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The exhumation history of collision-related mineralizing systems in Tibet: Insights from thermal studies of the Sharang and Yaguila deposits, central Lhasa

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ABSTRACT

The large, newly discovered Sharang porphyry Mo deposit and nearby Yaguila skarn Pb–Zn–Ag (–Mo) deposit reside in the central Lhasa terrane, northern Gangdese metallogenic belt, Tibet. Multiple mineral chronometers (zircon U–Pb, sericite $^{40}Ar–^{39}Ar$, and zircon and apatite (U–Th)/He) reveal that ore-forming porphyritic intrusions experienced rapid cooling (>100 °C/Ma) during a monotonic magmatic–hydrothermal evolution. The magmatic–hydrothermal ore-forming event at Sharang lasted ~6.0 Myr (~1.8 Myr for cooling from >900 to 350 °C and ~4.0 Myr for cooling from 350 to 200 °C) whereas cooling was more prolonged during ore formation at Yaguila (~1.8 Myr from >900 to 500 °C and a maximum of ~16 Myr from >900 to 350 °C). All porphyritic intrusions in the ore district experienced exhumation at a rate of 0.07–0.09 mm/yr (apatite He ages between ~37 and 30 Ma). Combined with previous studies, this work implies that uplift of the eastern section of the Lhasa terrane expanded from central Lhasa (37–30 Ma) to southern Lhasa (15–12 Ma) at an increasing exhumation rate. All available geochronologic data reveal that magmatic–hydrothermal–exhumation activities in the Sharang–Yaguila ore district occurred within four periods of magmatism with related mineralization. Significant porphyry-type Mo mineralization was associated with Late Cretaceous–Eocene felsic porphyritic intrusions in the central Lhasa terrane, resulting from Neotethyan oceanic subduction and India–Asia continental collision.

1. Introduction

Low temperature thermochronology studies (commonly zircon and apatite U–Th/He and fission-track) of porphyry-type deposits associated with subduction–collision related magmatism at convergent margins elucidate the regional tectonic evolution and exhumation process (Campos et al., 2009; Harris et al., 2008; Li et al., 2014; Maksaev et al., 2004, 2009, 2010; McInnes et al., 2005a,b). Numerous studies have concentrated on crustal shortening and uplift in and around the Tibet–Himalayan orogen (e.g. Zheng et al., 2000; Blisniuk et al., 2001; Clark et al., 2005; Duvall et al., 2011), but few have focused on the thermal evolution of porphyry-type deposits in the Lhasa terrane, associated with Mesozoic Neo-Tethys oceanic subduction and Cenozoic India–Asia continental collision (Hou and Cook, 2009; Qin, 2012). Thermochronologic studies provide insight into the degree of erosion of intrusive ore deposits and comparative preservation potential (McInnes et al., 2005a,b). The cooling history and exhumation of shallowly-intruded (<6 km from surface) porphyry deposits formed in this collisional environment could constrain the genesis and preservation of deposits in relation to uplift and exhumation of the Tibetan plateau during different metallogenic epochs.

This study provides new zircon U–Pb, sericite $^{40}Ar–^{39}Ar$, and zircon-apatite (U–Th)/He ages for porphyritic rocks in the large and recently discovered Sharang porphyry Mo deposit (current proven ore reserve: 100 Mt at 0.061% Mo) and nearby Yaguila skarn Pb–Zn–Ag (–Mo) deposit (10.5 Mt at 4.25% Pb, 2.15% Zn, and 95.35 g/t Ag) in the central Lhasa terrane. These data are combined with previously published data to reveal the magmatic–hydrothermal–thermal history of the

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deposits, demonstrate their connection with plateau formation, and reconstruct the magmatic–hydrothermal evolution of the ore district.

2. Regional and deposit-scale geology

2.1. Regional 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–Milasha Fault (LMF) (Fig. 1). In the southern Lhasa subterrane, the well-known Gangdese batholith mainly consists of extensive Cretaceous Andean-type arc magmatism and extensive Eocene felsic magmatic activity (Coulon et al., 1986; Harris et al., 1990; Wu et al., 2010). Most reported porphyry Cu–Mo deposits are associated with Miocene high-K calc-alkaline intrusions, clustered within the Gangdese batholith (Hou and Cook, 2009). In the northern subterrane, Mesozoic volcanic rocks occurred within the Lower Cretaceous volcano-sedimentary sequence (Pan et al., 2012), and Cretaceous plutonic rocks intruded the Jurassic–Cretaceous sedimentary sequences (Xu et al., 1985). Although the extensive intermediate-felsic volcanism and magmatism extended to the northern subterrane, few porphyry-type or skarn-type deposits are reported. In the central Lhasa subterrane, Carboniferous–Permian metasedimentary sequences and lower Cretaceous volcano-sedimentary sequences (Zenong and Duoni formations; Zhu et al., 2009a), are intruded by widespread Mesozoic granitoids (~210–90 Ma) with abundant dioritic enclaves (He et al., 2007; Zhu et al., 2011), and Paleocene–Eocene granitoids (Ji et al., 2009). Recent studies revealed several new porphyry- and skarn-type deposits within the central subterrane, such as the Sharang porphyry Mo deposit (Zhao et al., 2012), Jiru porphyry Cu deposit (Zheng et al., 2014) and Yaguila skarn Pb–Zn–Ag deposit (Gao, 2010).

The Sharang–Yaguila ore district is located in the northern part of the central Lhasa subterrane (Fig. 1). Regional stratigraphy in the Sharang–Yaguila district includes, from oldest to youngest, the pre-Ordovician Songduo Formation, Early Carboniferous Nuocuo Formation, Late Carboniferous–Early Permian Laigu Formation (C_2P_1l) and Late Permian Luobadui Formation (P_2l) (Geological Survey Bureau of Henan, 2009). The contacts of these strata units are northeast- and east-striking fault systems (Fig. 1). The pre-Ordovician Songduo Group consists of metamorphic calcareous siltstones and schists in contact with epicontinental clastic carbonate sediments of the Late Permian Laigu Formation. The Late Permian Luobadui Formation is overthrust onto the Laigu Formation (C_2P_1l), along with northeast-striking faults formed during Early Cretaceous regional northwest–southeast compressional stress. These rocks are unconformably overlain by Cretaceous rhyolitic pyroclastic rocks and andesite–dacite–rhyolite of the Eocene Pana Formation, which are intruded by multi-stage intrusions with ages ranging from Jurassic to Miocene (Fig. 1).

2.2. Sharang porphyry Mo deposit

With an area of intensive hydrothermal alteration extending over 16 km^2, the recently discovered Sharang porphyry Mo deposit in the eastern section of the Gangdese metallogenic belt contains a resource

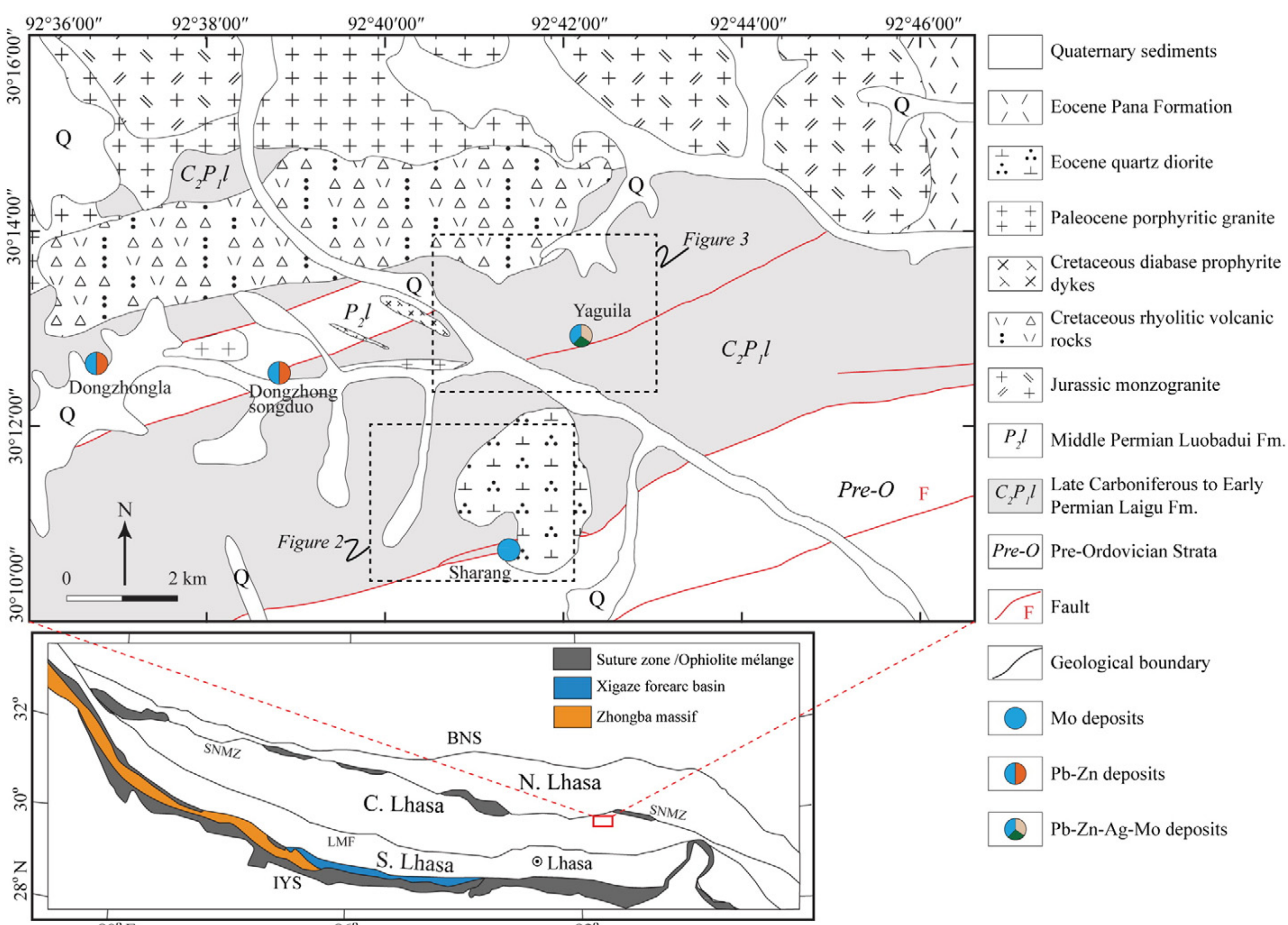

Fig. 1. Regional map of the Sharang–Yaguila ore district modified from the Geological Survey Bureau of Henan (2009), and the different units of the Lhasa terrane from Pan et al. (2012). IYS = Indus–Yalu Suture, BNS = Bangong–Nujiang suture, SNMZ = Shiquanhe–Nam Tso Mélange Zone, LMF = Luobadui–Milasha Fault.