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Geochemical differences between subduction- and collision-related copper-bearing porphyries and implications for metallogenesis

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ABSTRACT

Porphyry Cu (–Mo–Au) deposits occur not only in continental margin–arc settings (subduction-related porphyry Cu deposits, such as those along the eastern Pacific Rim (EPRIM)), but also in continent–continent collisional orogenic belts (collision-related porphyry Cu deposits, such as those in southern Tibet). These Cu-mineralized porphyries, which develop in contrasting tectonic settings, are characterized by some different trace element (e.g., Th, and Y) concentrations and their ratios (e.g., Sr/Y, and La/Yb), suggesting that their source magmas probably developed by different processes. Subduction-related porphyry Cu mineralization on the EPRIM is associated with intermediate to felsic calc-alkaline magmas derived from primitive basaltic magmas that pooled beneath the lower crust and underwent melting, assimilation, storage, and homogenization (MASH), whereas K-enriched collision-related porphyry Cu mineralization was associated with underplating of subduction-modified basaltic materials beneath the lower crust (with subsequent transformation into amphibolites and eclogite amphibolites), and resulted from partial melting of the newly formed thickened lower crust. These different processes led to the collision-related porphyry Cu deposits associated with adakitic magmas enriched by the addition of melts, and the subduction-related porphyry Cu deposits associated with magmas comprising all compositions between normal arc rocks and adakitic rocks, all of which were associated with fluid-dominated enrichment process.

In subduction-related Cu porphyry magmas, the oxidation state (fO_2), the concentrations of chalcophile metals, and other volatiles (e.g., S and Cl), and the abundance of water were directly controlled by the composition of the primary arc basaltic magma. In contrast, the high Cu concentrations and fO_2 values of collision-related Cu porphyry magmas were indirectly derived from subduction modified magmas, and the large amount of water and other volatiles in these magmas were controlled in part by partial melting of amphibolite derived from arc basalts that were underplated beneath the lower crust, and in part by the contribution from the rising potassic and ultrapotassic magmas. Both subduction- and collision-related porphyries are enriched in potassium, and were associated with crustal thickening. Their high K_2O contents were primarily as a result of the inheritance of enriched mantle components and/or mixing with contemporaneous ultrapotassic magmas.

1. Introduction

Porphyry Cu deposits are the world's main source of Cu as well as a source of significant amounts of Mo and Au; as such, these deposits have been the focus of a large amount of research, both theoretical and applied (e.g., Sillitoe, 1972, 1973, 1998, 2000, 2005, 2010; Richards, 2003, 2009, 2011a,b, 2013; Hou et al., 2004, 2009, 2011; Richards and Kerrich, 2007; Sun et al., 2013). Typical porphyry Cu deposits occur in subduction-related continental and island arc settings, such as those of the Pacific Rim, which are closely associated with the subduction of oceanic crust (e.g., Kelser et al., 1975; Skewes and Stern, 1995; Kirkham, 1998; Kay et al., 1999; Kerrich et al., 2000; Richards et al., 2001). The classic model of porphyry Cu mineralization (e.g., Sillitoe, 1972), which is based on porphyry deposits formed in arc settings, has been the basis of successful exploration and discovery of porphyry deposits in the circum-Pacific metallogenic belt (Fig. 1a; e.g., Mitchell and Garson, 1972; Jorhan et al., 1983; Bektas et al., 1990; Solomon, 1990; Rui et al., 2004). More recent discoveries have highlighted the

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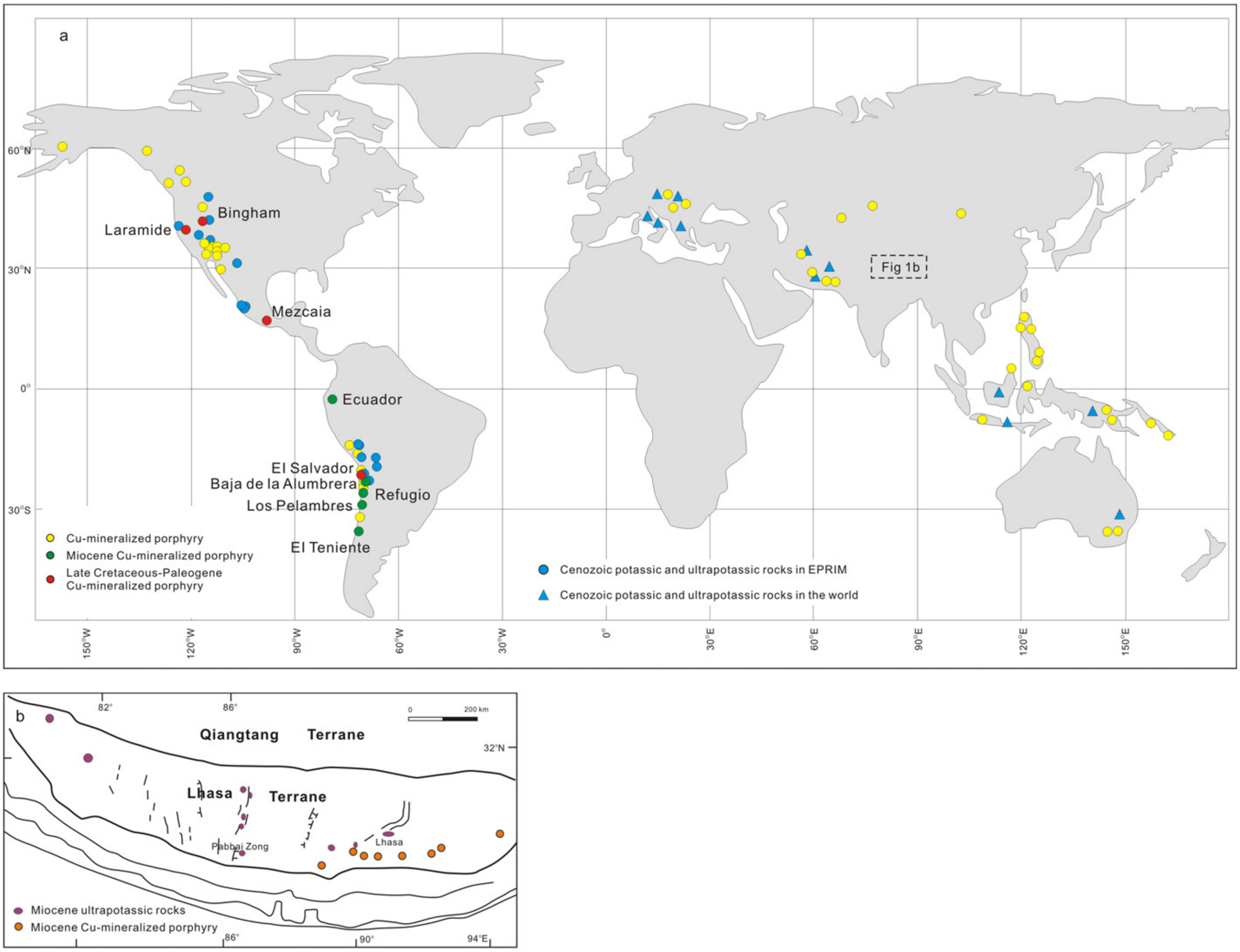

Fig. 1. (a) Worldwide distribution of porphyry Cu deposits and Cenozoic potassic and ultrapotassic rocks on the Eastern Pacific Rim (EPRIM) and in the world (modified from Müller et al. (1992), and Sillitoe (2010)) and (b) Miocene porphyry Cu mineralization and ultrapotassic rocks in the Gangdese porphyry Cu belt of southern Tibet (modified from Hou et al. (2004, 2009), and Zhao et al. (2009)). Distribution of Cenozoic potassic and ultrapotassic rocks on EPRIM and in the world based on Wallace and Carmichael (1989), Müller et al. (1992), Kay et al. (1994), Carlier et al. (1997), Redwood and Rice (1997), Haschke et al. (2002), Maughan et al. (2002), Carlier and Lorand (2003), Sandeman and Clark (2004), Conticelli et al. (2007), Jiménez and López-Velásquez (2008), Mamani et al. (2010), Gómez-Tuena et al. (2011), Prelević et al. (2014), and Saadat et al. (2014).

occurrence and formation of porphyry Cu (–Mo–Au) deposits in continent–continent collisional settings, such as in southern Tibet, Iran, and western Pakistan (e.g., Rui et al., 1984; Hou et al., 2001, 2003, 2004, 2009, 2011; Qu et al., 2001; Richards, 2009, 2011a,b; Shafiei et al., 2009; Pettke et al., 2010; Richards et al., 2012; Ayati et al., 2013; Asadi et al., 2014; Fig. 1a, b). Research on deposits in these collisional environments has led to the establishment of a model of collisional orogenic porphyry mineralization (e.g., Rui et al., 2006; Hou et al., 2007, 2009, 2011; Hou and Cook, 2009; Lu et al., 2013; Yang et al., 2014; Wang et al., 2014b,c). The development of porphyry Cu deposits in different tectonic settings, such as those of subduction-related continental margin–arcs (referred to as 'subduction-related porphyry Cu deposits' in this study) and continent–continent collisional (referred to as 'collision-related porphyry Cu deposits' in this study) settings, suggests that the magmas associated with these deposits were derived either from sources with different compositions and/or formed through different mechanisms.

Although a few studies have compared subduction- and collision-related porphyry Cu deposits (e.g., Hou et al., 2009, 2011), most of this previous research has concentrated on the genetic association between adakitic rocks and porphyry Cu deposits (e.g., Richards and Kerrich, 2007; Richards, 2009; Sun et al., 2011, 2012). Thus, it is unclear whether there are systematic geochemical differences between subduction- and collision-related copper-bearing porphyries. Here, we use published geochemical data for typical patterns of Cu-bearing porphyries to identify differences in geochemical characteristics of subduction- and collision-related Cu-bearing porphyries. The data are from continental margin arc settings along the eastern Pacific Rim (EPRIM; based on two stages of formation, during the Late Cretaceous–Paleogene and the Neogene), and from a continent–continent collision zone in southern Tibet (which formed during the Miocene), and we discuss variations in the source compositions and formation mechanisms of the deposits, thereby providing a basis for further exploration of other areas with tectonic settings suitable for porphyry Cu mineralization.

2. Temporal and spatial distribution of porphyry deposits

Globally, porphyry Cu (–Mo–Au) deposits occur mainly in the circum-Pacific, Tethys–Himalaya, and ancient Asia (Central Asia) metallogenic belts (e.g., Cooke et al., 2005; Sinclair, 2007; Richards,