

## Origin of the Ore-forming Fluids of the No.2 Porphyry Cu-Au deposit in Xiongcu district, Gangdese Porphyry Copper Belt, Tibet

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### Abstract

The No.2 porphyry Cu-Au deposit in the Xiongcu district located in Gangdese porphyry copper belt (GPCB), Tibet, is characterized by the superposition of multiple quartz veins. Four distinctly different quartz veins have been identified in the deposit, including early barren quartz veins (V1), quartz-chalcopyrite-pyrite  $\pm$  magnetite veins (V2), quartz-molybdenite veins (V3), and late quartz veins (V4). Here, oxygen and hydrogen isotope analyses were carried based on these veins to determine the origin and evolution of the ore-forming fluids. The V1 and V2 veins have high  $\delta D_{fluid}$  values ( $-80.3\text{‰}$ ,  $-86.4$  to  $-81.1\text{‰}$ , respectively) and  $\delta^{18}O_{fluid}$  values ( $5.6\text{‰}$ ,  $4.9$  to  $6.4\text{‰}$ , respectively). The V3 veins have moderate  $\delta D_{fluid}$  values ( $-88.4$  to  $-84.0\text{‰}$ ) and  $\delta^{18}O_{fluid}$  values ( $-0.2$  to  $3.7\text{‰}$ ). The V4 veins are characterized by low  $\delta D_{fluid}$  values ( $-92.8$  to  $90.2\text{‰}$ ) and  $\delta^{18}O_{fluid}$  values ( $-3.2$  to  $-1.4\text{‰}$ ). Oxygen and hydrogen isotope data indicates that the ore-forming fluids of the No.2 Porphyry Cu-Au deposit are mainly derived from magmatic water in the early stage. Being accompanied with the fluid evolution in the late stage, the proportion of meteoric waters precipitation gradually increased.

### Keywords

Ore-forming fluids, Oxygen and hydrogen isotope, Xiongcu, Tibet.

### 1. Introduction

Gangdese porphyry copper belt (GPCB) located in the southern Lhasa subterranean is one of the most important metallogenic belts in China. Mesozoic subduction-related porphyry Cu-Au deposits (e.g., Xiongcu district) and Cenozoic collision-related Cu-Mo deposits (e.g., Qulong, Jiama, Bangpu, Bairong, Tinggong, and Chongjiang deposits) have been discovered in this belt [1-5]. Recently a large number of studies have been concentrated on the Cenozoic collision-related Cu-Mo deposits to discuss their metallogenic mechanisms. For the subduction-related porphyry Cu-Au deposits, however, the metallogenic mechanism has not been in-depth studied. The Xiongcu Cu-Au district is a typical representative of Mesozoic subduction-related porphyry mineralization in GPCB. Three porphyry Cu-Au deposits (No. 1, No. 2, and No. 3) have been discovered in this district. Previous studies primarily concentrated on the geologic features, timing of the mineralization, and genesis of ore-bearing porphyry of these deposits [1, 2]. In addition, Xu et al. investigated only the origin of the ore-forming fluids of the No.1 porphyry Cu-Au deposit [6]. Regarding the No.2 porphyry Cu-Au deposit, the origin and evolution of the ore-forming fluids is unknowable. In this paper, multiple quartz veins recording the evolution of ore-forming fluids have been identified in the deposit and the origin and evolution of the ore-forming fluids of the magmatic-hydrothermal systems that formed the deposit have been reconstructed on the basis of these veins cutting relations and H-O isotope compositions. Our results contribute to an improved understanding of the subduction-related porphyry mineralization in the GPCB.

### 2. Geologic background and deposit geology

The Xiongcu district is located in the western segment of the Gangdese porphyry copper belt (GPCB), which is approximately 50 km wide and 500 km long and is situated at the southern margin of the southern Lhasa subterranean (Fig. 1a) [7]. In the southern Lhasa subterranean, the magmatism was

mainly generated between the Late Jurassic and the Paleogene as a result of the northward subduction, or possibly the break-off, of the Neo-Tethys oceanic slab beneath the Lhasa terrane. The Miocene intrusions, which formed in a post-collisional geologic setting, have an adakite-like affinity. However, Early Mesozoic magmatic rocks are relatively rare in the southern Lhasa subterrane and mainly consist of intermediate-acid intrusive rocks, with coeval volcanic rocks of the Sangri Group and Yeba Formation. Significant porphyry Cu (Mo-Au) deposits have been discovered in the GPCB, such as Xiongacun, Qulong, Jiama, Bangpu, Bairong, Tinggong, and Chongjiang deposits. The vast majority of porphyry Cu (Mo-Au) deposits in GPCB were generated in post-collisional setting related to Miocene intrusions with the exception of the Xiongacun district formed in subduction-related settings associated with Jurassic intrusions [1, 2, 8].

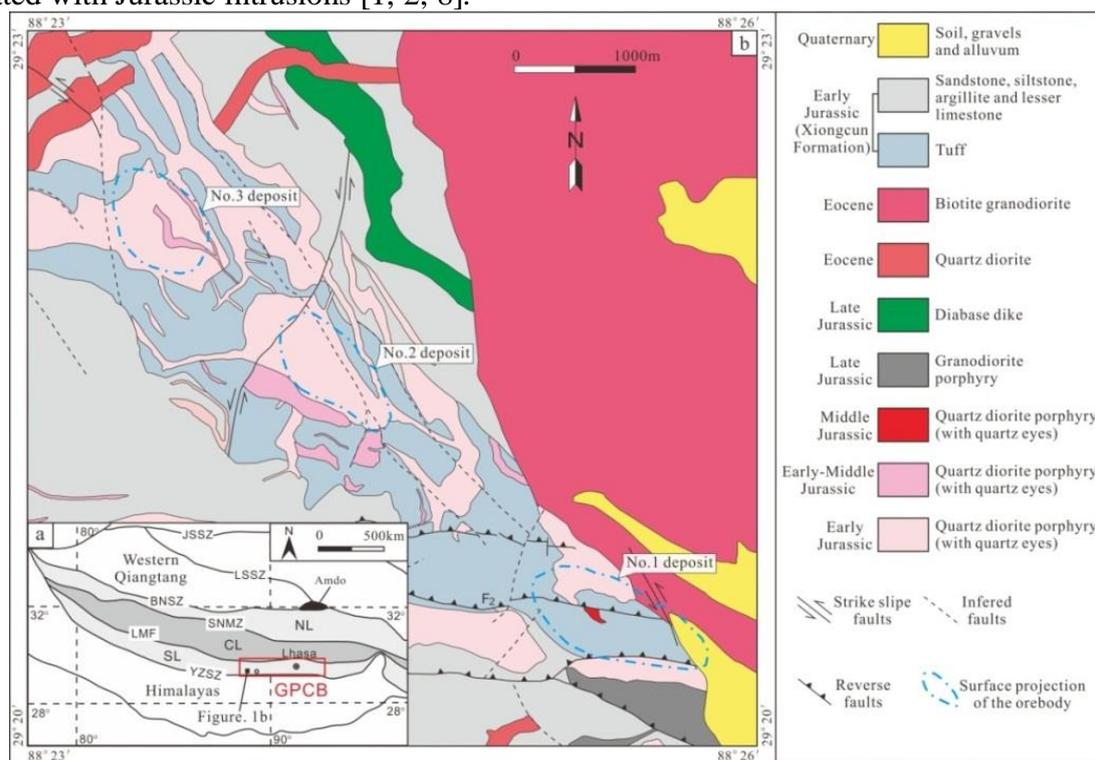


Fig. 1 (a) Simplified regional geological map of the Himalayan–Tibetan orogeny, showing the location of Gangdese porphyry copper belt (GPCB), modified from Zhu et al. [9]. (b) Geological map of the Xiongacun district, modified from Tang et al. [2]. BNSZ: Bangong–Nujiang Suture Zone; SNMZ: Shiquan River–Nam Tso Mélange Zone; LMF: Luobadui–Milashan Fault; YZSZ: Yarlung–Zangbo Suture Zone; SL: Southern Lhasa subterrane; CL: Central Lhasa subterrane; NL: Northern Lhasa subterrane; LSSZ: Longmu Tso–Shuanghu Suture Zone; JSSZ: Jinshajiang Suture Zone; GPCB: Gangdese porphyry copper belt.

The strata exposed in the Xiongacun district belongs to the Lower–Middle Jurassic Xiongacun Formation (Fig. 1b), which comprises tuff, sandstone, siltstone, argillite, and lesser limestone. The intrusive rocks in the Xiongacun district are of Jurassic and Eocene ages (Fig. 1b). The Jurassic intrusions include Early Jurassic quartz diorite porphyry (181–175 Ma), Early–Middle Jurassic quartz diorite porphyry (174 Ma), Middle Jurassic quartz diorite porphyry (167–161 Ma) and diabase dikes [1]. The Eocene intrusions include biotite granodiorite, quartz diorite, granitic aplite dikes, and lamprophyre dikes. The main structures in the Xiongacun district are the F1 and F2 faults (Fig. 1b), which occur along the hanging wall and footwall of the No.1 deposit, respectively. Other faults are steep post-mineralization structures that trend NE, N, EW, and NW (Fig. 1b).

Three porphyry Cu–Au deposits (No. 1, No. 2, and No. 3) have been discovered in the Xiongacun district (Fig. 1b). The mineralization was hosted in the Jurassic porphyries and the surrounding contemporary volcanic rocks [1, 2]. The No. 1 deposit, which contains 1.04 Mt Cu, 143.31 t Au, and 900.43 t Ag with average grades of 0.48% (Cu), 0.66 g/t (Au), and 4.19 g/t (Ag), is associated with the

Middle Jurassic quartz diorite porphyry and metallogenic age at ca.  $161.5 \pm 2.7$  Ma (Re-Os)[1, 10]. The No. 2 deposit (1.34 Mt Cu, 76.34 t Au, and 193.78 t Ag; average grades = 0.35% Cu, 0.22 g/t Ag, and 1.30 g/t Ag) is associated with the Early Jurassic quartz diorite porphyry and metallogenic age at  $172.6 \pm 2.1$ Ma (Re-Os) [1, 10]. The No. 3 deposit is a newly discovered porphyry Cu-Au deposit with similar geological characteristics to the No. 2 deposit.

In the No.2 deposit, the mineralized porphyry and the tuffs proximal to porphyry show obvious alteration similar to that in other porphyry Cu-Au deposits, including potassic, sodic-calcic, phyllic, chlorite-sericite, and propylitic alteration.

Four distinctly different vein types have been identified in the No.2 Porphyry Cu-Au deposit, including early barren quartz veins (V1), quartz–chalcopyrite–pyrite  $\pm$  magnetite veins (V2), quartz–molybdenite veins (V3), and late quartz veins (V4).

V1 veins are rare and were observed only in the deep drill hole. No obvious crosscutting relations were observed between V1 veins and other veins. V1 veins have irregular wavy margins, and thickness generally range from < 1 cm to 3 cm (Fig. 2a). They are dominated by equigranular quartz grains, devoid of sulfides and are surrounded by variably pervasive potassic alteration.

V2 veins are most abundant vein types in this deposit and were usually observed in the potassic alteration zone in the central orebody and host the bulk of the Cu-Au mineralization. V2 veins have irregular wavy margins similar to the V1 and thicknesses range from  $\sim 0.5$  cm to 3 cm. They are usually cut by later veins with straight walls, such as V3 veins (Fig. 2c). V2 veins are quartz dominated, with chalcopyrite and pyrite as the dominant sulfide. Chalcopyrite and pyrite crystals (0.1–1 mm) generally occur in the form of centerline in V2 veins (Fig. 2b). In addition, minor anhydrite and biotite also were observed in V2 veins. At shallow levels, magnetite is present locally.

V3 veins are relatively rare than V2 veins and generally occur in the central orebody. They are range from a few millimeters to 3 cm in thickness and tend to have straight walls (Fig. 2c). Crosscutting relations distinctly indicate they postdate V2 veins and predate V4 veins. Molybdenite crystals generally occur as thin platy crystals in the veins, and chalcopyrite and pyrite were occasionally observed.

V4 veins are the youngest generation of vein observed in the deposit. Vein truncation relationships distinctly indicate they postdate epidote veins (EV) (Fig. 2d), which cutting V3 veins and generally range in thickness from  $\sim 1$  mm to 2 cm and composed of epidote with minor calcite and sericite. V4 veins range from  $\sim 0.5$  cm to several centimetres in thickness and have straight walls (Fig. 2d). They are dominated by quartz, which makes up over 95 vol % of most V4 veins. Minor calcite and epidote also were observed in these veins. Pyrite as the only sulfide was occasionally observed in V4 vein. Late quartz veins are distributed sporadically in potassic alteration and propylitic alteration.

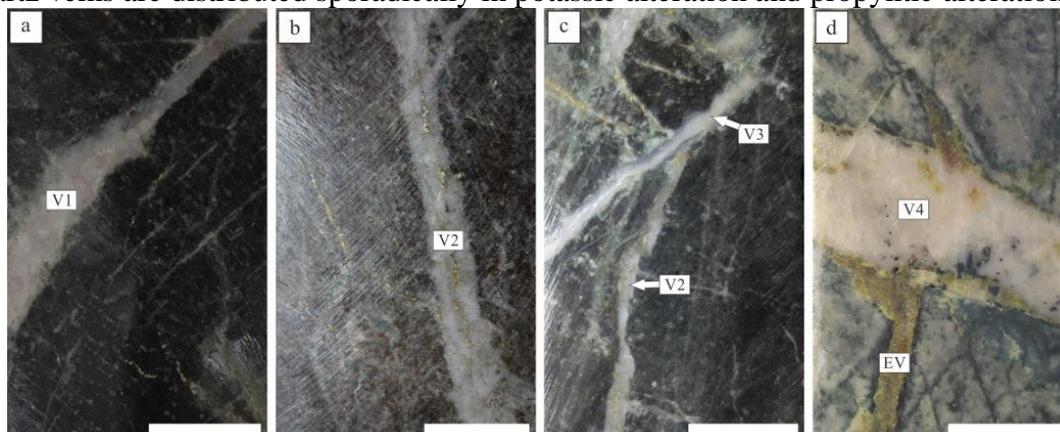


Fig. 2 Photographs showing various vein types from the No.2 porphyry Cu-Au deposit in the Xionggun district. (a) V1 veins with potassic alteration. (b) V2 veins with potassic alteration. (c) V3 veins crosscutting V2 veins with potassic alteration. (d) V4 veins crosscutting epidote veins (EV). All scale bars are 2 cm in length.

### 3. Analysis methods

A total of 11 quartz grain samples collected from V1 to V4 veins were selected for oxygen and hydrogen isotope analyse. Quartz grains were extracted from crushed and washed sample fragments, and purified by hand picking under a binocular microscope. The oxygen and hydrogen isotopic compositions of the quartz were determined using a Finnigan-MAT 253 mass spectrometer at the Analytical Laboratory, Beijing Research Institute of Uranium Geology. The analytical method has been described by Zhu et al. [11]. Oxygen was liberated from quartz by reaction with  $\text{BrF}_5$  and converted to  $\text{CO}_2$  on a platinum-coated carbon rod [12]. Hydrogen isotope ratios on bulk fluid inclusions in quartz were measured by mechanical crushing of about 5 g of quartz grains to 1–5 mm in size, according to the method described by Simon [13].  $\text{H}_2\text{O}$  was collected from quartz decrepitation under vacuum at  $550^\circ\text{C}$  and then reduced by Zn at  $400^\circ\text{C}$  to obtain  $\text{H}_2$ . All data were normalized with V-SMOW standards with analytical precisions better than  $\pm 0.2\text{‰}$  and  $\pm 1\text{‰}$  for  $\delta^{18}\text{O}_{\text{quartz}}$  and  $\delta\text{D}_{\text{fluid}}$ , respectively.

### 4. Results

Oxygen and hydrogen isotope data are listed in Table 1. The measured  $\delta^{18}\text{O}_{\text{quartz}}$  values of 11 quartz samples from V1 to V4 veins range from 8.7 to 12.6‰. The  $\delta^{18}\text{O}_{\text{fluid}}$  values were calculated using the quartz-water equilibrium function [14],  $1,000\ln_{\text{aqtz-water}} = 3.38 \times 10^6 \times T^{-2} - 3.40$ , with the average homogenization temperature of fluid inclusions in quartz. The calculated  $\delta^{18}\text{O}_{\text{fluid}}$  values from V1 to V4 veins are 5.6‰, 4.9 to 6.4‰,  $-0.2$  to 3.7‰, and  $-3.2$  to  $-1.4\text{‰}$ , respectively (Table 1). The measured  $\delta\text{D}_{\text{fluid}}$  values of fluid inclusions from V1 to V4 veins are  $-80.3\text{‰}$ ,  $-86.4$  to  $-81.1\text{‰}$ ,  $-88.4$  to  $-84.0\text{‰}$ , and  $-92.8$  to  $90.2\text{‰}$ , respectively (Table 1).

Table 1 Oxygen and hydrogen isotope compositions from the No.2 deposit in the Xiongkun district

Samples	Sample description	Th ( $^\circ\text{C}$ )	$\delta\text{D}_{\text{fluid}}$ (‰)	$\delta^{18}\text{O}_{\text{quartz}}$ (‰)	$\delta^{18}\text{O}_{\text{fluid}}$ (‰)
7231-396	Quartz from V1 vein	350	-80.3	10.9	5.6
7229-229.2	Quartz from V2 vein	350	-86.4	11.7	6.4
7229-321	Quartz from V2 vein	350	-82.4	10.9	5.6
7229-324.9	Quartz from V2 vein	350	-86.1	10.2	4.9
7223-246	Quartz from V2 vein	350	-81.1	11.6	6.3
7231-175	Quartz from V3 vein	250	-84.0	8.7	-0.2
7238-595.5	Quartz from V3 vein	250	-88.4	9.7	0.8
7229-182.5	Quartz from V3 vein	250	-84.4	11.5	2.6
7223-221.3	Quartz from V3 vein	250	-86.3	12.6	3.7
7229-483.5	Quartz from V4 vein	190	-92.8	9.2	-3.2
7223-93.5	Quartz from V4 vein	190	-90.2	11.0	-1.4

Notes: Th is the average homogenization temperature of the fluid inclusions

### 5. Discussion

Taylor estimated that the magmatic water in equilibrium isotope with silicate melts at magmatic temperature [15], its  $\delta^{18}\text{O}_{\text{fluid}}$  values and  $\delta\text{D}_{\text{fluid}}$  values vary from 6 ‰ to 9 ‰ and  $-40$  ‰ to  $-85$  ‰, respectively (Fig. 3). The V1 veins from the No.2 deposit show relatively high  $\delta^{18}\text{O}_{\text{fluid}}$  (5.6‰) and  $\delta\text{D}_{\text{fluid}}$  ( $-80.3\text{‰}$ ) values, consistent with the magmatic water and those early veins reported in other porphyry systems [16]. The oxygen and hydrogen isotopic signature of the V2 veins are similar to the V1 veins: relatively high  $\delta^{18}\text{O}_{\text{fluid}}$  (4.9 to 6.4‰) and  $\delta\text{D}_{\text{fluid}}$  ( $-86.4$  to  $-81.1\text{‰}$ ) values. In the  $\delta\text{D}_{\text{fluid}}$  vs.  $\delta^{18}\text{O}_{\text{fluid}}$  plot (Fig. 3), samples from V1 and V2 veins plot in or adjacent to the box of primary magmatic water, indicating that the initial ore-forming fluids were magmatic in origin. Four samples from V3 veins show relatively low  $\delta^{18}\text{O}_{\text{fluid}}$  ( $-0.2$  to 3.7‰) and  $\delta\text{D}_{\text{fluid}}$  ( $-88.4$  to  $-84.0\text{‰}$ ) values, and are plotted in the region between the primary magmatic water box and the meteoric water line, suggesting that the ore-forming fluids formed V3 veins were a magmatic–meteoric mixture. The depressed  $\delta^{18}\text{O}_{\text{fluid}}$  ( $-3.2$  to  $-1.4\text{‰}$ ) and  $\delta\text{D}_{\text{fluid}}$  ( $-92.8$  to  $90.2\text{‰}$ ) isotopic compositions of fluids that

formed the V4 veins are extremely depleted, strongly implying the involvement of meteoric water in late stage fluids. In the  $\delta D_{\text{fluid}}$  versus  $\delta^{18}O_{\text{fluid}}$  diagram (Fig. 3), all isotopic values of quartz gradually decrease from V1 to V4 veins, indicating that the ore-forming fluids have a dominantly magmatic signature in the early stage and were diluted by meteoric waters during the late stage.

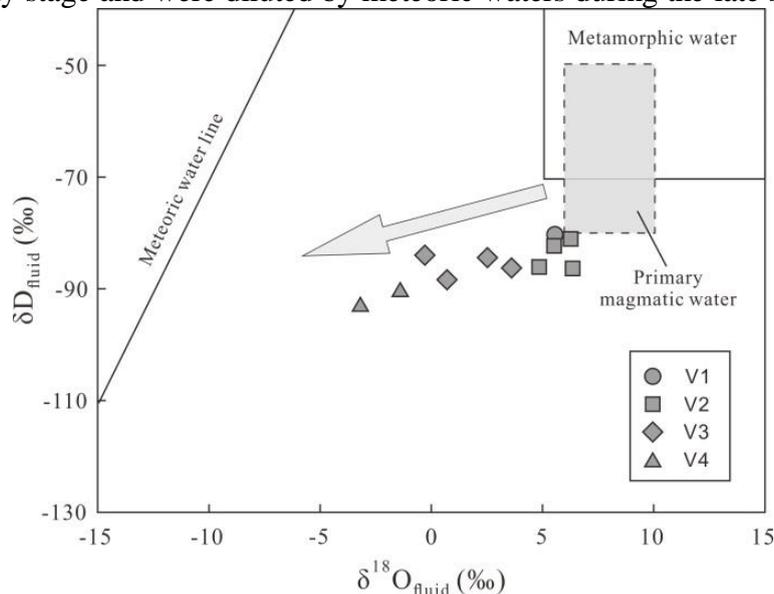


Fig. 3 Oxygen and hydrogen isotopic compositions of waters in quartz from the No.2 porphyry Cu-Au deposit in the Xionggun district. The primary magmatic and metamorphic water boxes are from Taylor [15].

## 6. Conclusion

Four distinctly different vein types (V1 to V4) have been identified in the No.2 Porphyry Cu-Au deposit in the Xionggun district. These veins record the origin and evolution of ore-forming fluids. Oxygen and hydrogen isotope data indicates that the ore-forming fluids of the No.2 Porphyry Cu-Au deposit are mainly derived from magmatic water in the early stage. Being accompanied with the fluid evolution in the late stage, the proportion of meteoric waters precipitation gradually increased.

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