Hydrothermal alteration of the Oblaga Cu-Au skarn deposit and the Oblaga porphyry Cu-Au prospect, Inner Mongolia, China

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Abstract

The Oblaga Cu-Au skarn deposit and porphyry prospect is located in the southeastern edge of the Gobi Desert in western Inner Mongolia. The deposit occurs within metamorphosed middle Paleozoic volcanic, plutonic and sedimentary rocks.

Ivanhoe geologists recognise eight main rock types in the area. Calcareous sediments include conglomerate, interlayered siltstone-sandstone, and limestone. Covering the calcareous sediments is a slab of thrusted biotite granite, and above it is rhyodacitic lithic tuff, which, in places, is overlain by alluvial sediments. Various plutonic rocks and related intrusion breccias have intruded these units. Monzodiorite, quartz-monzonite and monzonite tend to form thin, high-angle intrusions, and the youngest andesitic intrusions are generally wider and sub-horizontal.

The Oblaga Cu-Au skarn, which occurs in the calcareous sediments, shows typical prograde and retrograde mineralogy. Petrographic studies show that prograde skarn minerals have been overprinted by retrograde skarn minerals, and original host rock minerals have been texturally obliterated and completely replaced. The mineralogy of the Oblaga skarn deposit is very similar to other Cu-Au skarn deposits worldwide.

Sericitic and minor chloritic alteration occurs throughout the study area and may relate to porphyry-style mineralisation. Generally, this alteration is not intense and most rocks have retained their original texture. Geochemical analyses suggest that K-metasomatism is not widespread at Oblaga. XRD analyses suggest an upward and outward transition from sericitic to chloritic alteration.

Comparisons between Oblaga and other porphyry Cu-Au deposits worldwide show that Oblaga has very similar characteristics to deposits that have undergone sericitic alteration. However, Oblaga is special because it also has relatively intense chloritic alteration, which is uncommon in other porphyry Cu deposits described in the literature.

Key words: *Skarn Cu-Au deposit, porphyry, People's Republic of China, Inner Mongolia, Oblaga, hydrothermal alteration.*

Introduction

Porphyry Cu-Au deposits have been an important metal resource, and approximately 20% of the world’s giant Au deposits (e”600t Au) are porphyry type (Sillitoe, 2000). Copper-gold skarn deposits are commonly related to and occur in close proximity with porphyry Cu-Au deposits, and many provide additional high-grade orebodies near porphyry deposits (Einaudi, 1982). Therefore, large tonnage porphyry orebodies with related skarn deposits have become attractive exploration targets.

The northern margin of North China Plate and the adjacent suture zone, the Central Asian Orogenic Belt (Fig. 1), are enriched with various types of ore deposits. This area is one of the prominent Au provinces in China, hosting approximately 900 Au deposits, including orogenic lode Au deposits, placer Au deposits, Cu-Au skarn deposits and porphyry Cu-Au deposits (Hart et al., 2002; Zhou et al., 2002). Deposits predominantly occur in Precambrian metamorphic rocks, and some occur in Paleozoic to Mesozoic felsic plutons. Mineralisation occurred during episodic tectonic events related to the Permian to Triassic continental collision of the Angara and North China Plates, and later Mesozoic continental rifting.

Figure 1. Map of China. The Inner Mongolia Autonomous Region is shaded (Modified from Zhou et al., 1995). Tectonic units in Inner Mongolia. The section of Central Asia Orogenic Belt that crossed the Inner Mongolia Autonomous Region is highlighted. (Modified from Cao et al., 2002).

Situated near the northern margin of the North China Plate, at the southeastern edge of the Gobi desert, the Oblaga area contains a variety of metallic mineral deposits and occurrences. Copper, Zn and Pb are the most commonly enriched metals in the area; they are extracted from small scale local mines (Sung et al., 1982). Significant deposits include the recently abandoned Oblaga mine in the middle of the study area, which was producing 130 tonnes of ore per day, with an average grade of 1.2% Cu and 1 to 1.5g/t Au (Williams et al., 2003).

The China Non-Ferrous Metal Bureau, Division No. 511, first discovered Cu-Au mineralisation at Oblaga during the 1960's. Systematic exploration started in 1980, and a small incoherent resource was defined, which led to small-scale mining in 1987 (Williams et al., 2003). In 2003, reconnaissance studies carried out by Ivanhoe Mines on the surrounding areas shows erosion to deep levels and insignificant Cu-Au concentration on the ground surface (Williams et al., 2003).

This paper describes the geologic setting, lithology, and alteration mineralogy of the Oblaga Cu-Au skarn deposit and the related porphyry Cu-Au prospect.

Geology

The regional geology of the Inner Mongolia region is complex due to active tectonism since the Precambrian. It sits at the southern border of the ENE-WSW trending suture zone of the Central Asian Orogenic Belt (ªengör et al., 1993; Fig 1) between the North China Plate and the Angaran Craton. The suture zone is composed of island-arcs, continental blocks and ophiolites. Hence, the area has experienced widespread intense metamorphism with frequent tectonic and volcanic activity (Hsü and Chen. 1999).

Northwest and North China are mostly underlain by Precambrian continental crust, with basement rocks ranging from Archean to Middle Proterozoic. Since the Precambrian, the Angara Craton and the North China Plate formed chains of subduction related volcanic arcs, similar to the modern Indonesian Archipelago. During the Paleozoic, the two plates consumed the seafloor in between and collided and amalgamated to form the Central Asian Orogenic Belt (Hsü and Chen, 1999, Cao et al., 2002).

From Middle Jurassic to Early Cretaceous, the North China Plate underwent intraplate rifting (Ritts et al., 2004.), which formed regionally extensive subaerial basins and widespread volcanism, accompanied by intracontinental seismic activity and high heat flow (80mWm-2) (Liang et al., 2004). Magmatic activity persisted throughout the Paleozoic, the Mesozoic and during the early Cenozoic. Back-arc magmatism formed various magmatic belts along the northern edge of the North China Plate (Hsü and Chen, 1999) where calc-alkaline volcanism and plutonic intrusions were widespread.

The Oblaga Cu-Au skarn deposit and Cu-Au porphyry prospect are located in western Inner Mongolia, 60km southwest of the Wulatihouqi city. Oblaga is at the northern margin of the North China Plate, near the southern edge of the Central Asian Orogenic Belt, within the Sonid granites and volcanic belt (Cao et al., 2002; Hsü and Chen, 1999). The deposit occurs within metamorphosed middle-Paleozoic basement with Carboniferous volcanic, plutonic and sedimentary rocks (Angeles et al., 2003).

Three sets of faults dominate the Oblaga area (Fig. 2). A regional, sub-vertical N-S trending structure that extends into Outer Mongolia cuts across the volcanic-sedimentary complex in the Oblaga area. The second set of faults is predominantly E-W to WNW-trending, such as the Oblaga Fault, and its subsidiary horsetail fault splays crosscut the N-S trending structures at the studied area. The WNW-trending faults crosscut the Oblaga volcanic-sedimentary complex and divide it into the northern and southern fault blocks. The third set of faults are NE-trending and locally abundant in the southern fault block. These faults are comparatively less extensive, and only occur at a local scale (Angeles et al., 2003; Williams et al., 2003).

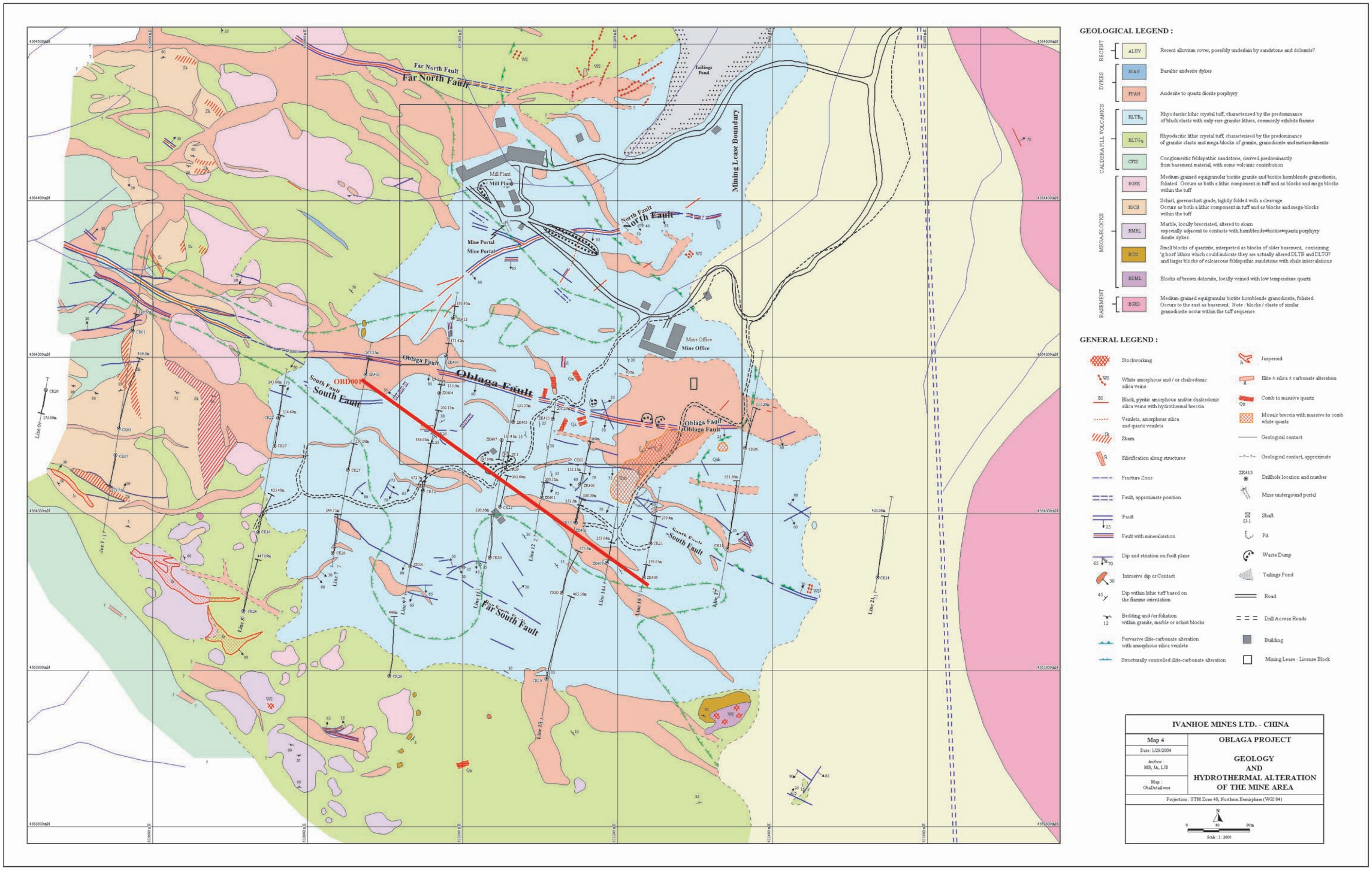

Figure 2. Geologic map of the Oblaga deposit.

Lithology

Lithologic and stratigraphic relationships reported in this paper are based on descriptions and interpretations from Ivanhoe geologists. There are eight main rock types in the Oblaga area, as briefly described below from oldest to youngest.

Biotite granite forms the basement rock in the area, outcropping on the eastern side of the Oblaga mine area (Fig. 2). It is characterised by vaguely foliated, macrocrystalline textures. Quartz phenocrysts are generally fractured with undulose extinction.

The calcareous sediments contain three different units, from oldest to youngest: conglomerate, interlayered calcareous siltstone-sandstone, and limestone. The maximum total thickness of all three units is approximately 45m. The calcareous sediments are skarnified where they are cut by intrusions.

Intrusion breccias cut biotite granite and calcareous sediments. At least three different types of intrusion breccia can be distinguished based on their clast types and abundance: monomict clast-supported breccias, polymict clast-supported breccias, and milled breccias.

A slab of biotite granite, with a maximum thickness of 35m, was thrust over the calcareous sediments. It has a very similar texture and mineralogy to the biotite granite from the basement, but its quartz phenocrysts lack undulose extinction and are less fractured.

Rhyodacitic lithic tuff covers most of the Oblaga area (Fig.2). It is characterised by the presence of fiamme and contains a very fine-grained microcrystalline quartz matrix.

Four intrusive rock types have been identified at Oblaga. The most common ones are the porphyritic monzonite intrusions with compositions ranging from monzodiorite to quartz monzonite. Porphyritic and aphanitic andesite dykes form the youngest intrusions as they crosscut all other rock types in the area.

Alteration mineralogy

The alteration mineralogy described below is based on XRD results and petrographic studies of 80 samples collected from the area. The paragenetic sequence of alteration minerals is derived from textural and crosscutting relationships observed in hand specimens and in thin sections.

The underground Oblaga mine was shut down when we undertook this study. Therefore, the skarn study was based mainly on grab samples from the mine dump, and three dimensional relationships of various skarn alteration minerals could not be mapped *in situ*. However, the grab samples show clear textural and paragenetic relationships of the minerals. Furthermore, drill core samples and logs show that skarn alteration occurs within the calcareous sediments, particularly where cut by monzonite intrusions.

Skarn alteration is intense and pervasive at Oblaga, as skarn minerals have completely replaced and destroyed the original textures of the calcareous sedimentary host rocks. Skarn mineralisation at Oblaga shows the distinct skarn mineral assemblages and paragenetic sequence of a typical Cu-Au skarn deposit (Fig.3). It can be divided into contact metamorphism, prograde and retrograde skarn minerals.

Contact metamorphism at Oblaga forms wollastonite in the limestones, but the brecciated texture of the limestone unit is not destroyed. Hornfels outcrops about 1 km southwest of the Oblaga mine.

The two most abundant prograde skarn minerals are andraditic garnet and pyroxene. Most samples show early, subhedral pyroxene porphyroblasts flooded by massive andradite, and later replaced by euhedral actinolite and epidote. Thin section studies show a high garnet: pyroxene ratio, which is typical for Cu-Au skarn deposits (Einaudi et al., 1981). Generally,

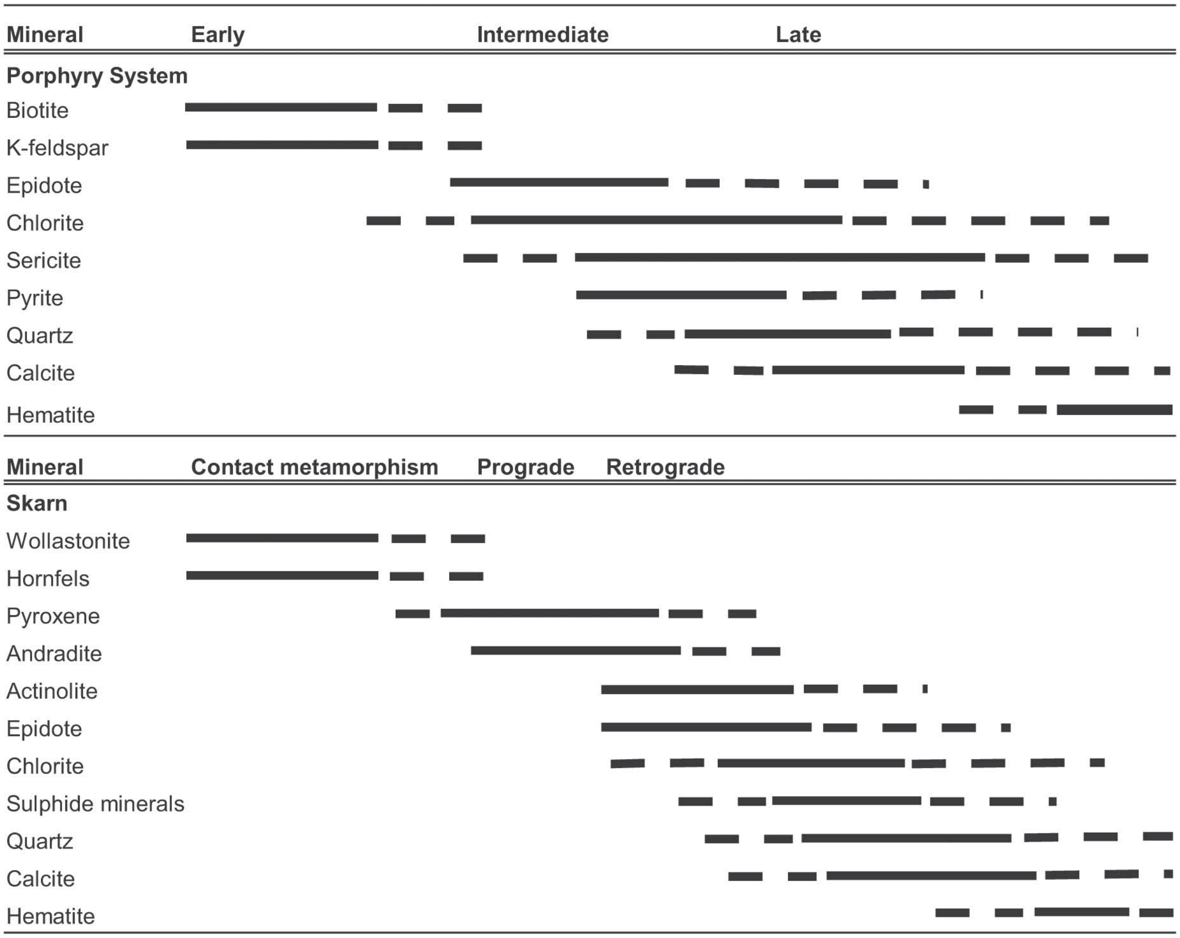

Figure 3. Generalised figure illustrating the paragenetic sequence of alteration minerals in the porphyry and skarn system at Oblaga.

prograde skarn minerals completely replace the original wall rock, but some samples show a banded texture that might reflect sedimentary layering in the parent rocks.

At Oblaga, the retrograde skarn alteration mineral assemblage includes actinolite, tremolite, epidote, chlorite, calcite, quartz, pyrite, chalcopyrite, arsenopyrite, sphalerite, bornite, and hematite. Various sulphides and oxides occur as disseminations and as veins. Calcite veins and some quartz veins appear as late stage alteration, yet neither was intense enough to completely destroy previous mineralisation.

Hydrothermal alteration at the Oblaga porphyry Cu-Au prospect is irregular and no overall widespread alteration pattern or zonation can be delineated. Generally, the alteration is pervasive but not intense and rarely texturally destructive. Two major alteration minerals prevail in nearly all samples, sericite and chlorite. There are also isolated biotite-altered zones that range up to 60 m across and are spatially associated with monzonite intrusions. Other localised alteration minerals include feldspar, epidote, calcite, silica and pyrite. Overprinting of earlier alteration minerals by later alteration minerals is common, and it obscures the identification of alteration patterns and zonation.

The XRD results show strong sericite alteration in the area regardless of the rock type, especially at depths below 400m. Thin section studies indicate that sericite commonly occurs as tiny inclusions in feldspar phenocrysts, forming an even dusting of sericite that replaces most of the feldspar phenocrysts. Sericite also replaces the groundmass and some forms alteration rims around quartz phenocrysts. It also occurs as veinlets, commonly as quartz-sericite and sericite-chlorite veins or quartz-calcite veins.

Chlorite alteration exists in nearly all samples, especially those from the top 400m. It is related to biotite and pyrite and is replacing both phenocrysts and groundmass. However, the intensity of chlorite alteration varies. Epidote is comparative less abundant, and tends to occur in the top 200m in section OBD001. It is generally associated with chlorite alteration.

The most common sulphide mineral at Oblaga is pyrite. It occurs as disseminated grains and veinlets, and is commonly associated with chlorite and biotite. Pyrite also forms quartz-pyrite and chlorite-pyrite veinlets.

Porphyry style hydrothermal alteration in Oblaga is not intense. No sample has shown complete destruction of the original texture. Furthermore, hydrothermal alteration in Oblaga is irregular; it lacks the important hydrothermal alteration features of most economic porphyry deposits, such as porphyry style intense stockwork and the potassic alteration mineral assemblage of potassic feldspars, biotite and magnetite with chalcopyrite, pyrite and bornite (Sillitoe, 2000). No systematic alteration pattern or zonation can be distinguished along the drill line profile of OBD001.

Discussion

The Oblaga skarn mine displays the distinct hydrothermal alteration and paragenetic sequence of a typical Cu-Au skarn deposit. Skarn deposits commonly have certain alteration patterns due to their alteration evolution (Einaudi et al., 1981; Meinert, 1992). Petrographic and XRD analyses of skarn samples from Oblaga confirm the classic paragenetic sequence and mineralogy for a Cu-Au skarn deposit (Fig.3). Skarn alteration at the Oblaga skarn deposit is intense, obliterating texture and completely replacing the original host rocks with coarse-grained, euhedral porphyroblasts.

Retrograde skarn is the major mineralising stage of skarn deposits, and it overprints prograde skarn (Einaudi et al., 1981; Meinert, 1992). At Oblaga, retrograde alteration has completely destroyed previous alteration minerals in several samples, some samples still retain minerals from previous alteration, therefore indicating the comparatively low intensity and non-pervasiveness of retrograde alteration in this deposit.

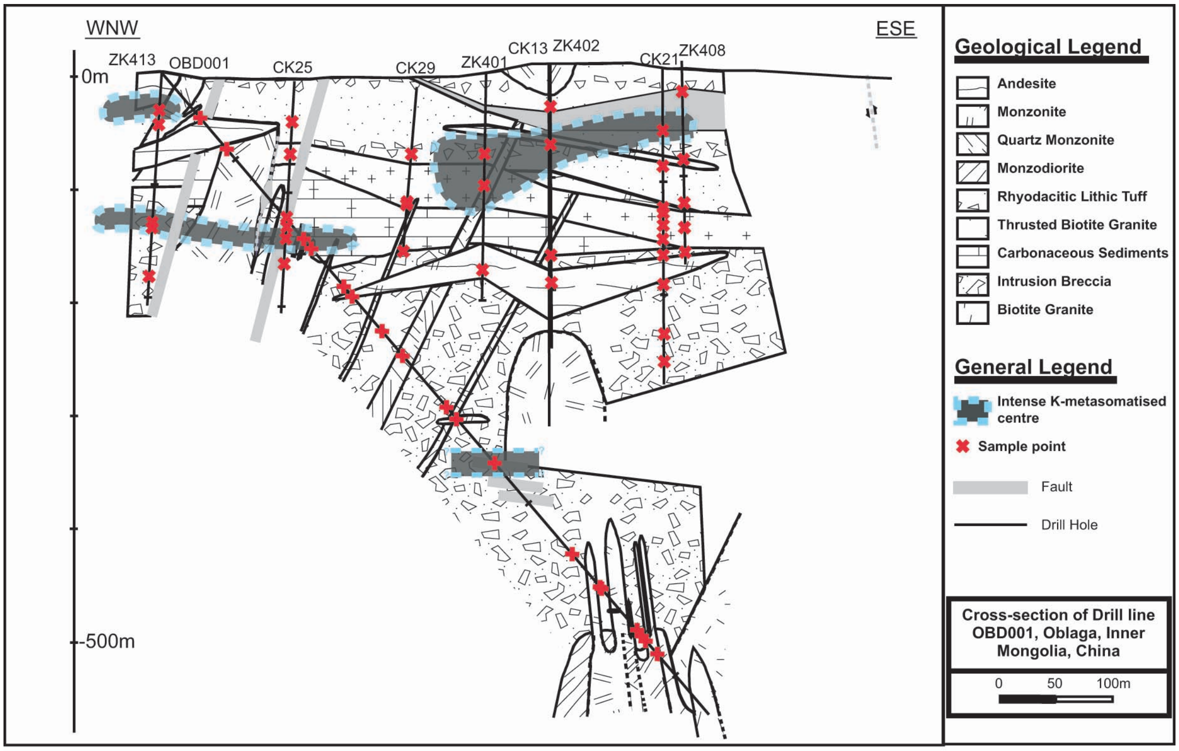

Figure 4. Cross-section of drill line OBD001, showing the stratigraphic relationship. The shaded area indicates isolated centres with intense sericitic alteration. This figure shows that there are no systematic pattern in the K-metasomatism at Oblaga. Cross section modified from interpretation of the mine staff's report.

Copper-gold skarn deposits can occur in close proximity to either barren or mineralised stocks (Einaudi, 1977; Einaudi et al., 1981). Thin section observations on the skarn minerals from Oblaga suggest a low fluid flow in the area. Both prograde and retrograde skarn minerals at Oblaga form euhedral, coarse grained crystals, formed under a less dynamic hydrothermal environment with restricted fluid movement, thus allowing the growth of large crystals, which are considered typical for nonporphyry-related skarn deposits (Einaudi et al., 1981). These skarn deposits are commonly found either at greater depths or more distal to their parental intrusion. Therefore, Oblaga might represent a nonporphyry-related or distal skarn deposit.

Porphyry Cu-Au deposits generally have an upward and outward alteration zonation pattern with a potassic alteration core where the bulk mineralisation is concentrated (Lowell and Guilbert, 1970; Sillitoe, 2000). Therefore, evaluation of the extent of K-metasomatism is useful of gaining insight of the geochemical processes and mobility of major elements. At Oblaga, thin section studies indicate that K-metasomatism mainly involves replacement of feldspar by sericite and small isolated centres of biotite alteration. Petrographic studies and XRD results show that there are localised pockets of intense sericitic alteration along section OBD001 (Fig.4), however, these pockets are juxtaposed with samples that are only slightly K-metasomatised. Monzonite-related biotite altered areas are located to the west of section OBD001. They show features that are similar to the potassic core of a porphyry system, but at a much smaller scale.

Petrographic observations show that besides the typical sericitic alteration mineral assemblage, there is also propylitic alteration with minerals such as chlorite, albite and epidote at Oblaga. The co-existence of two alteration mineral assemblages reflects overprinting of early-stage propylitic alteration by late-stage sericitic alteration, suggesting that the area may be at the periphery of a porphyry deposit. Furthermore, the two major propylitic alteration minerals, epidote and chlorite, have limited spatial occurrence. Hydrothermal epidote is limited to the top 200m, and samples that show a prevailing chloritic alteration are limited to the top 400m. This pattern could reflect a transition zone from sericitic alteration zone grading upward and outward into propylitic alteration zone. There is exploration potential for a deep-seated porphyry system at Oblaga. However, for this study all samples from below 400m were collected solely from drill hole OBD001. Therefore, in order to confirm this hypothesis, a larger sample suite from depth with wider spatial distribution would be required.

Conclusions

The Oblaga Cu-Au skarn deposit shows distinctive characteristics of a Cu-Au skarn deposit. The skarn alteration at the Oblaga mine is intense, but localised, forming small but high-grade pockets of ore. Skarn minerals at Oblaga tend to form coarse-grained euhedral porphyroblasts, suggesting that Oblaga may represent a distal or nonporphyry related Cu-Au skarn deposit (Einaudi et al, 1981).

The Cu-Au porphyry prospect at Oblaga shows irregular hydrothermal alteration, dominated by sericitic alteration with minor chlorite alteration and isolated biotite-altered areas. The porphyry system at Oblaga lacks the typical potassic alteration core and porphyry style stockwork veins. The alteration mineralogy suggests that Oblaga might be sitting at the periphery of a porphyry system at the sericitic alteration zone grading into the chloritic alteration zone.

The tectonic history of Oblaga since the Paleozoic has provided an ideal environment for the formation of a porphyry Cu-Au deposit with related Cu-Au skarn deposit. Magmatic activity throughout the Paleozoic, Mesozoic and Tertiary provided sources of heat and potential sources of metals and hydrothermal fluids. The development of sedimentary basins during the late Mesozoic led to formation of calcareous sediments, which now host the Oblaga skarn deposits. Further exploration may reveal whether there is a deep-seated porphyry Cu-Au deposit at Oblaga.

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