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Petrogenesis of Paleocene-Eocene porphyry deposit-related granitic rocks in the Yaguila-Sharang ore district, central Lhasa terrane, Tibet

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ABSTRACT

The Paleocene-Eocene ore deposits in the Gangdese Metallogenic Belt, Tibet, are thought to have been formed during the main period of India-Asia continental collision. This paper reports the whole-rock major element, trace element, and Sr-Nd-Hf isotopic compositions and zircon trace element contents of volcanic and intrusive rocks from the Paleocene Yaguila skarn Pb-Zn-Ag deposit and adjacent Eocene Sharang porphyry Mo deposit in the central Lhasa terrane, Tibet. Geochemical signatures and Nd-Hf isotopic compositions indicate that the Yaguila Cretaceous rhyolitic rocks were formed by the melting of ancient continental crust, whereas the Paleocene causative granite porphyry may have resulted from the interaction between mantle-derived and crustal-derived materials when continental collision was initiated. The dramatic increase of $\varepsilon_{Nd}(t)$ values between emplacement of the granite porphyry and later porphyritic biotite granite suggests a greater involvement of mantle materials during the crystallization of the barren biotite granite stock. The post-ore Miocene granodiorite porphyry has a similar geochemical signature to the Sharang Miocene dykes, suggesting they were both generated from melting of enriched lithospheric mantle. Nd-Hf mixing calculations indicate an increasing contribution of mantle materials in Paleocene to Eocene intrusions, consistent with the regional tectonic model of Neo-Tethyan oceanic slab roll-back and break-off. Zircons from both the Yaguila and Sharang ore-related porphyries have higher Ce anomalies than those from the barren granitoids, suggesting that Mo mineralization was closely related to highly oxidized and differentiated magma. The fertile intrusions in the Yaguila-Sharang district contain Eu_N/Eu_N^* values from 0.3 to 0.6, higher than the non-mineralized intrusions. The processes of early crystallization of plagioclase and/or SO_2-degassing from underlying magma can explain the observed negative Eu anomalies in zircon.

1. Introduction

Porphyry deposits are typically associated with highly oxidized magmas, facilitating the transport of metals and sulfur from the mantle to the shallow crust (Richards, 2003; Cooke et al., 2005; Sillitoe, 2010). However, the lack of suitable igneous minerals (such as primary Fe-Ti oxide and hornblende) in felsic intrusions, combined with (typically) intensive hydrothermal alteration, often hampers the determination of relative magma oxidation states. Fortunately, zircon rare earth element (REE) signatures have been shown to reflect the chemical and isotopic nature of the magma at the time of zircon crystallization, and zircon Ce^{4+}/Ce^{3+} ratios reflect the oxidation state of the parental magma (e.g. Ballard et al., 2002; Liang et al., 2006; Han et al., 2013; Qiu et al., 2013; Shen et al., 2015).

Miocene porphyry Cu-Mo deposits in the Tibetan continental collisional zone are characterized by an adakitic composition (e.g. Hou et al., 2004; J. Li et al., 2011; Y. Li et al., 2011; Z.-M. Yang et al., 2015), high oxidation state (e.g. Xiao et al., 2012; Wang et al., 2014), and high magmatic water content (Lu et al., 2015). In addition, they occur in a post-collisional environment (e.g. Hou and Cook, 2009; Qin, 2012; Richards, 2015). Recently, more Paleocene-Eocene ore deposits associated with granitic stocks have been reported in the Gangdese Metallogenic Belt (e.g. Zhao et al., 2012; Z. Yang et al., 2015; Zheng et al., 2015) (Fig. 1). This belt

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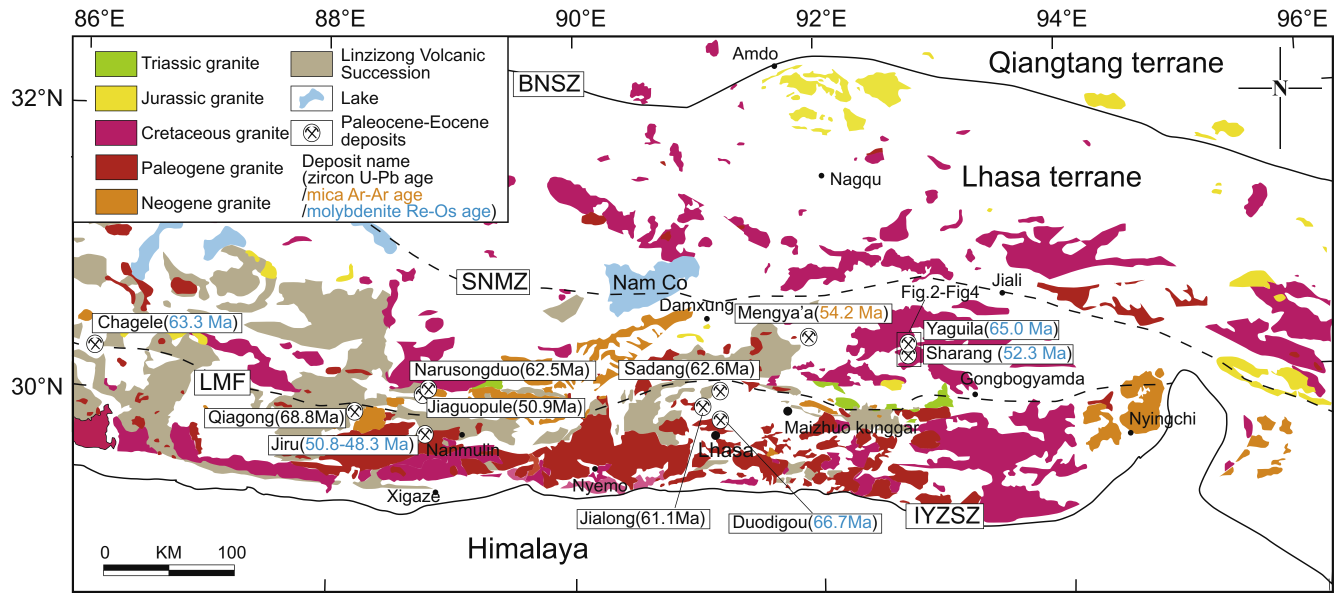

Fig. 1. Simplified regional geological map of the Gangdese belt with major Paleocene-Eocene ore deposits, Mesozoic-Cenozoic intrusions and Cenozoic Linzizong Volcanic Succession, modified from Pan et al. (2004). Three units of the Lhasa terrane (including northern Lhasa subterrane, central Lhasa subterrane and southern Lhasa terrane) have been separated by the SNMZ and IMF after Pan et al. (2012). The major Paleocene-Eocene ore deposits (and associated ages) in the southern Lhasa subterrane include: Qiagong skarn Fe deposit (J. Li et al., 2011; Y. Li et al., 2011); Jiru porphyry Cu deposit (Zheng et al., 2014; Z. Yang et al., 2015); Jialong skarn Fe deposit, Sadang vein-type Au-Ag deposit and Duodigou skarn Mo deposit (Huang et al., 2013). In the central Lhasa terrane: Chagele porphyry Cu-Mo deposit (Gao et al., 2012); Jiaduopule skarn Fe-Cu deposit (Yu et al., 2011); Narusongduo skarn Pb-Zn deposit (Ji et al., 2012); Mengya'a skarn Pb-Zn deposit (J.X. Li, unpublished data); Yaguila skarn-porphyry Pb-Zn-Ag-(Mo) deposit from Gao et al. (2011); Sharang porphyry Mo deposit (Zhao et al., 2014). IYZSZ = Indus-Yaluzangbo Suture Zone, BNSZ = Bangong-Nujiang Suture Zone, SNMZ = Shiquanhe-Nam Tso Mélange Zone, LMF = Luobadui-Milashan Fault.

primarily hosts collision-related deposits associated with Tibetan tectonic evolution (Hou and Cook, 2009; Qin, 2012). Previous studies have compared the magma oxidation state of causative porphyries between the Paleocene-Eocene and Miocene deposits (Wang et al., 2014; Zheng et al., 2015; Sun et al., 2016). However, because the intrusions in the Yaguila-Sharang district record magmatism from ~65 Ma to 50 Ma (Gao et al., 2011, 2015; Zhao et al., 2014, 2015), establishing the relative oxidation state of intrusions in this area would add important constraints to district-scale studies of magmatic sources during the main period of India-Asia continent-continent collision (Hou and Cook, 2009).

This study concerns with two adjacent deposits (Fig. 1): The Paleocene Yaguila skarn Pb-Zn-Ag-(Mo) deposit contains 10.5 Mt ore at an average grade of 4.25% Pb, 2.15% Zn, and 95.35 g/t Ag (Geological Survey Bureau of Henan, 2009) and the Eocene Sharang porphyry Mo deposit contains 0.63 Mt metal molybdenum with an average grade of 0.061% (No. 6 Geologic Exploration Team of Geological Survey Bureau of Tibet, China, 2009). Given the previous geochronologic and geochemical studies of the Sharang intrusions (Zhao et al., 2012, 2014) and the Yaguila causative porphyry (Gao et al., 2015), we present new geochemical and Sr-Nd-Hf isotopic composition data for magmatic rocks from the Yaguila deposits. We examine zircon Ce and Eu anomalies in the Paleocene-Eocene intrusions from the Yaguila and Sharang deposits, including both mineralized and barren intrusions. These data are combined to elucidate the petrogenesis and oxidation state of Paleocene-Eocene mineralizing magmas during this key period of India-Asian continent-continent collision.

2. Regional and deposit geology

The Lhasa terrane can be divided into the southern, central and northern subterranes, bounded by the Shiquanhe-Nam Tso Mélange Zone (SNMZ) and Luobadui-Milashan Fault (LMF) (Fig. 1). In the southern Lhasa subterrane, the east-west-trending Gangdese batholith mainly consists of extensive Jurassic-Cretaceous Andean-type arc magmatism and Paleocene-Eocene felsic magmatic activity (Coulon et al., 1986; Harris et al., 1990; Chung et al., 2003; Wu et al., 2010). Most reported porphyry Cu-Mo deposits are hosted in Miocene adakitic dike swarms or stocks, crosscutting or intruding the Gangdese batholith and meta-sedimentary formations in the southern Lhasa subterrane (Chung et al., 2003). These formed since the Early Miocene, during post-collisional extension (Hou et al., 2004). In the northern subterrane, Mesozoic volcanic rocks occur within the Lower Cretaceous volcano-sedimentary sequence (Pan et al., 2012), and Cretaceous plutonic rocks intrude the Jurassic-Cretaceous sedimentary sequences (Xu et al., 1985). It is still unclear as to whether this subduction-related magmatism is associated with southward Bangong-Nujiang oceanic subduction (e.g. Zhu et al., 2009) or northward Neo-Tethyan oceanic subduction (e.g. Zhang et al., 2012). Porphyry-type or skarn-type deposits associated with extensive intermediate-felsic volcanism and magmatism in the north are rarely reported. In the central Lhasa subterrane, Carboniferous-Permian meta-sedimentary sequences and lower Cretaceous volcano-sedimentary sequences are intruded by widespread Mesozoic granitoids (~210–90 Ma) with abundant dioritic enclaves (Zhu et al., 2011), Paleocene-Eocene granitoids (Ji et al., 2009) and volcanic rocks of the Linzizong Volcanic Succession (Mo et al., 2007). Most intrusions associated with porphyry-type and skarn-type deposits belong to I-type granitoids (e.g. Hou and Cook, 2009; Zhao et al., 2012; Z. Yang et al., 2015; Zheng et al., 2015), and some are associated with S-type granite or Linzizong rhyolitic stocks, such as the Chagele skarn Cu-Pb-Zn deposit (Gao et al., 2012) and Narusongduo skarn Pb-Zn deposit (Ji et al., 2012).

Both the Yaguila and Sharang deposits lie in the north of the eastern section of the Gangdese Metallogenic Belt (Fig. 1). Regional stratigraphy includes (from oldest to youngest): (1) Pre-Ordovician Songduo Formation of metamorphic calcareous siltstones and