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Preliminary Study of Formation Mechanism of the Erdenetiin Ovoo Porphyry Copper-Molybdenum Deposit and Environmental Effects of Erdenet Mine, Northern Mongolia

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Abstract. The Erdenetiin ovoo is a biggest porphyry copper-molybdenum deposit in Mongolia, which is situated in Northern Mongolia. The deposit has been mined since 1978 at an annual rate of approximately 20 Mt of ore. As it plays important role to country's economy and still have controversies calling researchers interest. Ore formation mechanism of the Erdenetiin Ovoo deposit and environmental impacts of the Erdenet Mine are study subjects of our team.

Keywords: Erdenet, porphyry copper-molybdenum deposit, mine, environmental effect

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INTRODUCTION

The Erdenetiin Ovoo deposit, at the Erdenet Mine, is located in northern Mongolia, about 350 km northwest of the capital city Ulaanbaatar. Mongolian - Czechoslovakian geologists discovered the deposit in 1964. Former Soviet geologists completed detailed exploration work of the deposit and started mining operation in 1978. The Erdenetiin Ovoo is the largest Cu-Mo porphyry deposit in Mongolia, with estimated metal reserves calculated in 1991 of 7.6 Mt Cu and 216 600 t Mo in approximately 1490 Mt of ore @ 0.509% Cu and 0.015% Mo (Erdenet Mining Corp., 2002). The deposit has been mined since its first operation at an annual rate of approximately 20 Mt of ore from an open pit, which currently covers an area of 2500 x 1150 m. Since its first discovery, numerous researchers have studied the deposit by different point of view, there are still number of problems to be solved. Formation mechanism of the Erdenetiin Ovoo porphyry copper-molybdenum deposit and environmental impact of the Erdenet Mine are main subject of our study.

Key methods of investigation include field survey, petrographical and alteration studies, conventional geochemical analyses for rock and soil samples, SEM-CL study and fluid inclusion microthermometry.

GEOLOGY AND MAGMATISM OF THE ERDENET DISTRICT

Many researchers have considered the deposit in terms of geology, magmatism, alteration and related mineralization (Geology of Mongolia, 1977; Khasin et al., 1977; Sotnikov & Berzina (1989), Koval, Gerel et al., (1985), Koval & Gerel (1986), Gavrilova et al., (1984), Gavrilova & Maksimyuk (1990) and others. Based on regional geology, the Erdenet district is situated within the Orkhon-Selenge trough (Mossakovsky & Tumurtogoo, 1976), which was developed on an active continental margin (Figure 1 (Gerel & Munkhtsengel, 2005)).

The Erdenetiin Ovoo deposit is hosted by Late Permian to Early Triassic intrusive complex (Figure 2, (Gerel & Munkhtsengel, 2005)) which forms part of the extensional volcano-plutonic belt within the Orkhon-Selenge trough.

The deposit is a cylindrical body of quartz-sulphide stockwork veins hosted by an ore-bearing stock, which is centered on the multiphase pre-ore Erdenet Pluton of the Selenge Intrusive Complex (Khasin et al., 1977). The Erdenet pluton is composed of series of intrusive masses ranging in composition from gabbrodiorite to granodiorite and granite. The main phase is composed

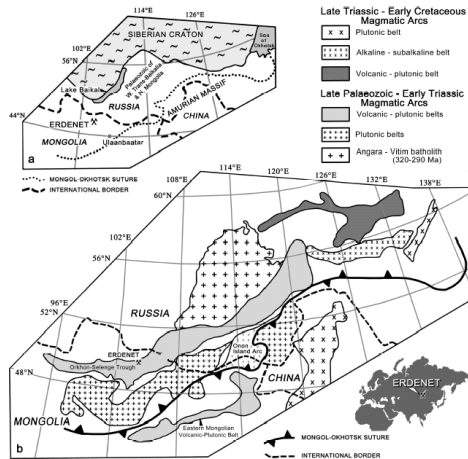


FIGURE 1. Schematic map of the Mongol-Okhotsk fold belt and the setting of the Erdenet ore deposit. **a.** Location and regional setting **b.** Tectono-magmatic elements of the Mongol-Okhotsk fold belt in the Khangay and western Khentey Mountains, northern Mongolia, northern China and southern Siberia.

of quartz diorite, granodiorite or porphyritic quartz-syenite and granites. Porphyritic granodiorite with feldspar phenocrysts is the dominant lithology, containing ovoid inclusions of quartz-diorite and quartz syenite. This granodiorite is coarse-grained and occurs as cupola-like bodies, which are porphyritic at surface, but become equigranular at depth, and are affected by weak quartz – K-feldspar alteration in association with veinlets containing chalcopryrite in occasion (Gavrilova & Maximyuk, 1990). Within the granite phase, plagioclase is usually rimmed by K-feldspar, while micrographic intergrowths in the groundmass are very common, and accessories are magnetite, sphene, apatite and zircon. Some of the rocks within the pluton are characterised by elevated alkalinity and comprise quartz-monzodiorite, monzonite to quartz-syenite and there is a characteristic paragenesis from biotite to amphibole and clinopyroxene. Biotite has a higher Fe content (Gerel, 1990). Mineralization related dykes and plugs wide spreading within the Erdenet district are distinguished as “Porphyry association” (Koval et al., 1985; Koval & Gerel., 1986) or “Porphyry Complex”. The age of the ore-bearing porphyries and their relationship to pre-mineralization magmatic associations are interpreted differently by many authors (Khasin et al., 1977; Gavrilova et al., 1984; Geology of Mongolia, 1977).

The porphyry associations and the ore-bearing stockwork are intruded into biotite-hornblende granites, granodiorites and quartz syenites of the Selenge Intrusive Complex. The porphyries crosscut the third phase granites of the Selenge Complex, which in turn

cuts the Permian sequence, including the uppermost mafic volcanic formation. Whole rock, amphibole and biotite K-Ar age determinations of the Selenge Intrusive Complex vary from 250 to 210 Ma (Gerel *et al.*, 1984). The Porphyry association intrusions (quartz-diorite to granodiorite porphyry and granite porphyry) post-date the Selenge Intrusive Complex intrusions and therefore cannot to be the last member of the Complex.

ALTERATION AND MINERALIZATION

Three principal alteration zones are developed within the Erdenetiin Ovoo deposit (Khasin et al., 1977), from core to the periphery, namely: i) sericitic (quartz-sericite) and late siliceous, ii) intermediate argillic (chlorite-sericite), and iii) propylitic (chlorite and epidote-chlorite).

Previous researchers have described slightly differing variations on the paragenesis of mineralization at the Erdenetiin Ovoo deposit, which may be amalgamated as follows: pre-ore i) quartz-sericite; followed by the ore stages of ii) quartz-chalcopryrite-pyrite; iii) quartz-pyrite-molybdenite-chalcopryrite; iv) quartz-chalcopryrite-tennantite; v)

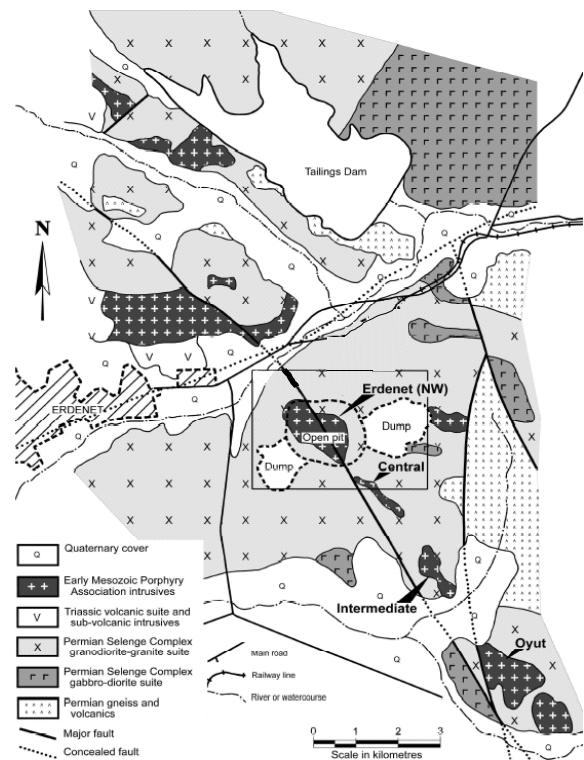


FIGURE 2. Location plan and geological sketch map of the Erdenet area, northern Mongolia. Topographic and cultural features from satellite image, geology based on Watanabe and Stein (2000).

quartz-pyrite-galena-sphalerite; vi) over-printing bornite-chalcocite-covellite; and post-ore vii) gypsum-calcite with pyrite.

STUDY PROGRESS

Major Problems of the Deposit and Mine

Currently major controversies for the Erdenetiin Ovoo deposit include the following problems.

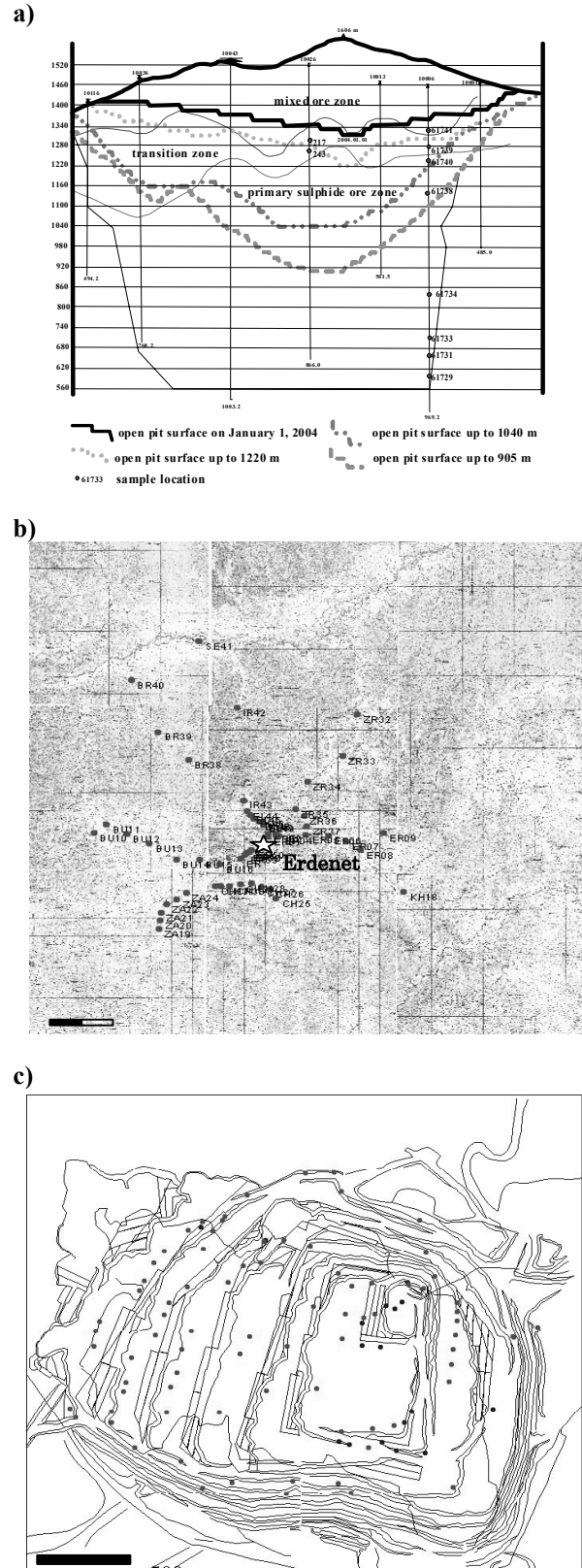
- Ore-dressing process at the Erdenet Mine is becoming complicated because of some alteration clay minerals. It is necessary to make clear which kind of minerals and where these minerals distribute mostly.
- Relation between host intrusive and volcanic rocks around the deposit is unclear. More detailed Sr-Nd isotopic study of igneous rocks around the deposit would be necessary.
- There are different ideas about the deposit formation model i). Host Selenge complex – Porphyritic intrusions – Mineralization, ii). Selenge complex – Mesozoic Mogod volcanic formation and its related porphyritic intrusions – Mineralization.
- Source and origin of fluids that formed Cu-Mo mineralization is not clear.
- The temporal relationship between porphyritic rocks and hydrothermal alteration is controversial. Origin of intermediate argillic alteration e.g. vapors condensate above the porphyry system and telescoping back over the porphyry system, etc. are also need more detailed study.
- Environmental impact of the mine is one of the major issues at the present time.

The Erdenet Mine plays great importance to the Mongolian economy, accounting for over half of the country's income and export earnings. As its great economic importance and complicated and interesting geological history, the mine and deposit still call for more detailed study.

Field Survey and Sampling

Field investigation has been done three times at the Erdenetiin Ovoo deposit and surrounding areas to collect rock and soil samples in summer 2004 and 2005. Open pit mine is sampled by horizons at surface and depth.

Quartz vein samples for fluid inclusion study from depth are taken from drill cores N10006 and N10026, which are drilled during the exploration works in 1980th. Soil samples are collected from dry and wet stream sediments around the mining area. Totally more than 100 rock samples and 54 soil samples are



collected for the laboratory analyses. Sample locations are shown in Figure 3.

Sample preparation and laboratory studies such as petrographical description of main rock types under microscope, SEM-CL studies of quartz vein samples, fluid inclusion microthermometry of quartz samples and geochemical analyses of soil samples are ongoing. **FIGURE 3.** Sample localities at the a) open pit surface b). cross section and drill holes and c) soil samples.

Research Target

- Petrographical study of the main rock types, i.e., porphyries, volcanics, host intrusive, basement rocks etc.

- Alteration studies utilizing principally polished thin-sections, powders and rock samples using XRD, PIMA and POSAM, to help characterize early very limited K-silicate alteration and the intermediate argillic alteration. The alteration studies should focus on defining alteration assemblages (alteration minerals that form together) and their paragenesis.

- Scanning electron microscope-cathodoluminescence (SEM-CL) analyses of quartz samples reveal textures that can yield insight into timing and physical conditions of quartz growth.

- Fluid inclusion studies of quartz veins. Role of magmatic fluid, from supercritical state, upward to where phase separation begins (liquid-vapor) to vapor only fluids at the apex of the porphyry system. In addition, the vertical zone will be examined. The fluid inclusion study will focus on these aspects, rather than document detailed information on temperature/salinity of fluid inclusions. A final part of the fluid inclusion study would be to examine the contents of selected fluid inclusions using Laser Ablation- ICP-MS.

- Environmental impact. Geochemical analysis of stream sediments will give the information about the mining pollution to the soil.

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