Sulfide MINERALs texture AT THE HUGO DUMMETT PORPHYRY Cu-Au DEPOSIT, OYU TOLGOI, MONGOLIA

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Abstract

Mineralogical studies of ore and alteration minerals have been conducted for the Hugo Dummett porphyry copper deposit. The Hugo Dummett porphyry copper gold deposit is located in the South Gobi region, Mongolia and currently being explored. This deposit divided into the Cu-rich Hugo Dummett South and the Cu-Au-rich Hugo Dummett North deposits. The Hugo Dummett deposits contain 1.08% copper (1.16 billion tonnes in total) and 0.23 g/t gold (Oyunchimeg et al., 2006). Copper-gold mineralization at these deposit are centered on a high-grade copper (typically > 2.5%) and gold (0.5–2 g/t) zone of intense quartz stockwork veining. The high grade copper and gold zone is mainly within the Late Devonian quartz monzodiorite intrusions and augite basalt, also locally occurs in dacitic rocks. Intense quartz veining forms a lens up to 100 m wide hosted by augite basalt and partly by quartz monzodiorite. Although many explorations have been carried out, only a few scientific works were done in the Oyu Tolgoi mining area. Therefore the nature of copper-gold mineralization and orgin of the deposit is not fully understood.

Copper-gold mineralization in the Hugo Dummett deposits occurs in dominantly quartz monzodiorite and minor augite basalt, dacitic rocks and locally biotite granodiorite. Chalcopyrite, pyrite, bornite, molybdenite, tennantite, tetrahedrite, enargite, sphalerite, chalcocite, covellite, eugenite, galena and gold occur as main ore minerals in the Hugo Dummett North and South deposits. These sulfides occur as: (1) a vague vein-like trail 1-3cm long and 2-3 mm wide, (2) minute, discontinuous cracks within quartz (micron scales), and (3) irregular blebs/spots (micron scales)and (4) disseminated within the sericite and plagioclase, commonly concentrated in the quartz. Sulfide minerals commonly display as a replacement, intergrown and minor exsolution texture in the both of the Hugo Dummet deposits.

1. Introduction

Oyu Tolgoi Cu-Au porphyry system is located in the south Gobi region, Mongolia, approximately 650 km south of Ulaanbaatar and 80 km north of the Chinese-Mongolian border. This porphyry system is situated within a sequence of Devonian rocks in the Gurvansayhan terrane, which is a large arc system that spread to Western China through the Altai Mountains in Western Mongolia from north eastern Mongolia (Fig. 1). Lamb and Badarch (1997) interpreted that the Devonian basalts formed the sequence has been interpreted to have formed in island-arc environment as part of the extensive Paleozoic Tuva Mongol arc. It is possible that at the time of its formation, the arc looked much like the modern-day Western Pacific, where subduction zones reverse polarity such as within the Phillippine arc, or exhibit sharp bends, such as within the Britain-Solomon-New Hebrides arc (Lamb and Badarch, 2001). The South Gobi district of Mongolia contains a number of major Cu-Au deposits, including Oyu Tolgoi, which is one of the world's largest porphyry Cu-Au deposit. The huge metal inventory of the Oyu Tolgoi has created significant interest in the genesis of the deposit and especially the in identification of particular features or processes, which may have contributed to its large size and high grade copper and gold.

Oyu Tolgoi copper-gold porphyry system consists of north to northeast trending and is 6 km long mineralized zone with five deposits: South Oyu Tolgoi, South west Oyu Tolgoi, Central Oyu Tolgoi, Hugo Dummett North and Hugo Dummett South (Khashgerel *et al.*, 2006). This porphyry system is characterized by extensive advanced argillic alteration zones caused by extreme hydrolytic alteration, similar to those observed in many porphyry Cu-Au districts worldwide. A leached outcrop with supergene alunite and Cu oxide minerals occurs as a prominent hill at Central Oyu Tolgoi. This outcrop was noted by Magma Copper Company geologists in September 1996 (Perello *et al.*, 2001) and ultimately led to the extensive exploration undertaken by BHP Minerals and subsequently by Ivanhoe Mines Mongolia Inc., which culminated in the discovery of the high-grade primary mineralization of the Hugo Dummett North and South deposits in 2003. The South Oyu Tolgoi deposit is characterized by subcircular zone about 600x400 m, with quartz viens and irregular quartz monzodiorite dikes intruding basaltic host rocks. There is observed malachite in the oxide and overlie hypogene sulfide zone. Southwest Oyu Tolgoi deposit is consists of pipelike high-grade zone of copper > 1% and centered on small quartz monzodiorite intrusions, intruding basaltic host rocks. Each of the five deposits of this large system has variable features and appears related to separate intrusive centers. All deposits are related to Late

Devonian quartz monzodiorite intrusions with similar field characteristics (Khashgerel et al., 2006).

Study of ore mineralogy from the Hugo Dummett North and South porphyry Cu-Au deposit is important to understand ore-forming processes of the newly discovered largest deposit in Mongolia. This investigation to describe ore minerals and ore minerals texture of the Hugo Dummett deposits.

2. Geological setting

The Oyu Tolgoi Cu-Au porphyry system is located in the middle to late Paleozoic Gurvansayhan terrane (Badarch et al., 2002; Fig. 1), which comprises basaltic to dacitic volcanic and sedimentary rocks. Stratigraphy of the Oyu Tolgoi porphyry Cu-Au system described by Wainwright et al., (2005) and Minjin et al., (2005) that deposit is underlain by Late Devonian basaltic to dacitic volcanic and sedimentary rocks belonging to the Alagbayan Formation overlain unconformably by Early Carboniferous basaltic volcanic rocks, with minor sedimentary units, belonging to the Sainshandhudag Formation. Alteration and mineralization occur in the lower part of the Late Devonian sequence augite basalt, overlying dacitic rock and upper part of the Late Devonian quartz monzodiorite and biotite granodiorite intrusions (Fig. 2). The dacitic rocks age based on U-Pb zircon dating, is 365 ± 4 Ma (Wainwright et al., 2005). Cretaceous red soil, up to 45 m thick and Quaternary gravel and sand cover most of the mineralized area. Elevation is about 1,100 m and the relief in the district is minimal <20–30 m (Khashgerel et al., 2006).

3.Hugo Dummett North and South deposits

The geology, alteration, and mineralization are similar at Hugo Dummett South and North. The main differences between Hugo Dummett South and North are that at the former, the Au-rich quartz monzodiorite is absent, and advanced argillic alteration is more extensive and overprints the quartz monzodiorite intrusions and basaltic host rocks to a relatively deeper level; in addition, the zone of high-grade mineralization (>2.5 wt % Cu) is about one-quarter the size of that at Hugo Dummett North. Another important difference is that the upper parts of the Hugo Dummett North deposit are extensively cut by postmineral biotite granodiorite intrusions (Fig. 3). Main mineralized zone at Hugo Dummett South being several hundred meters higher in elevation at present (Fig. 3), it is possible that Hugo Dummett South may have formed at a shallower paleodepth than Hugo Dummett North (Khashgere et al., 2006). These deposits mineralization associated with intense quartz veining and quartz monzodiorite intruded into basaltic volcanic host rocks.

4. Methology

Textural and petrographic relationship of sulfides was described in detail and their chemical composition under reflected light and with a Scanning Electron Microscope Energy with Dispersive Spectrometry (SEM-EDS). The number of samples used in the experiments was about 80 thin sections. This work was based only on drill core samples collected from the Hugo Dummett deposits (Fig. 3). Analyses were also performed using a JEOL-JSM5410 energy dispersive electron microprobe at the Tohoku University. Instrumental conditions were as follows: 15 kV accelerating voltage, 20 nA beam current, and ISUS software was functional

5. Ore minerals of the Hugo Dummett North and South deposit

The both Hugo Dummett deposits are oriented to north and northeast and extended over 2.5 km in length. High grade mineralization is enclosed by two major faults, West Bat and East Bat fault respectively. The high-grade (typically > 2.5% Cu) zone of copper mineralization at the Hugo Dummett deposits is concentrated in the intense quartz stockwork veining, the quartz monzodiorite and the augite basalt, also locally occurs in dacite tuff ash flow tuff. The intense stockwork vein has an elongate tabular form, with a long axis plunging shallowly to the northnorthwest, and an intermediate axis plunging moderately to the east. The moderate to high-grade Cu and Au values occur only in the Hugo Dummett North gold zone, at the depth of quartz monzodiorite to the west of the intense vein zone. In other respects the Hugo Dummett North and Hugo Dummett South deposits have similar mineralogy and zonation patterns. Two Re-Os ages of molybdenite (372 ± 1.2 and 373 ± 1.2 Ma) from the Southwest and Central Oyu Tolgoi deposits show that the mineralization is similar in age to the postmineralization quartz monzodiorite intrusion. Consequently, the age of quartz monzodiorite intrusions and mineralization is believed to be Late Devonian, albeit not precisely dated (Khashgerel et al., 2006, Wainwright et al., 2006).

Ore minerals identified by reflected light microscope and EDS-SEM analyses are pyrite (FeS_2), chalcopyrite ($CuFeS_2$), bornite (Cu_5FeS_4), molybdenite (MoS2), tennantite(CuFeZn)12(AsSb)4S13,tetrahedrite Cu,Fe)12Sb4S13, enargite (Cu3AsS4), sphalerite ((ZnFe)S), chalcocite (Cu2S), covellite (CuS), gold(Au), galena (PbS) and eugenite (Ag3Hg4). Chemical composition of each sulfide mineral has been examined (Table. 1) Bornite, chalcopyrite and pyrite are the principal ore in a Hugo Dummet deposits.

5.1 Ore texture

All of the ores texture is commonly observed as replacement/intergrown and minor exsolution texture in Hugo Dummett deposits. For example, many of the disseminated pyrite grains display brittle deformation effects (fracturing) and they especially replaced by chalcopyrite and partially replaced by bornite and tennantite.

In some case, pyrite shows zonation in the quartz monzodiorite intrusions (Fig. 4A). McClay and Ellis (1983) have noted that, coarsely crystalline pyrite can readily form at low temperatures in many ores as evidenced by the pyrite crystals observed in Mississippi Valley-type deposits where formation temperatures were less than 150°C and, in some cases, less than 100°C. Numerous studies have documented that there is a tendency for pyrite grain size to increase with increasing grade of metamorphism (Vokes 1969; McClay and Ellis 1983).

A nearly myrmekitic texture of bornite and chalcocite/digenite is commonly observed and this texture is interpreted as an exsolution texture (cf. Ramdohr, 1980; Craig and Vaughan, 1997) (Fig. 4B). This exsolution texture formed above 400°C (Yund and Kullerud, 1966). Tennantite is locally abundant as irregular, as inclusions, commonly intergrown with pyrite, chalcopyrite and bornite (Fig. 4C). Tennantite was replaced by pyrite and chalcopyrite. In some sphalerite grains, irregular and widespread distribution of chalcopyrite and other inclusions (Fig. 4F) are characteristic, so-called chalcopyrite disease described by Barton et al., (1987, 1993, 1995). Barton and Bethke, (1987) noted origin of chalcopyrite blebs in the sphalerite formed in the 200-400°C range and that have not been subsequently subjected to higher temperatures. Hematite is dominantly specularite and tabular occurs around pyrite and chalcopyrite aggregates surrounded by bornite and chalcocite (Fig. 4D). Laux et al., (2005) interpreted this texture suggested that hematite formed from iron released by the substitution of pyrite–chalcopyrite by bornite–chalcocite.

Open-space and replacement textures, those observed in hand specimens, are common in many of samples. Microtextures observed under the microscope, are normal grain boundary relations (e.g. between bornite and chalcopyrite), fissure-filling (e.g. chalcopyrite cutting pyrite), and exsolution (e.g., chalcocite exsolving bornite). Fracture-filling textures are related to the infilling of cataclastically formed fractures by other phases. Fractures within pyrite grains were often filled during late-deformational stages by remobilized chalcopyrite (Fig. 4C, 4E). Worldwide examples of these textures have been reported by Lianxing & McClay (1992). Gill (1969) considered that this texture develops at 0.7 to 1.7 kb pressure and 600°C. Disseminated grains of chalcopyrite occur either as inclusions within pyrite grains or filling fractures in cataclastically deformed pyrites suggesting a late remobilization of chalcopyrite. Generally the disseminated chalcopyrite occurs between underformed pyrite grains. Other microtextures are atoll and skeletal pyrite, lamellar hematite, bleb inclusions in sulfides and microstockworks of clear quartz veinlets.

6. Conclusion

Available geological, petrological and mineralogical characteristics of the Hugo Dummett deposits related sulfide ores lead to the following conclusions:

1. Copper-gold mineralization in the Hugo Dummett deposits occurs in dominantly quartz monzodiorite and minor augite basalt, dacitic rocks and locally biotite granodiorite.
2. Chalcopyrite, pyrite, bornite, molybdenite, tennantite, tetrahedrite, enargite, sphalerite, chalcocite, covellite, eugenite and gold occur as main ore minerals in the Hugo Dummett North and South deposits. These sulfides occur as: (1) a vague vein-like trail 1-3cm long and 2-3 mm wide, (2) minute, discontinuous cracks within quartz (micron scales), and (3) irregular blebs/spots (micron scales) and (4) disseminated within the sericite and plagioclase, commonly concentrated in the quartz. All of the ore minerals texture is commonly observed as replacement, intergrown and minor exsolution texture.
3. Pyrite-chalcopyrite, chalcopyrite-bornite, bornite-chalcocite-covellite and pyrite-bornite-chalcopyrite are the common sulfide associations in the Hugo Dummett North and South deposits.

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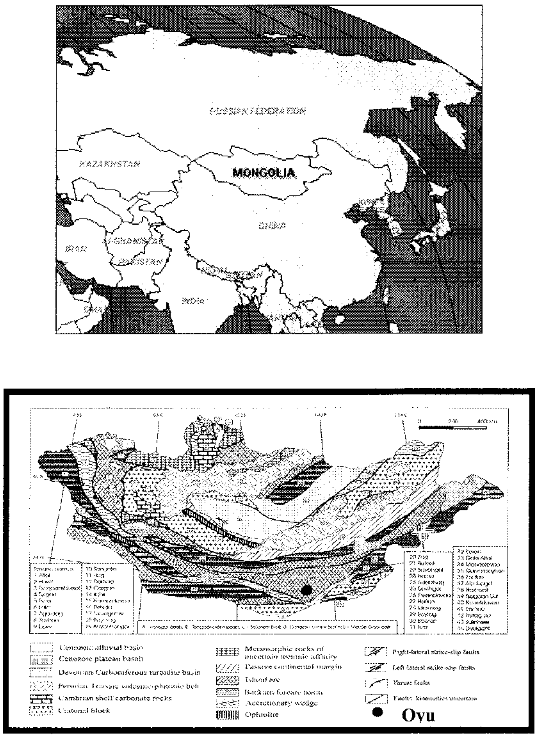

Figure 1. Tectonostratigraphic terrain map for Mongolia. Modified after Badarch et al., 2002

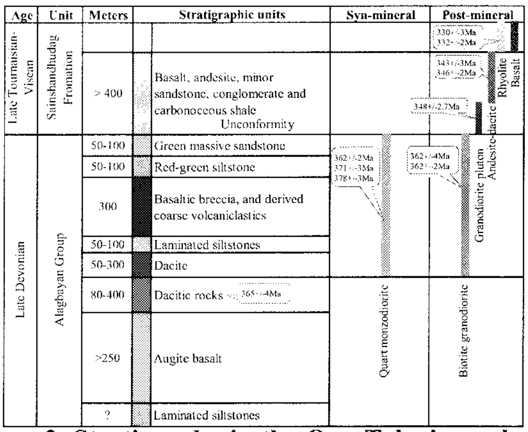

Figure 2. Stratigraphy in the Oyu Tolgoi porphyry Cu-Au deposit area and U-Pb zircon dates on intrusions and host rocks. Modified after Wainwright et al., (2005)