

Redox states and genesis of magmas associated with intra-continental porphyry Cu–Au mineralization within the Jinshajiang–Red River alkaline igneous belt, SW China



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ABSTRACT

The Jinshajiang–Red River alkaline igneous belt and the associated Cenozoic Cu–Au mineralization are located in an intra-continental strike-slip fault zone in SW China. The Ce⁴⁺/Ce³⁺ ratios of zircon from representative Cu-mineralized, Au-mineralized and barren porphyry intrusions from the belt indicate that the Cu–Au ore-bearing porphyry intrusions had much higher fO₂ of magma than the barren porphyry intrusions. Elemental and Sr–Nd isotope ratio data indicate that both the Cu–Au ore-bearing and barren porphyry intrusions were derived from partial melts of the ancient enriched metasomatized mantle sources (EMII type). The mantle source was possibly modified by subduction of the Paleo-Tethyan oceanic slab beneath the Changdu–Simao block between the early Permian and the late Triassic. The oxygen fugacity of the magma was likely related to the redox state of the source, and the different fO₂ calculated for the magmas that gave rise to Cu–Au ore-bearing and barren porphyry intrusions are a product of magmas from the different sources. The sources of the barren porphyry intrusions were influenced mainly by the slab-derived fluids, whereas the sources of the Cu–Au ore-bearing porphyry intrusions were modified by both the slab-derived fluids and slab-derived melts. Cenozoic strike-slip faulting in this region caused lithospheric-scale extension and upwelling of the asthenosphere; the heat produced by this process produced partial melts of the ancient enriched metasomatized mantle sources, resulting in the emplacement of alkaline porphyry intrusions and associated Cu–Au mineralization at ~40–30 Ma.

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1. Introduction

Porphyry Cu–Au systems are usually associated with calc-alkaline and alkaline igneous rocks, and they are primarily formed in arc environments (Sillitoe, 1972, 1997, 2002, 2010; Mitchell, 1973; Tatsumi, 1989; Richards, 1990, 2003; Muller and Groves, 1993; Ulrich et al., 1999; Ulrich and Heinrich, 2001; Hattori and Keith, 2001; Muller, 2002; Mungall, 2002; Heinrich et al., 2005). Porphyry Cu–Au mineralization in arc-settings is thought to be closely related to relatively oxidized calc-alkaline and alkaline magmas (Sillitoe, 1972, 1997, 2002, 2010; Richards, 1990, 2003, 2009, 2011a; Muller and Groves, 1993; Ulrich et al., 1999; Ulrich and Heinrich, 2001; Oyarzun et al., 2001; Mungall, 2002; Ballard et al., 2002; Imai et al., 1993; Imai, 2002, 2004; Sun et al., 2004, 2013). This association can be ascribed to the redox control of oxygen fugacity (fO₂) on the speciation and solubility of sulfur in a magma, and the influence of fO₂ on the fractionation of Cu- and Au-sulfides from a magma (Ballard et al., 2002; Mungall, 2002); under high fO₂ conditions, the majority of the sulfur exists as SO₂ or SO₄²⁻ with very low concentrations of S²⁻ in a magma; this prevents

saturation and precipitation of immiscible Cu- and Au-sulfides from a fractionating magma, thus, allowing concentration of Cu and Au during magmatic differentiation and eventually their localization in magmatic-hydrothermal ore-forming fluids (Carroll and Rutherford, 1987; Spooner, 1993; Wybon, 1994; Sillitoe, 1997; Streck and Dilles, 1998; Mungall, 2002; Richards, 2003; Sun et al., 2004, 2013). Numerous studies have suggested that the high fO₂ of arc-magmas which gave rise to porphyry Cu–Au mineralization, were primarily produced by oxidized silicate melts or hydrothermal fluids, released from a subducted oceanic slab (Wyllie, 1978; Tatsumi, 1989; Davies and Stevenson, 1992; Peacock, 1993; McInnes and Cameron, 1994; Brandon and Draper, 1996; Mungall, 2002; Oyarzun et al., 2008). There are also abundant porphyry Cu–Au systems in intra-continental settings (Hu et al., 1998, 2004; Bi et al., 2002, 2004, 2005, 2006, 2009; Hou et al., 2003a,b, 2004, 2007, 2011, 2013; Richards, 2009; Liu et al., 2012; Lu et al., 2013; Zhang et al., 2013); examples include the Cenozoic porphyry Cu–Au systems in the Jinshajiang–Red River alkaline igneous belt, SW China, the Mesozoic Dexing porphyry Cu(Mo–Au) system in eastern China, and the Miocene Gangdese porphyry Cu(Mo) belt in Tibet, western China (Hu et al., 1998, 2004; Bi et al., 2002, 2004, 2005, 2009; Hou et al., 2003a,b, 2004, 2007, 2011, 2013; Xu et al., 2010; Liu et al., 2012; Lu et al., 2013). These porphyry Cu–Au systems are usually linked to

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intermediate-acidic rocks that belong to a group of high-K calc-alkaline and shoshonitic magma series, and are not considered to be directly related to subduction of the oceanic slabs (Hou et al., 2004, 2007, 2011, 2013; Liu et al., 2012). In comparison with porphyry Cu–Au systems in arc-settings, the fO_2 of magmas associated with porphyry Cu–Au mineralization in intra-continental settings is not well understood. A few studies indicate that the magmas associated with intra-continental porphyry Cu–Au mineralization had elevated fO_2 (Liang et al., 2006a,b; Bi et al., 2006, 2009; Zhang et al., 2013), but the fO_2 of magmas related to ore-bearing and barren porphyry intrusions, and the factors controlling the oxygen fugacity of magmas are still not well understood (Hou et al., 2003a; Bi et al., 2006; Liang et al., 2006a,b; Zhang et al., 2013). It is therefore important to examine the principal controls on the oxygen fugacity of these types of magmas in intra-continental settings.

There are several methods for determining the oxygen fugacity of magmas (Wones and Eugster, 1965; Huebner and Sato, 1970; Chou,

1978; Sack et al., 1980; Kilinc et al., 1983; Wones, 1989; Carmichael and Ghiorsio, 1986; Wallace and Carmichael, 1994; Metrich and Clocchiatti, 1996; Ballard et al., 2002; Audetat et al., 2004; Stern et al., 2007). Oxygen barometers based on Fe–Ti oxides are easily affected by slow cooling of the magma, and empirical redox indicators such as Fe^{3+}/Fe^{2+} ratios of whole-rock, amphibole and biotite, and the presence of anhydrite rarely survive the processes of hydrothermal alteration and surficial weathering (Ballard et al., 2002). Ce^{4+}/Ce^{3+} ratios of zircon have been shown to be suitable in constraining the relative redox states of magmas (Ballard et al., 2002; Liang et al., 2006a,b). Zircon is a widespread mineral in many types of rocks, and is resistant to strong physical–chemical destruction after crystallization (Lee et al., 1997; Cherniak and Watson, 2001). Ce^{4+}/Ce^{3+} ratios of zircon are controlled by fO_2 of magmas, and not affected by temperature of crystallization (Ballard et al., 2002). For these reasons, the Ce^{4+}/Ce^{3+} ratio of zircon provides a very robust indicator of redox conditions.

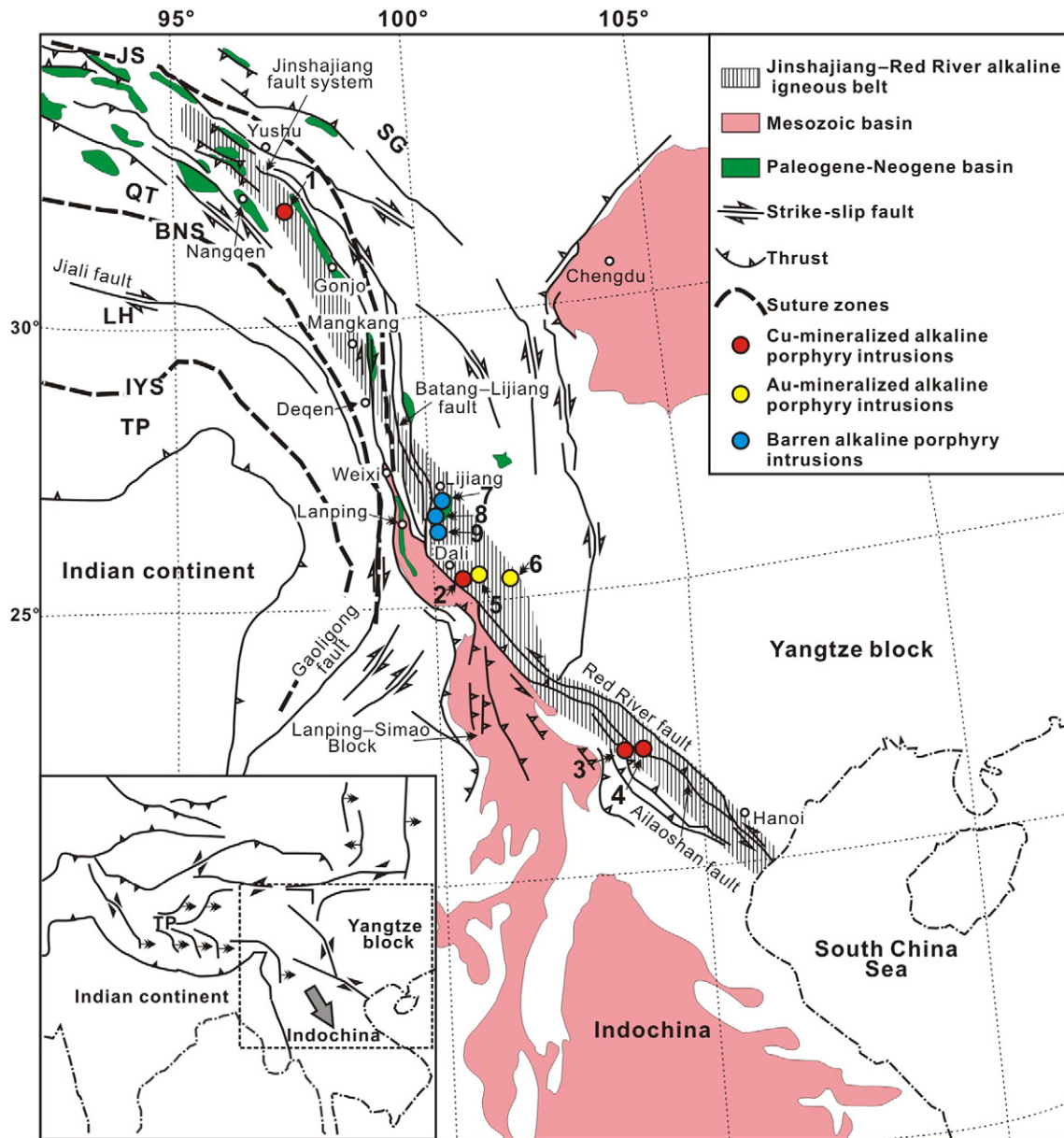


Fig. 1. A simplified geological map of the Jinshajiang–Red River alkaline igneous belt showing the representative Cu-mineralized, Au-mineralized and barren alkaline porphyry intrusions (modified from Wang et al., 2001). Abbreviations: SG—Songpan–Ganze terrane, QT—Qiangtang terrane, LH—Lhasa terrane, TP—Tibetan plateau, JS—Jinshajiang suture, BNS—Bangonghu–Nujiang suture, and IYS—Indian river–Yalu–Zangbu suture; Alkaline porphyry intrusions: 1—Yulong, 2—Machangqing, 3—Tongchang, 4—Chang’an chong, 5—Rentouqing–Jinchangqing, 6—Yao’an, 7—Liuhe, 8—Songgusi and 9—Yanshuiqing.

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