1. Introduction

Copper is one of the most important metals mining industry of Mongolia. According to monthly report of Ministry of Mineral Resources indicates that production of copper concentrate reaches up to 301.8 thousand tones and it makes almost 100% increase in comparison with last years production. Main type of copper mineralization is porphyry copper-gold and copper-molybdenum deposit, which are widely distributed along the ancient island arc terranes in the south and southwest Mongolia. Therefore, in this paper we tried to show main description of distribution characteristics of the porphyry copper deposits in south Mongolia, including main introduction of bigger copper deposits.

2. Regional Geology of South Mongolia

Traditionally, the territory of Mongolia is subdivided into a northern and southern domains. The southern domain is dominated by Lower to Middle Paleozoic arc-related volcanic and volcaniclastic rocks with fragments of ophiolites and serpentinite melanges. The evolution of these orogenic belts involved magmatism associated with a variety of geologic settings appropriate for formation of porphyry copper deposits. The southern domain contains six island arc terranes, which are from west to east Baitag, Edren, Khashaat, Gurvansaikhan, Mandal Ovoo and Enshoo (Fig. 1). The Baytag terrane occurs in southwestern Mongolia and extends into the eastern Junggar region of China (Fig. 1). It consists of Lower Devonian tholeiitic basalt, andesite, tuff, volcaniclastic rocks, Middle-Upper Devonian volcaniclastic sandstone, siltstone, chert, minor limestone containing conodonts, corals and brachiopods, Mississippian fossiliferous limestone and coal-bearing mudstone (Ruzhentsev et al., 1992b). The overall structure of the terrane is extremely complex with imbricated thrust stacks, melanges, high strain zones. The Edren terrane occurs east from Baidrag (Fig. 1) and contains two distinct sub units (Lamb and Badarch, 1997). The northern Huvin Har unit consists of Devonian metamorphosed thin-bedded siltstone, sandstone, minor chert, fossiliferous limestone, volcanic rocks and Carboniferous conglomerate, sandstone and limestone intruded by Permian alkaline granites, which are experienced intense brittle deformation, shearing and upright folding. The southern unit is dominated by Devonian and Mississippian volcaniclastic rocks, volcanic breccia, tuff, chert, clastic sediments, minor limestone, basalt and andesite (Yarmolyuk and Tikhonov, 1982). The terrane is imbricated by thrust faults, and has experienced intense brittle-ductile deformation and greenschist-grade metamorphism. The Mandalovoo terrane is a narrow and long belt in the northern part of the southern Mongolian domain, which extends to the east into NE China (Fig. 1). The terrane contains Ordovician and Silurian sandstone, siltstone, fossiliferous limestone, Lower-Middle Devonian conglomerate, sandstone, shallow-marine fossilrich felsic tuff, Upper Devonian pillow basalt, andesite, tuff, volcaniclastic rocks.
sandstone, chert, Mississippian marine sedimentary rocks and Devonian diorite and granodiorite plutons. Post-accretion assemblages include Pennsylvanian-Permian volcanic and sedimentary rocks, and granite plutons, and Jurassic-Cretaceous clastic rocks.

The Gurvansaikhan terrane occurs in the central part of the southern domain, south of the Mandalovoo terrane (Fig. 1). The terrane is composed of dismembered ophiolite, melanges, Ordovician-Silurian greenschist facies metamorphosed sandstone, siltstone, chert, volcaniclastic rocks, Upper Silurian-Lower Devonian radiolarian chert, tholeiitic pillow basalt, andesite, tuff, Middle Devonian-Mississippian volcaniclastic rocks, chert and minor olistostrome with coral limestone clasts (Zonenshain et al., 1975; Eenjin, 1983; Ruzhentsev et al., 1985; Voznesenskaya et al., 1986). The structure of the terrane is complex and dominated by imbricate thrust sheets, dismembered blocks, melanges, and high strain zones. The terrane contains porphyry copper deposits, such as Tsaagaan Suvarga and Oyu Tolgoi and several porphyry occurrences.

The Hashaat terrane occurs at the southwest of Gurvansaikhan terrane (Fig. 1). It consists of Precambrian marble, quartzite, metasandstone, Ordovician-Silurian greenschist facies metamorphosed andesite, tuff, limestone lenses, volcaniclastic turbidite, Devonian pillow basalt, andesite, gabbro, chert, volcaniclastic rocks containing brachiopods, Mississippian marine conglomerate, sandstone, chert, and siltstone (Badarch and Orolmaa, 1998). Ordovician to Carboniferous island arc volcanic rocks, and fragments of ophiolite occur along the southwestern continuation of the terrane in China (Wu, 1993). Overlap assemblages include Pennsylvanian, Permian, Jurassic and Cretaceous volcanic and sedimentary rocks, and granite plutons.

The Enshoo terrane occurs at the south east Gurvansaikhan terrane and extends to the east into Inner Mongolia, China (Fig. 1). It consists of variably metamorphosed and sheared gneiss, quartz-feldspathic schist, Devonian calc-alkaline basalt, andesite, dacite, tuff, volcaniclastic rocks, and minor limestone containing brachiopods, corals and bryozoans, Carboniferous shallow-marine sedimentary and volcanic rocks, Permian andesite, dacite, tuffaceous sandstone, siltstone, shale, limestone (Pavlova et al., 1991). The Enshoo Terrane is overlain by Jurassic to Cretaceous volcanic and sedimentary rocks, and intruded by Carboniferous and Triassic granodiorite, alkaline granite and leucogranite.

3. Copper mineralization of the Mongolia

Copper is one of the most important metals mining industry of Mongolia. According to monthly report of Ministry of Mineral Resources indicates that production of copper concentrate reaches up to 301.8 thousand tones
and it makes almost 100% increase in comparison with last years production. Main part of Mongolian copper reserve is detected in the porphyry type copper-molybdenum and copper-gold deposits, as Erdenetiin Ovoo, Tsagaan Suvarga and Oyu Tolgoi. The Erdenet deposit was found at late 1960's and mining activity is started since 1978. The Oyu Tolgoi is newly found large Au-Cu deposit, consisting of 6 porphyry type Cu-Mo and Cu-Au deposits and occurrence. There are several porphyry deposits and occurrences in south and south west part of Mongolia: Saran uul, Kharmagtai, Hunguit, Narin hudag, Bayan uul etc.

There are three copper metallogenic belts in the Mongolian territory: the Northern Mongolian, Central Mongolian and Southern Mongolian. Regarding to Mineral distribution map of Mongolia, copper mineralization is subdivided into several genetic types.

**Magmatic type copper mineralization** is mainly distributed at the northern and north western part of Mongolia in close relation with Middle Cambrian layered gabbroic intrusion. The representative mineralization areas are Oyut, Khairkhan, Serten Nomgon, Khotol, and Ons uul.

**VHMS type copper mineralization** is subdivided into several sub types. Cyprus type massive sulfide Cu-Zn mineralization is found in NeoProterozoic Khantaishir ophiolite belt, containing Naran davaa, Suvraa and Shar tal occurrences. Uralian type massive sulfide Cu-Zn mineralization is distributed in the Lake zone, Khan Khokhii zone of western Mongolia. Kuroko type Zn-Ph-Cu mineralization found in the Mongolian Altai belt, western Mongolia.

**Basalt hosted Cu mineralization** is distributed in the Khan Khokhii area in western Mongolia, Orkhon-Selenge basin, which hosts Erdenet copper porphyry deposit, in central Mongolia.

**Copper mineralization hosted by sedimentary rocks and shales** is characterized by stratabound sulfide mineralization accumulated within reddish colored schist, siltstone and sandstone. There are 25 occurrences of sediment hosted copper mineralization and mainly distributed at the western Mongolia along the Mongol Altai mountain range.

**Scarn type copper mineralization** usually associates with higher grade of gold and also show close spatial relation with Cu-Mo porphyry mineralization system. Scarn type copper mineralization is widely distributed in whole country and representative mineralized areas are: Lake zone, Urgamal zone in western Mongolia; Khangai and Bayankhongor zone in central and northern Mongolia and Gobi Altai zone in south-western Mongolia.

**Porphyry type copper mineralization** is widely distributed in whole country, and they are mainly related with small porphyric intrusions formed along the ancient island arc or continental arc setting. According to main constitute mineral and element abundance, this type is subdivided into three types: 1/porphyry copper mineralization, which is mainly found along the Paleozoic Gurvansaikhan island arc terrane in close association with Devonian and Carboniferous intrusive rocks. These are Kharmagtai, Ukhaa khudag, Ovoot khyar, Khunguut, Oyut Ulaan and Nariin khudag etc; 2/porphyry copper-molybdenum mineralization is widely distributed in the whole country and the biggest example is Erdenetiin ovoo deposit in northern Mongolia, Tsagaan suvarga deposit in South Mongolia; 3/porphyry gold-copper (Ag, Mo) mineralization associates with co-magmatic volcan-pluton complexes. They show spatial association with porphyry copper mineralization.

## 4. Copper porphyry mineralization of south Mongolia

In the regional tectonic and structural setting, the territory of Mongolia is subdivided into a northern and southern domains. The southern domain is younger and contains four ancient island arc terranes which hosts main copper, copper-molybdenum and copper gold porphyry deposits and occurrences of Mongolia. Half of all copper porphyry mineralization is found in South Mongolian ancient island arc terranes and there are more than 70 occurrences and 6 deposits.

### 4.1. Copper porphyry mineralization in Gurvansaikhan island arc terrane

The Gurvansaikhan terrane hosts main part of copper porphyry mineralization in south Mongolia. The terrane contains porphyry copper deposits, such as Tsagaan Suvarga and Oyu Tolgoi and several porphyry occurrences. The Tsagaan Suvarga porphyry copper-molybdenum deposit was found in early 80's. Studies on ore and host intrusive rocks indicate Ar-Ar sericite age of 364.9 ± 3.5 Ma (Lamb and Cox, 1998), and a Re-Os ages of 370.4 ± 0.8 Ma for molybdenite (Watanabe and Stein, 2000). The Oyu Tolgoi cluster of copper-gold and copper-molybdenum deposits was found on early 2000 and has mineralization age between 372 ± 1 Ma and 369 ± 1 Ma (Wainwrite, 2008).

**Oyu Tolgoi porphyry copper-gold, copper-molybdenum cluster deposits** one of the world's largest porphyry type mineralization system and is located in the
South Gobi region of Mongolia, approximately 550 km south of the capital, Ulaanbaatar, and 80 km north of the Mongolia-China border. The porphyry Cu-Au and Cu-Mo ore bodies in a north-northeast–trending zone at approximately 22 km long (Fig. 2), which includes eight known separate porphyry deposits (Table 1).

The porphyry Cu-Au and Cu-Mo deposits at Oyu Tolgoi are related to crystal crowded, porphyritic, high K calc-alkaline quartz monzodiorite intrusions that may have formed in an island arc environment (Kavalieris and Wainwright, 2005).

Based on U/Pb (Wainwright, 2008) and Re/Os (Kirwin et all, 2005), the deposits have similar ages and are all distributed along a thrust fault and bounded by steeper faults. Individual ore bodies vary in geometry, dominant hypogene ore mineralogy (chalcopyrite or bornite), dominant host rock (quartz monzodiorite, breccia, basalt), and alteration (Khasgerel, 2009). Some ore bodies are partly exposed at the surface; others are concealed beneath poorly consolidated Cretaceous sedimentary.

Structure of the Oyu Tolgoi deposit area includes complex networks of faults, folds, and shear zones. Most of these structures are poorly exposed on surface and can only be defined through integration of detailed exploration data, property-scale geological mapping, and geophysical data. Major structures strongly influence the distribution of mineralization by both controlling the original position and form of mineralized bodies (Fig. 3), and modifying them during post-mineral deformation events. The alignment of the Southwest Oyu, Central Oyu, and Hugo Dummett deposits, along with the elongate form of the Hugo Dummett deposit itself, strongly implies that an underlying north-northeast-striking fault or fault zone controlled emplacement of porphyry intrusions and related hydrothermal activity (David, 2012).

Copper, gold and molybdenum mineralization shows own independent characteristics on each deposit (Table 1, Fig. 3). The Hugo Dummett North deposit is the highest grade part of the Oyu Tolgoi deposits. The highest grades (>2.5 wt % Cu) are associated with bornite-rich mineralization in a narrow zone of intense A-type quartz veining, which is enveloped by advanced argillic alteration and overprinted by a quartz-sericite assemblage.

On the margins of the high-grade bornite-dominant zone, large chalcopyrite veins crosscut earlier sulfide assemblages. Enargite-pyrite occurs as veins in the outer parts of the Hugo Dummett deposits, within advanced argillic alteration, and enargite is also intergrown with tennantite and closely associated with high-grade bornite. The deep core of the Hugo Dummett North deposit is characterized by gold-bearing, bornite-chalcopyrite mineralization with subordinate tennantite (David, 2010).
The Central deposit is characterized as high sulfidation-state mineralization, with about 80% of the copper occurring as disseminated covellite. Pyrite accompanies the covellite and the gold content is low. The supergene chalcocite blanket overlies the pyrite-covellite mineralization over an area of about 500 x 700 m. The chalcocite blanket is of Cretaceous age based on K-Ar dates of 93 and 117 ± 1 Ma for supergene alunite (Perelló et al., 2001). A small occurrence of exotic copper is developed in a Cretaceous paleochannel on the northern side of the Central deposit.
The Southwest deposit comprises a large part of the southern Oyu deposits. Chalcopyrite dominates in the Southwest, Heruga, and Heruga North deposits but in their deeper parts bornite content increase. In the South deposit, chalcopyrite and bornite occur in equal proportions. Gold is associated with chalcopyrite and bornite.

> **Tsagaan-suvarga porphyry copper-molybdenum deposit** locates in south Mongolia within Gurvansaikhan island arc terrane, southeast 565 km from Ulaanbaatar. The deposit was first noticed by local herdsmen on 1964 and discovered in early 80's. The deposit is hosted in a multiphase middle paleozoic syenite-diorite, granodiorite, granosyenite and syenite, which are intruded by dikes of gabbro porphyrite and andesite porphyrite. Mineralization is associated with late-stage porphyry intrusions (Fig. 4). Chalcopyrite-bearing quartz stockworks are developed over a 1 km by 300m area, and the ore has been traced to depths up to 600 m.

During exploration project found 5 ore bodies, the biggest one is Serven Sukhait ore body, which is usually described as Tsagaan Suvarga deposit (Fig. 5).

Main ore mineral is chalcopirte and contains minor bornite, pyrite and molybdenite and rarely sphalerite and galena. Chalcopyrite forms as thin veinlet, impregnation, partly massive texture together with quartz and quartz-muscovite vein. Bornite is rare and usually associates with chalcopyrite and chalcocite. Molybdenite associates with chalcopyrite and bornite and individually found in the quartz vein. Average copper content on ore is 0.54% and molybdenum content is 0.19%. Result of metallurgical test work indicates that the ore contains gold 0.08 ppm, silver 2.64 ppm, rhenium 0.39 ppm, sulfur 0.19%. Result of metallurgical test work indicates that the ore contains gold 0.08 ppm, silver 2.64 ppm, rhenium 0.39 ppm, selenium 8.3 ppm and tellurium 12.8 ppm.

Host rock is altered and developed silicification, with stringers of quartz, quartz-sulfide and quartz-sericite-sulfide veins, containing copper ore higher than 0.4%. There is post stage carbonate, chlorite alteration without copper mineralization. Molybdenites from the deposit were dated at 370.1 ± 1.2 and 370.6 ± 1.2 by Re-Os dating (Watanabe and Stein, 2000).

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The ore zones at Altan Tolgoi, Tsagaan Sudal and Zesen Uul are associated with a core of quartz veins that were intensely developed in and the quartz diorite intrusive stocks and/or dykes. Au-Cu mineralization of Kharmagtai is represented as Au-Cu porphyry center, breccias pipe and gold base metal bearing silicified zones. There are 4 Au-Cu ore bodies: Zest, Altan Tolgoi, Tsagaan Sudal, Khartsaga and Burged.

### 4.2. Copper porphyry mineralization in Mandal ovo island arc terrane

The Mandalovoo island arc terrane is a narrow and long belt in the northern part of the Gurvansaikhan island arc terrane. It is one of the most familiar copper porphyry host structure in the southe Mongolia. Copper porphyry deposits in this terrane are medium to small size and they are usually tend to show higher content of gold and also characterized by tourmaline breccia related gold-copper mineralization. Oyu Ulaan, Nar'in Khudag, Bronze Fox deposits and other several occurrences within Mandakh intrusive complex belong to this terrane.

**Oyu ulaan copper deposits** is located south 500 km from Ulaanbaatar at the northeast part of Mandalovoo island arc terrane. The deposits area is composed of Devonian Undur uud formation (metamorphosed basalt, andesitebasalt with thin layers of red chert, sandstone and limestone) Lower Carboniferous Gunbayan formation volcanogenic-sedimentary sequences, Lower Carboniferous Doshiin Ovoo formation (andesite porphyrite, dacite porphyry, rarely tuff breccia and lava-conglomerate), which are intruded by Middle Carboniferous Mandakh complex granitoid rocks and dike series (Fig. 8). There are one deposit and 6 occurrences at the Oyu Ulaan area as following: Oyu ovoo copper deposit, Apltie copper occurrence, Bornite (stockwork) occurrence,
Diorite occurrence, New area occurrence and Old occurrence.

The Oyut Ulaan copper deposit was first found by Mongolian geologist Badamdorj on 1960, who noticed 4 remnants of ancient mining activity. Result of chemical analyses for the samples, taken from remnant of mining activity detected copper content 8.87% to 7.95%. The deposit is composed from quartz-tourmaline breccia body, eruption pipe. Tourmaline-quartz body is 400 x 200 m and 150 x 130 m in size. Copper mineralization presents as malachite, azurite, chalcocite, chrysocolla. Chalcopyrite associates with quartz tourmaline body and quartz vein. Copper content is 1.5-9.05% at the outcrop samples, and it decreases in the

![Geologic map of the Tsagaan Suvarga deposit](image1)

![Representative core samples and microphoto of Tsagaan Suvarga deposit](image2)
Fig. 6  Schematic geologic map of the Kharmagtai gold copper deposit area (Openfile report, 6422).

Fig. 7  Representitative core samples and microphoto of Kharmagtai deposit.

depth as: 0.02-0.07% copper in 4-14 m depth; 0.02% at 16-49 m depth; 0.05% at 55-73 m depth; 0.3% at 65-68 m depth. Result of laboratory analyses indicates: As=0.02%, Mo=0.01%, Bi=0.01%, Ag=30 ppm, Au=0.01 ppm. The Aplite occurrence located south 1.4 km from Oyut Ulaan deposit and consists of coarse grained partly porphyric granodiorite, intruded by small body of granosyenite, aplite dikes. Copper mineralization associates with potassic altered carbonate altered part of granodiorite as inmpregnations of malachite, azurite, rarely chalcopyrite. Lithogeochemical surveying carried out by 500 x 100m net and detected weak geochemical anomaly with copper content ranging from 0.02% to 1.0%, zinc content 0.01%. Bornite occurrence is located north west 4.5 km from Oyut Ulaan deposit. Result of chemical analyses detected copper content 0.3-1.69% at the interval 26.4-70.0 m depth. Copper content at sample taken from trench is 0.3-1.73%. The Diorite occurrence is located at the exo-contact part of small diorite body. Copper mineralization associates with strongly silicified potassic altered part of the diorite and presents as quartz stringers with malachite and chalcopyrite. Quartz veins and stringers are 2.5 cm in thickness and contains bornite, chalcopyrite, malachite, azurite and iron
Fig. 8 Schematic geological map of Oyu Ulaan cluster of copper porphyry occurrences (Erdene Mongol Website).

Fig. 9 Schematic geological map of Oyu Ulaan cluster of copper porphyry occurrences.
oxides. The Old occurrence locates north east 2.5 km from Oyut Ulaan deposit. Copper content at sample taken from trench is 0.1-0.62% and molybdenum is 0.002%, bore core samples show 0.2% copper content. Copper mineralization presents as chalcopyrite and pyrite with small amount of molybdenite and tennantite. At the central part of the mineralization found quartz-hematite-bornite-chalcopyrite vein with thickness up to 3-4 m. Result of chemical analyses at this part detected copper 0.71-4.66%.

4.3. Copper porphyry mineralization in Edren island arc terrane

The Edren terrane occurs north east from Baidrag and recent exploration result found several copper-molybdenum and molybdenum-copper occurrences and deposits. The Edren island arc terrane hosts Zuun mod Mo-Cu deposit, Khul Morit Cu-Au deposit, Khadat Gun Cu-Mo deposit and several occurrences as well as Au-Zn vein type occurrences. The biggest one is the Zuun mod molybdenum-copper deposit, which has 298 ± 1 Ma (Jargalan and Altankhuyag).

**Zuun mod porphyry molybdenum-copper deposit**

is located at the south east edge of Edren island arc terrane. It is south west 900 km of Ulaanbaatar. The deposit are was first found during geological mapping at scale 1:200000, then Erdene Mongol company carried out wide range exploration activity and discovered molybdenum-copper porphyry deposit. The dewposit area is composed from Upper Devonian to Carboniferous felsic to intermediate volcanic rocks and minor intercalated volcaniclastic sedimentary rocks crosscut by syenitic to granitic intrusions of Carboniferous age (320 to 315 Ma) and biotite+/-hornblende granodiorite cut by biotite microgranite and alkali granite of approximately coeval age (302 Ma) with associated porphyry-style quartz veining, hydrothermal alteration, and disseminated sulfides (298 Ma), which are in turn cut by syn- to post-mineral dikes of intermediate to felsic composition.

These are unconformably overlain by a thick sequence of poorly consolidated Cretaceous conglomerate to siltstone and by unconsolidated Quaternary alluvium. Within the Zuun Mod porphyry complex, three dominant structure systems are identified; NE-SW, NW-SE, and E-W.

The NE and NW systems are interpreted to be conjugate sets likely reflecting near N-S compression related to arc subduction. The E-W system appears to be later and controlled the emplacement of dykes which resulted in an intense localized superimposed fracture-cleavage. It is apparent from the preferred NE and NW orientation of mineralised intrusives, quartz zones and porphyry-related alteration zones, that mineralised fluids were focused primarily within these structural corridors.

Mineralization contains equal amounts of copper and molybdenum. Rock sampling values up to 0.4% Cu and 49 ppm Mo. The dimensions of the copper and molybdenum soil anomalies increased but remained open to the south and
Hydrothermal alteration is best developed in intrusive rocks and is characterized by widespread weak to moderate potassic and weak to intense phyllic alteration, corresponding with areas of quartz veining, and a widespread weak argillic overprint which is probably related to Cretaceous to recent weathering. A peripheral halo of propylitic alteration is difficult to distinguish from regional lower greenschist facies metamorphism. Tourmaline is locally abundant in both andesite and intrusive rocks. PIMA analysis of surface sample showed a vector of increasing temperature approaching zones with stockwork veining, based on illite crystallinity and mineral species. Petrographic examination of core samples from these higher-temperature areas showed a locally abundant fluorine-rich mineral assemblage which is attributed to early, high-temperature vapor phase alteration that was contemporaneous with or closely postdates strong potassic alteration (k-spar and biotite).

References