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Geochronology and geochemistry of porphyritic intrusions in the Duolong porphyry and epithermal Cu-Au district, central Tibet: Implications for the genesis and exploration of porphyry copper deposits

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ABSTRACT

The Duolong district in central Tibet hosts a number of porphyry as well as high sulfidation epithermal copper–gold deposits and prospects, associated with voluminous calc-alkaline volcanism and plutonism. In this study, we present new geochronological, geochemical, isotopic and mineralogical data for both economically mineralized and barren porphyritic intrusions from the Duobuza and Naruo porphyry Cu–Au deposits. Zircon U–Pb analyses suggest the emplacement of economically mineralized granodiorite porphyry and barren granodiorite porphyry at Naruo deposit took place at 119.8 ± 1.4 Ma and 117.2 ± 0.5 Ma, respectively. Four molybdenite samples from the Naruo deposit yield an isochron Re–Os age of 119.5 ± 3.2 Ma, indicating mineralization occurred synchronously with the emplacement of the early granodiorite porphyry. At Duobuza deposit, the barren quartz diorite porphyry intruded at 119.5 ± 0.7 Ma, and two economically mineralized intrusions intruded at 118.5 ± 1.2 Ma (granodiorite porphyry) and 117.5 ± 1.2 Ma (quartz diorite porphyry), respectively. Petrographic investigations and geochemical data indicate that all of the porphyritic intrusions were oxidized, water rich, and subduction-related calc-alkaline magmas. Zircons from the porphyritic intrusions have a wide range in the ε_{Hf} (0–11.1) indicating that they were sourced from mixing of mantle-derived mafic, and crust-derived felsic melts. Moreover, the variation of trace element content of plagioclase phenocrysts indicates that the magma chambers were recharged by mafic magmas. Comparison of the composition of amphibole phenocrysts indicates the porphyry copper–gold mineralization at Duolong was generated in magma chambers at low crystallization temperatures and pressures (754° to 791 °C, 59 M to 73 MPa, n = 8), and under highly oxidizing conditions (ΔNNO 2.2 to 2.7, n = 8). In contrast, barren intrusions were sourced from the magma chambers with higher crystallization temperatures and pressures (816° to 892 °C, 111 to 232 MPa, n = 22) that were less oxidizing (ΔNNO 0.6 to 1.6, n = 22). The requirement for a thermal contrast is supported by the declining of Ti content in magnetite crystals in barren intrusions (12,550 to 34,200 ppm) versus those from economically mineralized intrusions (600 to 3400 ppm). Moreover, the V content in magnetite crystals from economically mineralized intrusions (990 to 2510 ppm) is lower than those recorded from barren intrusions (2610 to 3510 ppm), which might reflect the variation in oxidation state of the magma. The calculated water solubility of the magma forming the economically mineralized intrusions (3.2–3.7 wt%) is lower than that of magma forming the barren intrusions (4.6–6.4 wt%). Based on the chemical–physical characteristics of economically mineralized magma, our study suggests that the development of porphyry Cu–Au mineralization at Duolong was initiated by shallow-level emplacement of a magma that crystallized at lower temperatures and pressures. Experimental studies show that copper and water solubilities in silicate melts decrease with falling temperatures and pressures, indicating metals and ore-forming fluids are more likely to be released from a magma reservoir emplaced at shallow crustal levels. We propose the magnetite might be a convenient exploration tool in the search for porphyry copper mineralization because the variations in Ti and V content of mineral concentrates and rock samples are indicative of barren versus mineralized intrusions.

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1. Introduction

Porphyry copper deposits (PCDs) supply three-quarters of the world's Cu and one-fifth of the Au (Sillitoe, 2010). Therefore, a better understanding of the genesis of PCDs can not only provide comprehensive insight into the evolution of magmatic-hydrothermal systems (Hedenquist and Lowenstern, 1994; Bissig et al., 2003; Rusk et al., 2008; Richards, 2009), but also facilitate mineral exploration as the recognition of physical and chemical features of porphyry systems could lead to the discovery of concealed ore deposits (Wilkinson, 2013).

Although the orthomagmatic model for the formation of PCDs has been widely accepted (Burnham, 1979a, 1979b; Cloos, 2001), implying genetic relationship between igneous processes and generation of PCDs, the scarcity of PCDs, compared with the widespread intermediate to felsic calc-alkaline intrusions around the world, indicates that some other factor controls the mineral potential. Numerous studies have been carried out to identify the factors that make magmas "productive" with respect to the development of mineralization. These include tectonic setting (Solomon, 1990; Cooke et al., 2005), the development of unusually Cu-rich parent magmas (Core and Kesler, 2006; Griffin et al., 2013), the high water content of the magma (Liu et al., 2010; Richards et al., 2012; Loucks, 2014; Wang et al., 2014), the addition of sulphur and/or metals from underlying mafic magmas (Hattori and Keith, 2001; Halter et al., 2005), and/or the oxidation state of the magma (Candela, 1992; Ballard et al., 2002). Other studies suggest that the formation of PCDs and associated high sulfidation Cu-Au epithermal deposits simply arise from the coincidence of common geological processes that are able to assemble unusually large accumulations of metal (Richards, 2003, Richards, 2015).

The Duolong district (32°42′–32°55′N, 83°16′–83°46′E), at an elevation of 4900 m, is located in central Tibet. In contrast to the Gangdese porphyry copper belt (GPCB) along the Indus–Yarlung suture zone (IYSZ), southern Tibet, where many porphyry copper deposits are well studied (Beaudoin et al., 2005; Hou et al., 2009; Yang et al., 2009; Mao et al., 2014), the Duolong district is located in the central Tibet, where basic geologic investigation is challenged by the harsh environment. The Duolong district consists of four major Cu–Au porphyry deposits, Bolong, Duobuza, Naruo, and Rongna (Fig. 1), and exploration has delineated a resource of 1.2 Gt of ore grading 0.4% Cu and 0.2 g/t Au (Tang et al., 2014), which makes Duolong one of the most important metallogenic districts in China. Research on the rocks hosting the Duolong Deposit has established a preliminary geochronological framework of magmatism and mineralization (She et al., 2009; Zhu et al., 2011; Li et al., 2011; Fang et al., 2015), and outlined the general sequence of petrogenesis (Li et al., 2013, 2014). In this paper, we present new petrographic, mineralogical, geochemical, geochronologic and isotopic data for barren and economically mineralized porphyritic intrusions from the Duobuza and Naruo deposits. We provide Re–Os age dates of molybdenite from the Naruo deposit to complement the existing geochronological framework data for rocks from the Duolong district, and we present results from an investigation of the petrological processes of magmatic systems at Duolong and the mechanism for the genesis of PCDs. We propose that indicator minerals may be used to distinguish mineralized from barren porphyries.

2. Geological setting

2.1. Regional geological framework

The Duolong district is located at the southern margin of the Qiangtang terrane, to the north of the Bangong–Nujiang suture zone (BNSZ) in Tibet (Fig. 1). The BNSZ extends over 2000 km across the central Tibetan Plateau and represents the remnants of the Bangong–Nujiang Tethyan Ocean (Zhu et al., 2013). An angular unconformity between the Upper Triassic flysch and the underlying ophiolites in Baila (Chen and Zhang, 2005) indicates that the Bangong–Nujiang Tethyan Ocean might have formed in the Permo-Triassic. Subduction along the BNSZ is believed to have been northward during the Jurassic (Kapp et al., 2003; Guynn et al., 2006). However, the existence of an OIB-type ophiolite in the belt with a SHRIMP U–Pb zircon age of 132.0 ± 3 Ma in Dong Tso (Bao et al., 2007) implies that north-dipping subduction extended into the Cretaceous. Zhu et al. (2006) suggested that southward subduction would provide a better interpretation for the spatial distribution and geochemical characteristics of the Late Jurassic to Early Cretaceous volcanic rocks in this area. In summary, it is possible that the Bangong–Nujiang Tethyan Ocean experienced both north- and south-ward subduction during the Jurassic and Cretaceous (Geng et al., 2011).

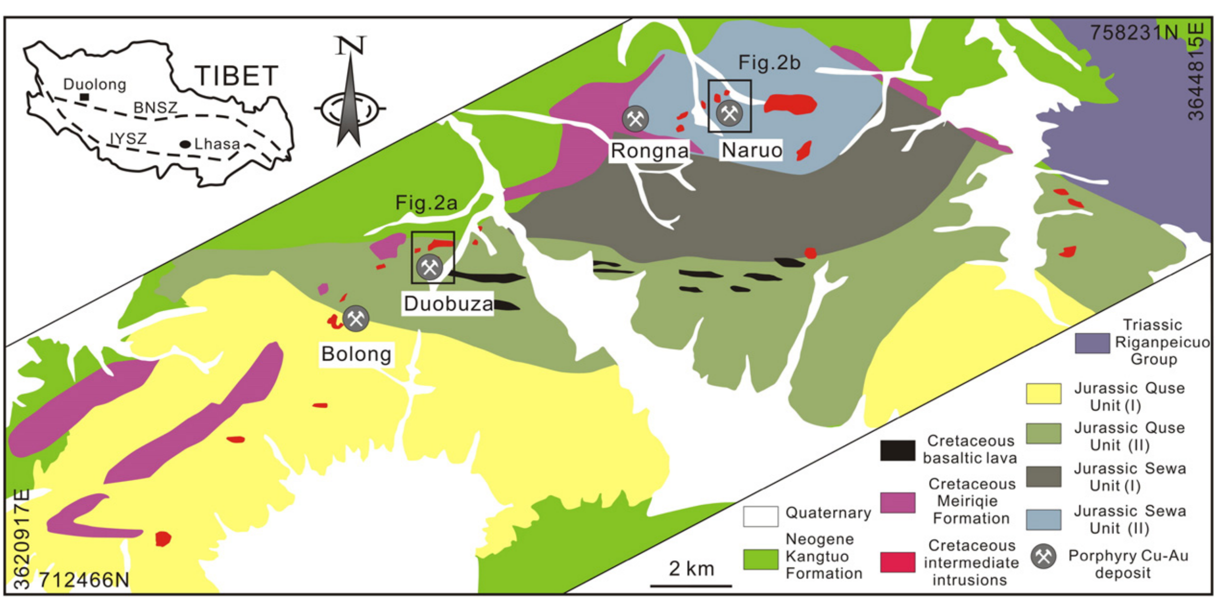

Fig. 1. Geological map of the Duolong district, Tibet, China (modified from the No. 5 Geological Exploration Team, Tibet Bureau of Geology and Exploration, 2010). Abbreviation: BNSZ, Bangong–Nujiang suture zone; IYSZ, Indus–Yarlung suture zone. UTM coordinates, datum WGS84, zone 44N.