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Origin of Ore-Forming Fluids of the Bangpu Porphyry Mo(Cu) Deposit, Tibet: Evidence from Helium and Argon Isotope in Pyrites

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1 Introduction

Porphyry-type ore deposits are arguably the most studied and potentially best known and understood ore deposit type (Sillitoe, 2010). Copper (Cu), gold (Au), and iron (Fe) are first concentrated in a sulfide melt during magmatic evolution (Halter et al., 2002). Gold enrichments may not occur where more abundant sulfides were present in the former arc complex, leading to more “normal” porphyry Cu±Mo systems, such as Kerman porphyry Cu belt of central Iran and the Gangdese porphyry Cu belt of Tibet (Richards, 2011). However, the factors controlling the metal ratios including Cu/Au and Mo/Cu are not clearly established (Seo et al., 2012). Magma compositions, depth of emplacement and mineralogical control are potential geologic al causes for the metals variation (Bodnar and Student, 2006; Landtwing et al., 2010).

Noble gas isotopes have been employed to trace the origin of ore-forming fluids trapped as fluid inclusions in minerals since 1990s (Simmons et al., 1987; Moreira et al., 1998; Burnard et al., 1999; Mao et al., 2002, 2003; Hu et al., 2004). The distinct characteristics (e.g. isotopic composition and elemental abundance) between crustal- and mantle-derived He and Ar provide unique and important constrains for the addition of mantle volatiles to the continental crust (Stuart et al., 1995). Thus, if the metals variation within porphyry deposits system formed in association with magms from different source region (e. g. crust and mantle), their ore-forming fluids should reflect different He and Ar characteristics. In this short review we present the He and Ar isotope from Bangpu, Tibet and constrain the origin of ore-forming fluids.

2 Geological setting

The porphyry Mo (Cu) deposit at Bangpu, locating in the east section of Gangdese, Tibet, containing 0.8 Mt of molybdenum and 0.1 Mt of copper (Fig. 1). Bangpu is hosted by series of mid-Miocene intrusions emplaced into Paleogene Dianzhong and lower Permian Luobadui sedimentary formations consisting of sand-slate and limestone. The sequence of mineralizing porphyries as currently recognized is (1) monzogranite porphyry (MP), (2) quartz monzonite porphyry (QMP) and (3) diorite porphyrite (DP). The deposit shows a distinct metal zonation, with shallow molybdenum mineralization (Mo stage) following the early monzogranite porphyry intrusion and spatially deeper copper mineralization (Cu stage) occurring in the late diorite porphyrite intrusions (Fig. 2). The molybdenum and copper orebody, as defined by the 0.079% and 0.278% ore grade, have the shape of a mushroom cap, whose rim extends irregularly downward, into Paleogene Dianzhong sedimentary rocks.

Molybdenite mineralization commonly without any copper sulfide is associated with abundant and multiple generations of quartz stockwork veins and pervasive potassic alteration (quartz±K-feldspar±biotite). Most Mo stage stockwork veins are contemporaneous with or postdate the intrusion of MP and finally cut by quartz-pyrite veins. Most copper-iron sulfide mineralization formed after the latest intrusion was emplaced, which is in and around quartz-chalcopyrite-pyrite veins with alteration envelopes containing biotite, chlorite and epidote. These veins are typically 1 to 10 mm thick, which consistently postdate the Molybdenite introduction. However, minor late molybdenite is precipitated as euhedral crystals along the margin of the Cu stage veins.

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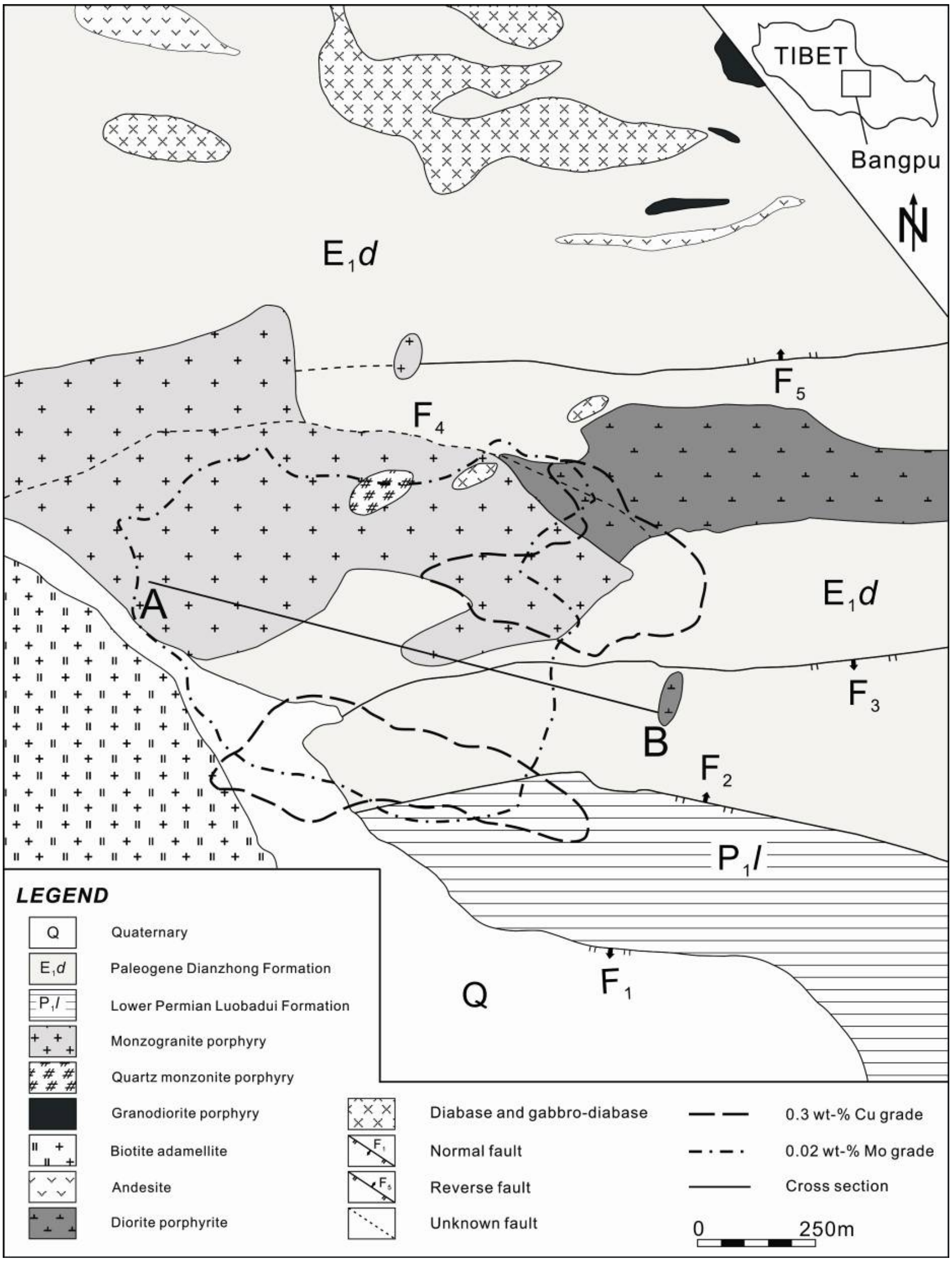

Fig. 1. Simplified geological map of the Bangpu porphyry Mo(Cu) deposit (Modified from Luo et al., 2012)

3 Results and discussions

Noble gases in hydrothermal fluids are most likely to be mixture of three possible sources: (1) Air-saturated water (ASW) (meteoric or marine) is characterized by atmospheric He and Ar isotope compositions ($^3He/^4He=1.39\times10^{-6}=1$ Ra, $^{40}Ar/^{36}Ar=295.5$; Turner et al., 1993). (2) The curstal fluid is ASW that has clearly been modified by addition of radiogenic ^4He and ^{40}Ar, so $^3He/^4He$ ratios and $^{40}Ar/^{36}Ar$ ratio in the crust should be similar to the characteristic values of 0.01~0.05Ra and $>$ 295.5 (Hu et al., 1998). (3) Mantle-derived fluids are not only rich in ^3He but also poor in ^{36}Ar, which consequently imply a likely mantle $^3He/^4He$ ratio of 6~9 Ra and a $^{40}Ar/^{36}Ar$ ratio of $>$40,000 (Dunai and Baur, 1995; Burnard et al., 1999; Gautheron and Moreira, 2002).

The He and Ar isotope composition of inclusions in pyrites from Bangpu help to trace the origin of ore-forming fluid. The concentrations of ^4He are $1.51\times10^{-}$

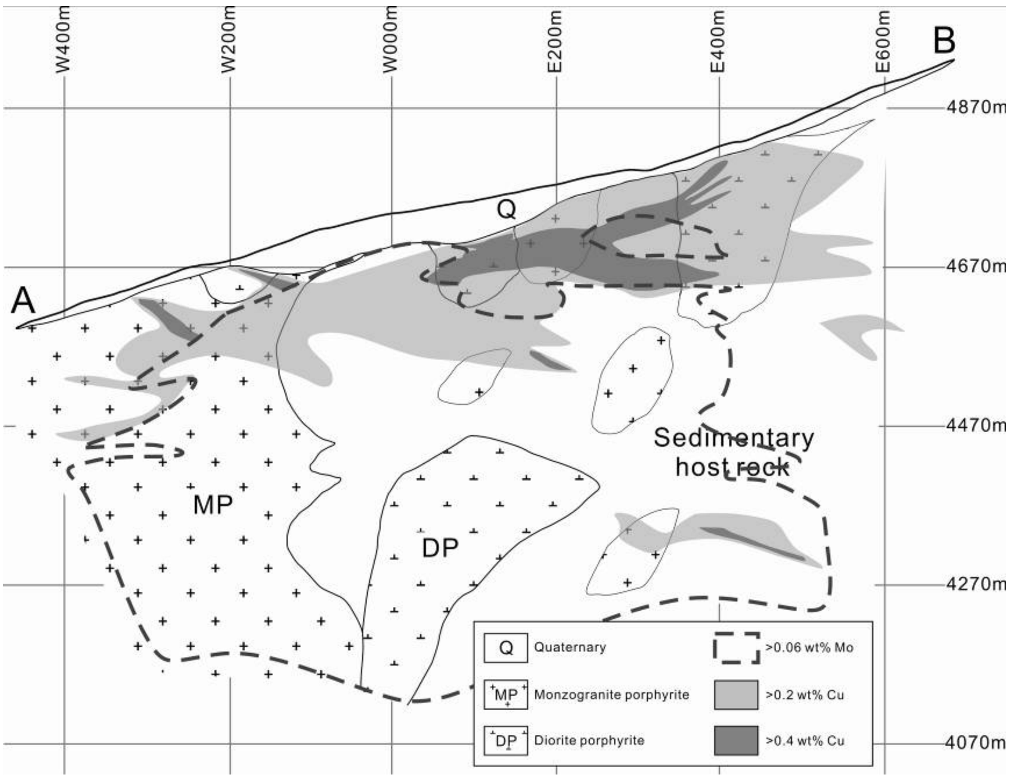

Fig. 2. NW-SE cross section through Bangpu (Modified from❶), showing lithologies and metal zonation

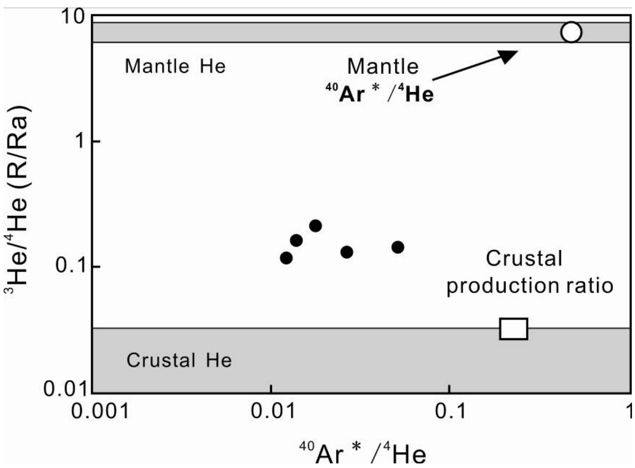

Fig. 3. $^{4}He/^{40}Ar^{*}$ vs. $^{3}He/^{4}He$ (Ra) plot of inclusion trapped fluids in pyrites (Modified from Ballentine et al., 2002)

^{7}~$3.5\times10^{-7}cm^{3}$STP/g, and those of ^{40}Ar are 0.49×10^{-7}~$9.31\times10^{-7}cm^{3}$STP/g. The large variations in noble gas concentrations probably reflect variations in fluid inclusion density and are unlikely to have genetic implications. Noble gas isotopic ratios are more consistent: $^{3}He/^{4}He$ ratios are 0.12~0.36 Ra, $^{40}Ar/^{36}Ar$ ratios are ranging from 299.1 to 363. As can be seen in Fig. 3, $^{3}He/^{4}He$ ratios of the ore-forming fluids from Bangpu (0.12~0.36 Ra) are relatively uniform and higher than those of the crust, but much lower than those of the mantle-derived fluids, in contrast, $^{40}Ar/^{36}Ar$ value (291.1~363) is close to the Ar isotopic composition of ASW. The ore-forming fluids has a $^{3}He/^{4}He$ ratio ＜air, but atmospheric, or nearly atmospheric, $^{40}Ar/^{36}Ar$, indicating that both mantle-derived and radiogenic noble gases are both present in these ore forming fluids. These radiogenic noble gases were most likely derived from the crust before mixing with the ^{4}He-enriched modified ASW.

Contemporary groundwaters and hydrothermal fluids are known to acquire radiogenic ^{4}He but not ^{40}Ar from the crust, because the blocking temperature of ^{4}He in most minerals is generally low (＜200℃, ＜100℃ for many U-bearing minerals), while that of of Ar is considerably higher (in most minerals ＞250°C). As a result, most these fluids have $^{3}He/^{4}He$ ratios lower than the atmospheric value but do not entrain radiogenic ^{40}Ar and have atmospheric $^{40}Ar/^{36}Ar$ (Burnard et al., 1999).

A $^{4}He/^{40}Ar^{*}$ ratio ($^{40}Ar^{*}$ is resolvable radiogenic ^{40}Ar, which is calculated assuming that all ^{36}Ar is atmospheric in origin, $^{40}Ar^{*} = {}^{40}Ar - {}^{36}Ar \times 295.5$; Hu et al., 2004) of 0.01~0.07 is obtained from the correlation between $^{3}He/^{4}He$ and $^{4}He/^{40}Ar^{*}$ (Fig. 3), similar to but a little bit lower than estimates of the likely $^{4}He/^{40}Ar^{*}$ production ratio of the crust (≈0.2). The ore-forming fluids from Bangpu acquired not only ^{4}He but also ^{40}Ar from crustal rocks, suggesting that they were relatively high temperature fluids (＞250°C).

4 Conclusions

Bangpu Mo(Cu) deposit, consequence of mineralization explosion during the extension environment after India-Asia continental collision, is a porphyry deposit related to calc-alkaline porphyries, which were mainly derived from a young mantle and partly mixed with old continental crust rocks during evolution (Luo et al., 2011). The Helium and Argon isotopic signatures in the present study indicates that ore-forming fluids at Bangpu were a mixture of crust and mantle fluids with the former dominates, and lack of meteoric water involvement during the whole mineralization.

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Key words: Helium and Argon isotope, pyrite, ore-forming fluid, Bangpu Mo(Cu) deposit, Tibet

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