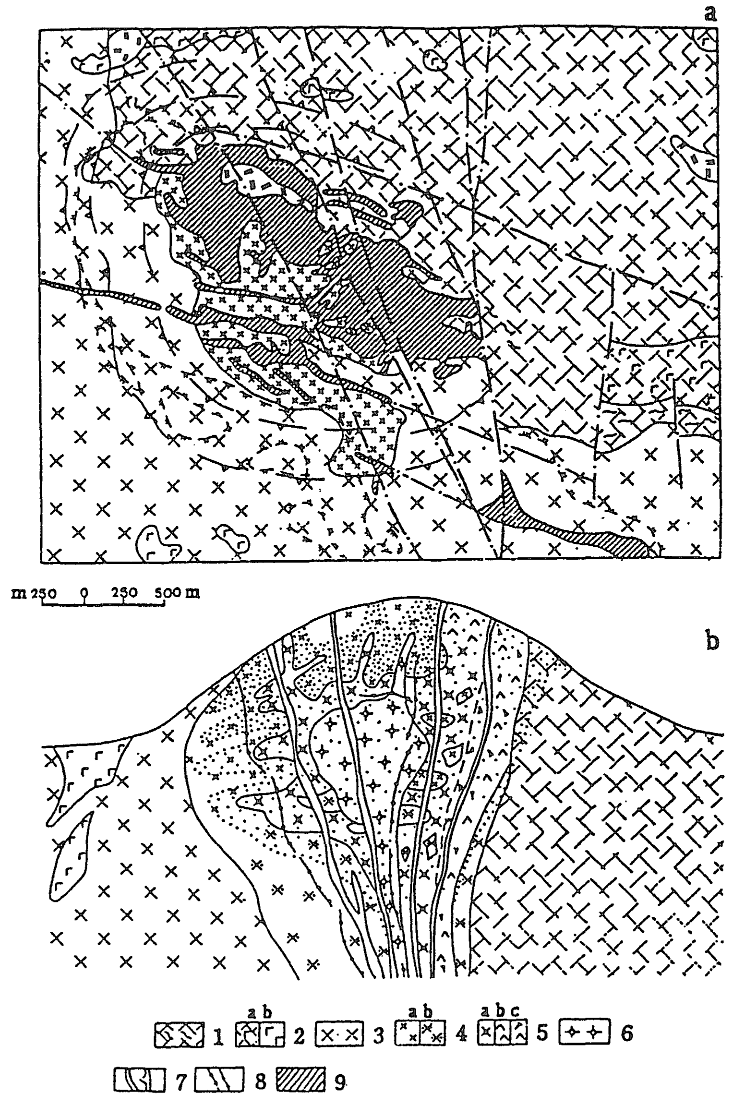

Fig. 4 The schematic structure of the Erdenetiin ovoo (Gavrilova *et al.*, 1989)
a : surface map of the Erdenetiin ovoo ; b : schematic cross section.
1 : Intrusive rocks with xenolith of shale ; 2 : gabbro, gabbro-diorite (a : Precambrian ; b : Permian Selenge complex) ; 3 : granodiorite of Selenge complex (a : fine-grained, porphyritic, b : middle-grained) ; 4 : granitoids of ore-bearing body (a : porphyritic, b : medium-grained, porphyritic) ; 5-8 : Erdenet complex : 5 : porphyries of first phase (a : granodiorite, b : dacite, c : magmatic breccia) ; 6 : porphyries of second phase (granodiorite porphyry, granite porphyry) 7 : porphyries of third phase (granodiorite porphyry, biotite-plagioclase porphyry, granite porphyry) ; 8 : dykes of fourth phase (plagio-porphyry, dacite, andesite) ; 9 : Erdenet complex.

distribution of hydrothermal alteration and the shape and focusing site of ore-bearing porphyritic intrusions. The right-lateral movement of N-S faults occurred during the ore formation, and the left-lateral movement of E-W and NE-SW faults occurred after ore formation (Gavrilova *et al.*, 1989). The N-S and NE-SW trending faults separate the Erdenet ore bearing zone into several parts, from northwest to southeast : 1/Northwestern block of the Erdenetiin ovoo deposit; 2/Central block; 3/Zavsarjn block; 4/Oyut block.

4. Porphyry copper-molybdenum mineralization

4.1 Timing of mineralization

The temporal relationship between porphyritic rocks and hydrothermal activity is controversial among researchers, and neither systematic study nor integrative review has been published. The granitoids of the Selenge Complex have 270-240 Ma K-Ar age. Quartz-sericite alteration product of the Erdenetiin ovoo deposit have 210-190 Ma K-Ar age. An explosive breccia from southern part of Erdenet ore bearing zone has 210 Ma

K-Ar age (Sotnikov *et al.*, 1985).

Khasin *et al.* (1977) considered that all primary minerals were formed within a stage between the injection of granodiorite porphyry stock and injection of dacite porphyry dike but did not report relationship between the porphyries and mineralization/alteration. Yakovlev and Tamsran (1977) proposed that the mineralization only took place in the third phase of the Selenge Complex. Sotnikov and Berzina (1989) observed that hydrothermal alteration and porphyritic intrusions have close spatial relationship, and considered that they are products of same magma-hydrothermal system. They also stated that the hydrothermal system at Erdenetiin ovoo was developed in the final period of development of the porphyritic system or after the solidification of the porphyries, but did not point which phase of intrusion was important for the mineralization. Gavrilova *et al.* (1989) examined each phase of the intrusions and proposed an idea on the relationship between magmatism and hydrothermal activity. They considered the first phase porphyry most important:

1) The first (main) stage of hydrothermal alteration of rocks developed after the intrusion of the first phase porphyry.

2) Second stage of hydrothermal alteration occurred after the second phase porphyry intruded with molybdenum mineralization. The hydrothermal solution in this stage caused brecciation of rocks and increased the number of quartz network

3) Porphyries of the third phase seems to have caused copper and molybdenum mineralization. The copper content is around 900-1900 ppm and molybdenum 10-40 ppm.

4) Porphyries of the fourth phase such as leucoporphyry, rhyodacite-dacite-andesite-dacite-tonalite porphyry accompany small amount of pyrite-chalcopyrite network.

5) Porphyries of the fifth (final) phase carry small amount of pyrite-quartz, molybdenite-quartz, chalcopyrite-pyrite-quartz networks.

Sotnikov and Berzina (1989) studied three phases of porphyries and concluded that the first and second phases are associated with mineralizations as follows:

1) Potassium feldspathization, with/without biotite.
2) Quartz-sericite alteration with pyrite.
3) Quartz-pyrite-molybdenite association with chalcopyrite.
4) Quartz-pyrite-chalcopyrite association with molybdenite.
5) Galena-sphalerite association.
6) Quartz-pyrite association.
7) Quartz (chalcedony)-carbonate association.

Gavrilova *et al.* (1984) and Gavrilova *et al.* (1989) clarified five stages of mineralization which accompanied by five phases of porphyritic intrusions.

4.2 Mineral association

Ore minerals, ore mineral association and mineralization stages are described by Yakovlev and Tamsran (1977), Khasin *et al.* (1977), Gavrilova *et al.* (1984, 1989) and Sotnikov and Berzina (1989). First description of minerals has given by Yakovlev and Tamsran (1977). By Khasin *et al.* (1977), the mineralogy of the deposit was shown as follows:

1) Major minerals of primary ore are pyrite, chalcopyrite, chalcosine, covellite, bornite, sphalerite, galena, magnetite, clay-ore, molybdenite, quartz, feldspar, and sericite. Accessories are gypsum and fluorite.

2) Predominant minerals of secondary enrichment zone are chalcosine, covellite, chalcopyrite, bornite, molybdenite, pyrite, clay-ore, turquoise, and chrysocolla.

3) Major minerals in oxidized and leached zone are malachite, chessylite, chrysocolla, brochantite, native copper, and powellite.

Khasin *et al.* (1977) is different from Yakovlev and Tamsran (1977) on the following points:

1) The chalcocite, covellite and bornite have two origin as hypogene (in primary ore) and as supergene (in secondary sulfide zone).

2) The turquoise is formed in secondary sulfide enrichment zone.

Gavrilova *et al.* (1989) clarified following mineral associations: magnetite, pyrite-quartz, molybdenite-quartz, chalcopyrite-pyrite-quartz, metacrystals of pyrite, pyrrhotite (cubanite)-chalcopyrite (drop-like), chalcocite-bornite, galena-sphalerite-tennantite (polymetallic) and zeolite-gypsum-carbonate associations. Magnetite association is developed widely at marginal portion of the deposit. The magnetite association is distributed in the southwestern, western and northwestern parts of the deposit. Pyrite-quartz association occurs in two places: one in the periphery with chlorite and the other in the center of the deposit forming special pyrite pillar: in the place, where is decreased the scale of quartz-sericite metasomatite. Pyrite is formed an insets of different size and a network with different thickness. Pyrite of the central part of the deposit is different from that of the periphery part which is large size and occurrence is inclusions of chalcopyrite, molybdenite and others. Molybdenite-quartz association distributes in all horizons of primary and secondary ores. But scales of the minerals are different. The association is presented molybdenite-quartz network and rare inset of molybdenite. In molybdenite-quartz network is marked a presence of pyrite and chalcopyrite. Chalcopyrite-pyrite-quartz association is developed in all horizons of the deposit. The ratio of pyrite and chalcopyrite in this association is changed vertically in the cross section, for example pyrite is dominant in the upper part, and chalcopyrite is dominant in the lower part. Chalcopyrite is replaced by chalcocite and covellite in the above horizons of secondary sulfide enrichment zone, and monomineral chalcopyrite occurs in size of 0.n mm in the lower part of the deposit, rarely with network of 0.5-1 cm thickness. Gavrilova *et al.* (1989) noted that chalcopyrite of the association is replaced by hypogene chalcocite and bornite in the lower part of the deposit. Pyrrhotite-chalcopyrite (drop-like) association occurs in massive pyrite of pyrite-quartz and chalcopyrite-quartz associations by drop-like form. Sometimes cubanite is observed in this association.

Hypogene chalcocite-bornite association was described by Gavrilova *et al.* (1984). Gavrilova *et al.* (1989) noted that the abundance of sulfur and copper in hydrothermal solution lead to form of hypogene bornite. They also marked that this association occurs in secondary sulfide enrichment zone or in deeper levels. This association distributes mainly in southeastern part of the deposit. This association consists of bornite, chalcocite, chalcopyrite, pyrite, sphalerite, tennantite, galena, molybdenite and rutile, and hematite occurs in the upper horizons, and magnetite occurs in the lower horizons. Monomineral bornite and chalcocite-bornite veinlets distribute widely. Metacrystals of pyrite is observed in cubic form including micro-inclusions of quartz, rutile, magnetite, pyrrhotite and others.

Polymetallic association occurs by separated zones of the deposit. This association consists of galena, sphalerite and tennantite, and forms network. Pyrite-quartz, molybdenite-quartz, chalcopyrite-pyrite-quartz associations are cut by this network. Zeolite-gypsum-carbonate non-ore association occurs by network, crossing all hypogene associations and all rocks in ore bearing stockwork. Zeolite is presented by clinoptilolite and laumontite. Gypsum is developed in the upper horizons of the deposit, and anhydrite develops in the lower horizons. Carbonates distribute widely and are presented mainly by calcite. Bornite-chalcocite-covellite supergene association distributes in secondary sulfide enrichment zone. Primary chalcopyrite, tennantite, sphalerite and other minerals are replaced by chalcocite, covellite and bornite.

Distribution of some minerals show the vertical zonal structure. Content of pyrite, sphalerite, galena, tennantite and especially clay-ore decrease toward deeper part. Clay-ore is found only in the upper part of the deposit. Changes of trace elements content in ore-minerals show the vertical zonal structure. For example, Se and Co contents in pyrite increase into deeper part of the deposit, but Ni content decreases. Se content in chalcopyrite increase into deeper part of the deposit. Anhydrite is distributed from 400 m to 1200m. Calcite increases in deeper part. Copper content in primary ore changes from 0.4-0.5% in the center of stockwork down to 500 m depth from the present surface, and between 500-1000 m depth, 0.2-0.3%. Molybdenum content is 0.025% in primary ore. Molybdenum has an opposite tendency to the distribution for Cu. Molybdenum content in marginal area of ore body is 0.02%, but 0.012% in the central part.

4.3 Hydrothermal alteration

Regionally the alteration shows a zonal distribution. The quartz-sericite zone is developed in the center of the stockwork being changed outward into sericite-chlorite and then carbonate-epidote-chlorite zone. In the upper part of the zone argilization is noticed. Sometimes potassium feldspathization with or without hydrothermal biotite and tourmaline is observed. The quartz-sericite zone changes the degree of alteration place to place with quartz-sericite ratio to host rock from 10 % to more than 70 %. An altered rock with the quartz-sericite composition>70 % is called secondary quartzite at the mining office. In the eastern part of the deposit the porphyritic stock and alteration zones are cut by a large fault of N-S direction.

4.4 Secondary zone

The vertical zonal structure is traced clearly as follows: oxidized and leached ore zone, secondary sulfide enrichment zone, primary ore zone. In the southeastern part, hypogene chalcocite-bornite association in upper part changes into chalcopyrite-pyrite-quartz association in deeper part.

The thickness of oxidized and leached zone changes from 10 m to 90 m and of secondary sulfide enrichment zone from 60 m in the side to 300 m in the center of the ore body. The content of Cu changes from 0.8% to 7.6% in secondary sulfide zone of central part of the deposit and is decreased into margin of the deposit. The content of Mo is changed from 0.001% to 0.76% in secondary sulfide zone. The primary ore zone is discovered in 150-500 m depth from surface and is marked in 1000 m depth by drill hole.

The secondary sulfide enrichment zone includes 85% of ore. The size of the ore body is 2800m by 300-1300 m in the surface and is 1000 m by 600 m in the primary ore zone.

5. Isotopic studies

Sulfur isotopic composition of ore was studied by Tugarinov *et al.* (1974). They determined the ratio of sulfur isotopic composition (Fig. 5). The $\delta^{34}S$ value of the sulfides ranges from −3.3 to +2.7 ‰ with an average value of +0.4 ‰ Molybdenite is weakly enriched in $\delta^{34}S$ (+1 to +1.5 ‰) compared to sulfides of copper and pyrite. The values show no difference in vertical section. Such homogeneous sulfur composition is a result of homogenization of sulfur before the mineralization. The value of $\delta^{34}S$ for the sulfates ranges from +9.1 to +12.5 ‰ The study evidenced two stages

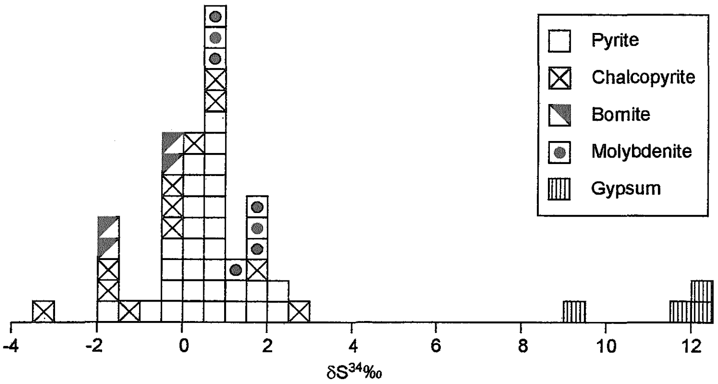

Fig. 5 Sulfur isotope composition of sulfides and sulfates of copper-molybdenum deposits of Erdenetiin ovoo. (Tugarinov *et al.*, 1974).

of hydrothermal ore formation. In the second stage, ore formation is characterized by increasing in oxidation potential of solution. The precipitation of molybdenite was related to the first stage, but chalcopyrite precipitated during the first and second stage. The additional study of sulfur isotope was done by Voinkov *et al*. (1977). The δ^{34}S values of pyrite and chalcopyrite show bimodal distribution with peaks at -2 ‰ (in network) and at 0 ‰ (in disseminated type), and bornite with peaks at -2 ‰ and 0 ‰. Based on such result, they interpreted the schematic process of ore formation in the Erdenetiin ovoo deposit as follows: (1) after intensive fracture of host rocks, the hydrothermal solution was precipitated small amount of ore in network and disseminated-type with sulfur isotope composition of similar to meteoritic composition; (2) new fractures which were related to the intrusion of dikes were developed and ore minerals were precipitated, and in this stage the hydrothermal solution was more oxidized. Perhaps second fracturing was more intensive and local, so the sulfides with decreased δ^{34}S were distributed locally only in the lower part of the deposit. The precipitation of larger size and disseminated chalcopyrite may be related with the second stage.

6. Concluding remarks

According to the information available, the Erdenetiin ovoo deposit is controlled by complicated combination of structure, magmatic and geochemical factors. Gavrilova *et al.* (1989) well described features of the Erdenetiin ovoo deposit as follows: 1) intermittent rhythmical injection of magmatic source and fluid-hydrothermal activity and associated ore mineralization; 2) close relationship between magmatic rocks, hydrothermal-metasomatic products and ore minerals in all phases or stages of the magma-hydrothermal activity; 3) change in morphology of magmatic rocks from stock-like to dike with concomitant decrease of the scale in magmatism and in ore-metasomatic process; 4) change in shape of ore-bodies from network-stockwork to veinlet or string. The mineralization is related genetically and spatially to stocks of porphyritic intrusions, Erdenet Complex. The ore-bearing porphyries intruded rhythmically into the Selenge Complex. Many authors are thinking that each phase of porphyry is associated with mineralization but some authors are assuming single pulse mineralization.

The mineralized zone in the Erdenet Complex holds a two-layer structure. The lower layer is steep-angle root of magma-hydrothermal system and includes separated pillar-like ore zones. The upper layer surrounds mostly all portion of the deposit and has sickle-like shape with a flat portion. Gavrilova *et al.* (1989) considered that the upper layer of ore body corresponds to a chamber, where ore bearing solution and fluid deposited.

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References

Gavrilova, S. P., Didenko, M. I., Orolmaa, D. (1988) The role of study of space picture and morphology of surface for discovery of central structure in region of palaeo-volcanism: Complex study of rare metal ore area, Publication of IMGRE*[2], Moscow, 8-28 (in Russian).

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*[2] IMGRE is the acronym of the Institute of Mineralogy, Geochemistry and Crystalgeochemistry of Rare Elements of Russia (*Editor's note*).

Gavrilova, S. P., Maximyk, I. E., Orolmaa, D. (1984) Features of magmatism and composition of ore of copper-molybdenum deposit Erdenetiin ovoo. *In* Endogenic Ore Formations of Mongolia, Nauka, Moscow, 101-105 (in Russian).

Gavrilova, S. P., Maximyk, I. E., Orolmaa, D. (1989) The molybdenum-copper porphyritic deposit Erdenetiin ovoo, Mongolian People's Republic, Publication of IMGRE*2, Moscow, 40 p. (in Russian).

Gerel, O. (1990) Petrology, geochemistry and mineralization of subalkaline Mesozoic magmatism in Mongolia. D. Sc. Dissertation, Irkutsk, 30 p. (in Russian).

Gerel, O., Koval, P. V. and Tseden, Ts. (1984) Geochemistry of Late Paleozoic porphyritic intrusive of Erdenet area. Abstracts of the Conference, Geochemistry and Geochemical Exploration Method of Ore Deposits, 37-38 (in Russian).

Kepejinskas, V. V., Luchitskii, I. V. (1973) The Permian volcanic association of central Mongolia. *In* Associations of Volcanic Rocks in Mongolian People's Republic and Its Composition and Stratigraphycal Position, Nauka, Moscow, 71-93 (in Russian).

Kepejinskas, V. V., Luchitskii, I. V. (1974) Continental Volcanic Associations of Central Mongolia, Nauka, Moscow, 72 p. (in Russian).

Khasin, R. A., Marinov, N. A., Khurts, Ch., Yakimov, L. I. (1977) Copper-molybdenum deposits Erdenetiin ovoo in northern Mongolia. *Geology of Ore Deposits*, no. 6, 3-15 (in Russian).

Koval, P. V., Gerel, O., Smirnov, V. N., Tseden, Ts. (1985) The porphyritic association of Erdenet area (petrography and chemical composition). *In* Questions of Geology and Metallogeny of Eastern Mongolia, The Kherlen Geological Expedition Issue, Ulaanbaatar, 59-112 (in Russian).

Koval, P. V., Gerel, O. (1986) Volcanic association of areas of porphyritic copper mineralization of Mongol-Okhotsk zone. *In* Geochemistry of Volcanic Rocks of Different Geo-Dynamical Situations, Nauka, Novosibirsk, 69-93 (in Russian).

Matrenitskii, A. T. (1977) A new data about volcano-plutonic association of Orkhon-Selenge depression of Mongolia. *In* Fundamental Problems of Geology of Mongolia, Nauka, Moscow, 101-104 (in Russian).

Matrenitskii, A. T. (1981) Characteristics of Upper Paleozoic orogenic magmatism and its ore-bearing (for example of Orkhon-Selenge depression of MPR). *In* Petrology and Mineralization of Magmatic Formation Indicator, Nauka, Moscow, 353-373 (in Russian).

Mikhalov, E. V. (1971) Intrusive complexes of northeastern Mongolia. *In* Magmatism and Metallogeny of Mongolian People's Republic, Nedra, Moscow, 60-77 (in Russian).

Mikhalov, E. V., Shabalovskii, A. E. (1971) Ore controlling significance of cross and diagonal faults in eastern and central Mongolia. *In* Magmatism and Metallogeny of Mongolian People's Republic, Nedra, Moscow, 142-147 (in Russian).

Mossakovskii, A. A. (1975) Orogenic structures and volcanism of Paleozoic of Eurasia and its position in process of the motion of continental earth crust, Nauka, Moscow, 318 p. (in Russian).

Mossakovskii, A. A., Tomortogeo, O. (1972) The scheme of stratigraphy of Permian and Mesozoic volcano-sedimentary formations of Orkhon-Selenge depression, Mongolian People's Republic, *Reports of the USSR Academy of Sciences*, **206**, no. 5.

Mossakovskii, A. A., Tomortogeo, O. (1976) Upper Paleozoic of Mongolia, Nauka, Moscow, p 127.

Movsesyan, S. A., Isaenko, M. P. (1974) Complex copper-molybdenum deposits. Nedra, Moscow (in Russian).

Pavlenko, A. S., Filippov, L. V., Orlova, L. P. (1974) Granitoid Formations of Central Asian Fold Belt, Nauka, Moscow, 223 p. (in Russian).

Saltykovskii, A. K., Orolmaa, D. (1977) Upper Paleozoic to early Mesozoic volcanism of northern Mongolia and western Zabaikalya, Nauka, Moscow, 202 p. (in Russian).

Sotnikov, V. I., Berzina, A. P. (1985) On the place of ore porphyries in the scheme for orogenic magmatism of copper-molybdenum ore knots of Mongolia. *Geology and Geophysics*, no. 5, 3-10 (in Russian with English abstract).

Sotnikov, V. I., Berzina, A. P. (1989) Prolonged discrete oriented development of ore-magmatic systems in copper-molybdenum formation. *Geology and Geophysics*, no. 1, 41-45 (in Russian with English abstract).

Sotnikov, V. I., Berzina, A. P., Bold, D. (1984) Regularity of distribution of copper-molybdenum mineralization of Mongolia. *In* Endogenic Ore Formations of Mongolia, Nauka, 89-101 (in Russian).

Sotnikov, V. I., Berzina, A. P., Skorokhodov, V. N. (1981) Metallogeny of copper and molybdenum of Mongolian People's Republic. *In* Questions of Magmatism and Metallogeny of Mongolian People's Republic, Nauka, Novosibirsk, 9-18 (in Russian).

Sotnikov, V. I., Berzina, A. P., Jamsran, M. (1985) Copper Ore Formations of Mongolian People's Republic, Nauka, Novosibirsk, 225p. (in Russian).

Sotnikov, V. I., Tamsran, M., Berzina, A. P. (1979)

About endogenic copper formations of Mongolia. *In* Geological Construction and Regularity of Distribution of Territory of MPR, Ulaanbaatar (local publication), 32-33.

Tugarinov, A. I., Voinkov, D. M., Grinenko, L. N., Pavlenko, A. S., (1974) Isotopic composition and sources of molybdenum-copper mineralization of Mongolia. *Geochimia*, no. 2, 171-178 (in Russian with English abstract).

Voinkov, D. M., Grinenko, L. N., Garamjav, D., Tamsran, M. (1977) About sequence of ore formation in porphyritic copper deposit Erdenetiin ovoo in Mongolia. *Proceedings of the USSR High Educational Institute, Geology and Exploration*, no. 1, 77-80 (in Russian).

Volchanskaya, I. K. (1980) The regularity of distribution of endogenic mineralization of Mongolia on faults of morphostructure analysis. *Geology of Ore Deposits*, no. 4, 86-96 (in Russian).

Volchanskaya, I. K., Baskina, V. A., Favorskaya, M. A. (1978) Meridional ore concentrated structures of central and eastern Mongolia. *Reports of the USSR Academy of Sciences*, **240**, no. 3, 666-668 (in Russian).

Yakovlev, B. A., Tamsran, M. (1977) Erdenetiin ore knot: Geology of Mongolian People's Republic, v. 3, Useful Ore-Mineralization, Nedra, Moscow, 167-175 (in Russian).

Yashina, R. M., Matrenitskii, A. T. (1978) Petrochemistry of volcanic and intrusive rocks of the Orkhon-Selenge depression (Mongolia). *Proceedings of the USSR Academy of Sciences*, no. 10, 26-42 (in Russian).

Yashina, R. M., Matrenitskii, A. T. (1979) Upper Paleozoic magmatism of northern Mongolia and its metallogenic features: Geology and Magmatism of Mongolia, Nauka, Moscow, 96-113 (in Russian).

Yashina, R. M., Pavlov, V. A., Arakalyants, M. M. (1977) Absolute age and structural story of the Paleozoic granitoid and alkaline rocks in the northern Mongolia. *Proceedings of the USSR Academy of Sciences, Geological Series*, no. 6, 20-33 (in Russian).

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モンゴル国エルデネティンオヴォ鉱床に関する研究の総括

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要　旨

モンゴル国最大のポーフィリー型銅鉱床であるエルデネティンオヴォ（通称エルデネット鉱山）について既存のロシア語文献を調査した．鉱床はエルデネットクロスストラクチャーに構造規制されている．鉱化帯には二畳紀のセレンゲ複合岩体とそれに貫入する三畳紀のエルデネット複合岩体が広く分布する．銅鉱化作用は後者に密接に伴っており，変質帯のセリサイトは210から190 Maの値を示す．したがって鉱化作用の主体はエルデネット複合岩体に起因すると考えられる．硫化物の硫黄同位体比は双峰性分布を示すが十分な研究は行われていない．