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Geology, fluid inclusion and isotope constraints on ore genesis of the post-collisional Dabu porphyry Cu–Mo deposit, southern Tibet

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ABSTRACT

The Dabu Cu-Mo porphyry deposit is situated in the southern part of the Lhasa terrane within the post-collisional Gangdese porphyry copper belt (GPCB). It is one of several deposits that include the Qulong and Zhunuo porphyry deposits. The processes responsible for ore formation in the Dabu deposit can be divided into three stages of veining: stage I, quartz–K-feldspar (biotite) ± chalcopyrite ± pyrite, stage II, quartz–molybdenite ± pyrite ± chalcopyrite, and stage III, quartz–pyrite ± molybdenite. Three types of fluid inclusions (FIs) are present: liquid-rich two-phase (L-type), vapor-rich two-phase (V-type), and solid bearing multi-phase (S-type) inclusions. The homogenization temperatures for the FIs from stages I to III are in the ranges of 272–475 °C, 244–486 °C, and 299–399 °C, and their salinities vary from 2.1 to 49.1, 1.1 to 55.8, and 2.9 to 18.0 wt% NaCl equiv., respectively. The coexistence of S-type, V-type and L-type FIs in quartz of stage I and II with similar homogenization temperatures but contrasting salinities, indicate that fluid boiling is the major factor controlling metal precipitation in the Dabu deposit. The ore-forming fluids of this deposit are characterized by high temperature and high salinity, and they belong to a H_2O–NaCl magmatic–hydrothermal system. The H–O–S–Pb isotopic compositions indicate that the ore metals and fluids came primarily from a magmatic source linked to Miocene intrusions characterized by high Sr/Y ratios, similar to other porphyry deposits in the GPCB. The fluids forming the Dabu deposit were rich in Na and Cl, derived from metamorphic dehydration of subducted oceanic slab through which NaCl-brine or seawater had percolated. The inheritance of ancient subduction-associated arc chemistry, without shallow level crustal assimilation and/or input of the meteoric water, was responsible for the generation of fertile magma, as well as CO_2-poor and halite-bearing FIs associated with post-collisional porphyry deposits. The estimated mineralization depths of Qulong, Dabu and Zhunuo deposits are 1.6–4.3 km, 0.5–3.4 km and 0.2–3.0 km, respectively, displaying a gradual decrease from eastern to western Gangdese. Deep ore-forming processes accounted for the generation of giant-sized Qulong deposit, because the exsolution of aqueous fluids with large fraction of water and chlorine in deep or high pressure systems can extract more copper from melts than those formed in shallow systems. However, the formation of small-sized Dabu deposit can be explained by a single magmatic event without additional replenishment of S, metal, or thermal energy. In addition, the ore-forming conditions of porphyry Cu–Mo deposits in GPCB are comparable to those of porphyry Cu ± Au ± Mo deposits formed in oceanic subduction-related continental or island arcs, but differ from those of porphyry Mo deposit formed in the Dabie-Qinling collisional orogens. The depth of formation of the mineralization and features of primary magma source are two major controls on the metal types and ore-fluid compositions of these porphyry deposits.

1. Introduction

The porphyry deposits, particularly giant ones, are the results of an optimal alignment and combinations of tectonic controls, host rock types, and focused flow of fluids (Richards, 2013). Their

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formation is generally associated with Cu-rich and/or anomalously S-rich parental melts with high oxygen fugacity and water content formed under magmatic conditions (Halter et al., 2005; Core et al., 2006; Sillitoe, 2010; Richards, 2011a, 2011b; Sun et al., 2013a; Loucks, 2014; Lu et al., 2015). Recently, many porphyry copper deposits have been discovered along the non-arc or post-collisional setting of the eastern Tethys; examples include the deposits in the Kerman porphyry Cu belt in Iran (Fig. 1a; Shafiei et al., 2009; Richards et al., 2012) and the Gangdese porphyry Cu–Mo belt (GPCB) in Tibet, China (Fig. 1a; Zheng et al., 2004; Hou et al., 2009). These deposits are geochemically associated with rocks formed from adakite-like calc-alkaline (Jahangiri, 2007; Shafiei et al., 2009; Asadi et al., 2014) or high-K calc-alkaline and shoshonitic magmas (Chung et al., 2005; Qu et al., 2007; Hou et al., 2011).

The GPCB, located on the northern margin of the Indus–Yarlung Zangbo suture zone, is regarded as one of the most richly endowed copper provinces in the Alpine–Himalayan orogenic belt (Fig. 1b; Mao et al., 2014; Hou and Zhang, 2015; Zheng et al., 2015a). In GPCB, there are numerous porphyry Cu–Mo deposits that formed in a post-collisional setting, such as Qulong, Zhunuo, and Dabu (Fig. 1b; Zheng et al., 2004, 2007, 2014; Yang, 2008; Yang et al., 2009; Wu et al., 2014, 2016).

The world-class giant Qulong porphyry Cu-Mo deposit, firstly described by Zheng et al. (2004), Gao and Zheng (2006) and Zheng et al. (2006), is situated in the central segment of south Lhasa terrane about 50 km eastern of Lhasa (Fig. 1b). This deposit contains >10 Mt Cu and 0.44 Mt Mo at an average grade of 0.44% and 0.02%, respectively (Zheng et al., 2015a). Metal reserves are expected to increase as a result of exploration in the periphery and at depth. The Qulong Cu–Mo deposit is associated with the stock-shaped Miocene intrusive complex, with an outcrop area of 8 km^2 and ages ranging from 19.6 Ma to 15.7 Ma. Mafic enclaves and magmatic anhydrite are commonly present (Yang, 2008; Xiao et al., 2012; Zheng et al., 2013). The Zhunuo deposit is a large-sized porphyry Cu-Mo deposit in the western segment of south Lhasa terrane which is located about approximately 165 km western of Xigaze (Fig. 1b). This deposit contains reserves of 2.3 Mt Cu at an average grade of 0.57% (Zheng et al., 2015a). The mineralization-associated monzogranite porphyry at the Zhunuo deposit has a zircon U–Pb age of 14.4 ± 0.2 Ma (Zheng et al., 2014), similar to molybdenite Re–Os age of 13.7 ± 0.6 Ma (Zheng et al., 2007). The Dabu deposit in the southern part of the Lhasa terrane is a porphyry Cu-Mo deposit formed in a post-collisional setting in the GPCB, which is classified as small-sized porphyry-type deposit with a reserve of approximately 0.5 Mt Cu at an average grade of ~0.31 wt% (Zheng et al., 2015a). The geology, geochemistry, and geochronology of post-subduction porphyry deposits in the GPCB have been extensively studied (Zheng et al., 2002, 2015a; Qu et al., 2004, 2007; Yang et al., 2009, 2015a; Qin, 2012; Wang et al., 2014a, 2014b, 2014c, 2015a; Hou et al., 2015b; Lu et al., 2015; Wu et al., 2016). However, little is actually known regarding the key controls on the diversity in scale of deposits in the GPCB (e.g., giant, large, small; Fig. 1b). Due to a lack of systematic fluid inclusion studies, the ore-forming process, as well as the characteristics and source of ore metals and fluids, compared to porphyry deposits formed in magmatic arc settings (Bodnar et al., 2014), are still poorly understood (Hou et al., 2009; Landtwing et al., 2010), which undermines efforts to model the porphyry-style ore deposits in the GPCB.

The Dabu deposit is a small-sized porphyry Cu-Mo deposit in GPCB. Previous studies were mainly focused on geochronology and geochemistry (Wu et al., 2014, 2016). However, an integrated study of the fluid evolution and source of the Dabu deposit have so far not been reported. Fluid inclusions (FIs), as the record of ore-forming fluids, are critical for understanding the physical and

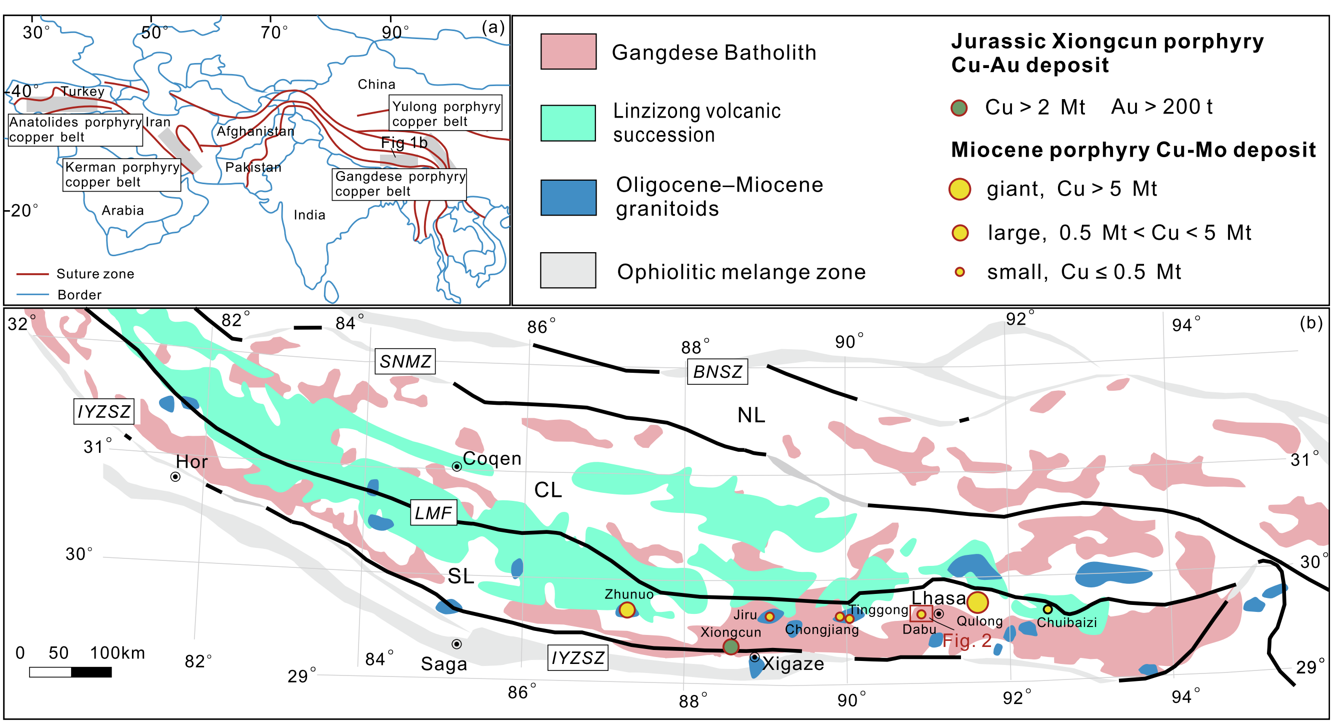

Fig. 1. (a) Distribution of some collision-related porphyry copper belts in the Alpine–Himalayan orogenic belt (modified after Singer et al., 2005 and Hou et al., 2011); (b) simplified geologic map of the Lhasa terrane showing the distribution of major porphyry deposits and the location of the study area (modified after Mo et al., 2008; Zhu et al., 2011a and Wu et al., 2014). The three kinds of yellow circles denote different size of porphyry deposits. Abbreviations: BNSZ–Bangong-Nujiang suture zone, SNMZ–Shiquan River-Nam Tso Mélange Zone, LMF–Luobadui-Milashan Fault, IYZSZ–Indus-Yarlung Zangbo Suture Zone, SL–southern Lhasa subterrane, CL–central Lhasa subterrane, NL–northern Lhasa subterrane. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)