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Stratigraphy and tectonic setting of Laochang massive sulfide deposit in the North Qinling belt, central China

Zhen Yan [a,*], Lei Chen [b], Solomon Buckman [c], Changlei Fu [a], Xianqing Guo [b]

[a] Institute of Geology, Chinese Academy of Geological Sciences, Beijing 100037, China
[b] Institute of Mineral Resources, Chinese Academy of Geological Sciences, Beijing 100037, China
[c] School of Earth & Environmental Science, University of Wollongong, NSW 2522, Australia

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ABSTRACT

The Qinling orogenic belt in central China is the northernmost orogenic collage within the Tethyan domain, which records the evolution of the Paleo-Tethys Ocean. A suite of volcano-sedimentary rocks containing rare fossils and several VHMS deposits is exposed along the North Qinling belt. These units are separated into the Caotangou, Xieyuguan and Erlangping groups from west to east. Systematic studies on the facies and geochemistry demonstrate that the Caotangou Group represents a bimodal volcanic sequence formed in a backarc setting with massive sulfide horizons closely associated with a siliciclastic-felsic volcanic sequence. SHRIMP and LA-ICP-MS zircon U-Pb data from rhyolite and tuff of the Caotangou Group indicate that the volcanism took place between ca. 440–406 Ma, which is similar to the dacite and andesitic basalt of the Xieyuguan Group. The Precambrian xenocrystic zircon grains suggest that the subduction-related crustal source of those volcano-sedimentary rocks in the North Qinling belt is closely related to the Qinling Group. Based on the combination of previous fossil ages, U-Pb dating of volcanic rocks and geochemistry of lavas and sulfides, we suggest that a southward-facing subduction-accretionary system developed along the southern margin of the North China plate during 490–410 Ma. Subduction-related calc-alkaline magmatism continued until at least ca. 410 Ma before collision of the arc with the Qinling terrane to the south during the Early Devonian led to the continent-continent collision between the Qinling terrane and North China craton in the Late Carboniferous.

1. Introduction

Backarc basins develop along active convergent margins but not all subduction systems have a backarc basin (Karig, 1971). Active modern backarc basins include; (1) continental margin backarc basins such as the Okinawa Trough of the East China Sea, (2) intra-oceanic backarc basins such as the Marianas Trough, Lau Basin and East Scotia Sea, and (3) transitions between continental to oceanic such as the Berring Sea of the Aleutian arc (Marsaglia, 1995). The formation of backarc basins is linked to extension and spreading within the supra-subduction zone region probably as a result of slab rollback mechanisms (Garfunkel et al., 1986). Backarc basins are typically dominated by volcano-sedimentary sequences (Marsaglia, 1995; Critelli et al., 2002), which commonly host volcanic-hosted massive sulfide (VHMS) deposits (e.g., Allen, 1988, 1992; Solomon and Quesada, 2003; Boulter et al., 2004; Franklin et al., 2005; Piercey, 2010, 2011; Tornos et al., 2015) as well as some hydrocarbon potential (Schlanger and Combs, 1975). The Manus and Woodlark basins of the Bismark Sea are modern day examples of active black smokers forming in a backarc setting (Hannington et al., 2011). However, backarc basins are rarely preserved in the stratigraphic record because they are subjected to high uplift and erosion rates and are prone to destruction during subduction and terrane accretion associated with ocean closure (McCann and Saintot, 2003; Draut and Clift, 2012). In addition, mineralized volcanic sequences are often strongly hydrothermally altered, metamorphosed and deformed, making the tectonic origins of these volcanic sequences difficult to recognize. Therefore, careful interpretation of volcano-sedimentary sequence of backarc basins is critical to reconstruct the plate framework of ancient orogenic belts and also assists in understanding the genesis of contained mineral deposits.

A suite of volcano-sedimentary rocks, consisting of mafic-felsic lava and volcaniclastic rocks with Ordovician-Silurian fossils, occurs in the North Qinling belt. It was named after the Caotangou, Xieyuguan, Yunjiashan and Erlangping groups in the western, central and eastern portion of this belt (Fig. 1b) in Chinese literature (BGMRSP, 1989; BGMRHP, 1989), respectively. These rocks host several massive sulfide deposits, e.g. Liushanyan Zn-Cu, Shuitongling Zn-Cu and Zn-Pb-Cu and Shangzhuangping Zn-Pb-Cu deposits (Wei et al., 2003; Yan et al., 2008; Xu et al., 2009), Tongyu Cu deposit (Dai, 1982; Ning, 1984; Lee et al., 2010), and Laochang Pb-Zn deposit (Li et al., 2010). Their geological characters are summarized in Table 1. Early interpretations, based

* Corresponding author.
E-mail address: yanzhen@mail.iggcas.ac.cn (Z. Yan).

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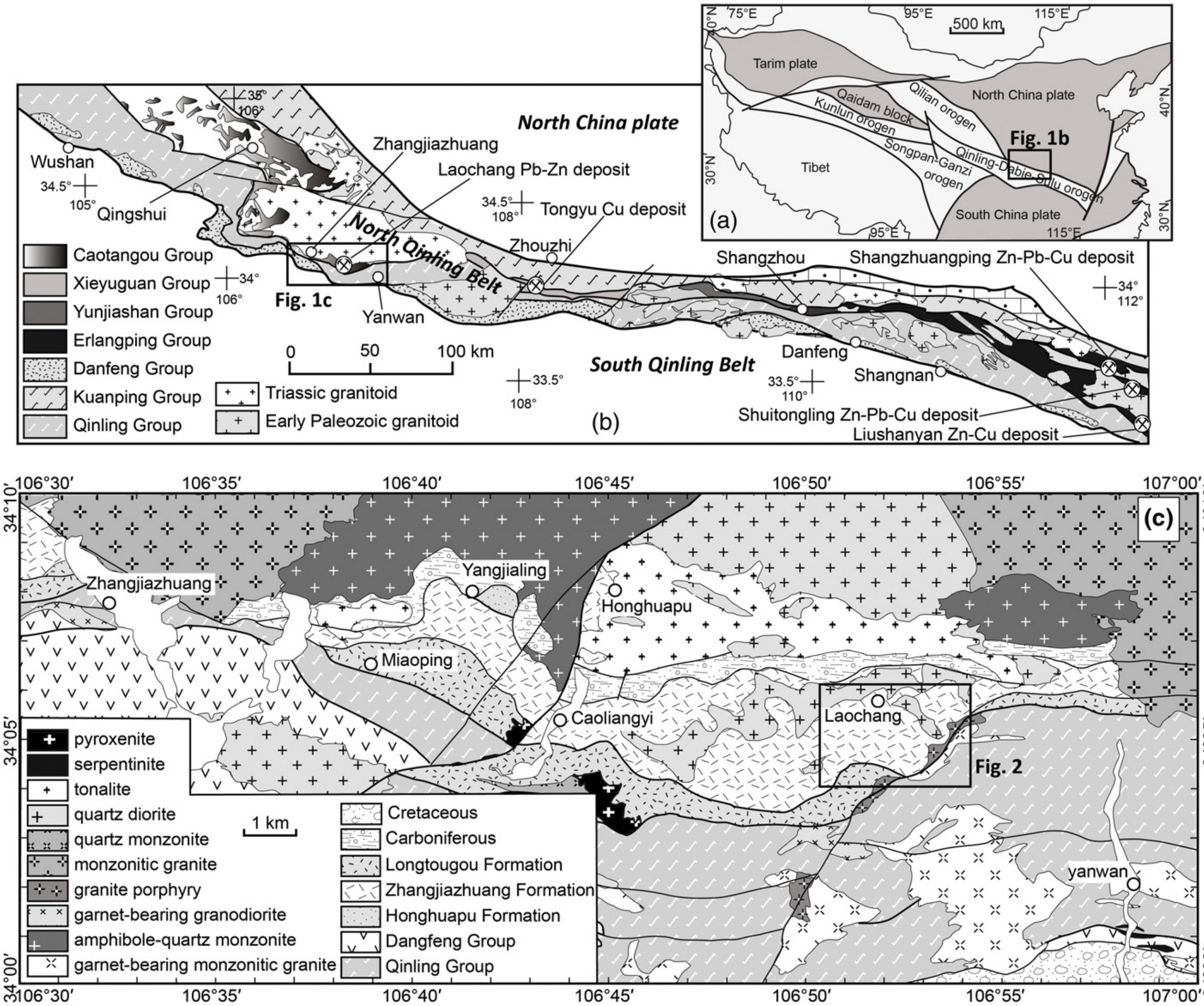

Fig. 1. (a) Tectonic framework of China and location of the Qinling orogenic belt; (b) simplified geological map of the North Qinling belt and location of the study area; distribution of the Caotangou, Xieyuguan, Yunjiashan and Erlangping groups is after Zhang et al. (1993). Data for the Laochang, Tongyu, Shangzhuangping, Shuitongling and Liushanyan deposits are after Dai (1982), Ning (1984), Wei et al. (2003), Yan et al. (2008), Xu et al. (2009), Lee et al. (2010), Li et al. (2010) and Zhu et al. (2013). (c) Geological map of the Caotangou Group (Modified from Yang et al., 1984; Sun and Dong, 1995).

on geochemical and isotopic data, suggest that the igneous protolith erupted in an Ordovician intra-oceanic island arc (Liu et al., 1989; Zhang et al., 1989; Xue et al., 1996; Hacker et al., 2004; Yan et al., 2007; Wang et al., 2009a, 2009b; Ratschbacher et al., 2003, 2006; Bader et al., 2013; Wu and Zheng, 2013) or a backarc setting (Meng and Zhang, 1999; Dong et al., 2011a, 2011b; Xu et al., 2014). Little attention has been paid to the volcanic sequences and high-precision zircon U-Pb age on mineralized felsic volcanic rocks. In particular, Silurian-Devonian fossils within the sequence have remained poorly documented. Knowledge of the volcanic sequence and stratigraphic-volcanic setting is, therefore, vital to reasonably reconstruct the tectonic evolution of the Qinling orogenic belt and the genesis of the deposits.

This paper aims to unravel the tectonic setting and metallogenic age of the Laochang deposit via a combination of zircon U-Pb isotopic dating, geochemistry and fossil age constrains from the volcano-sedimentary sequence of the Caotangou Group. These data will provide the framework from which we interpret the tectonic setting and depositional environment in which the VHMS deposits formed in the North Qinling belt.

2. Geological setting

The Qinling orogen is situated between the North China and Yangtze cratons and stretches E-W more than 1500 km. It links the Kunlun and Qilian orogens in the west with Tongbai-Dabie orogen in the east (Fig. 1a), which together constitute the geographic, geologic, and cultural 'Heart of China' (Zhang et al., 2001). The Qinling orogen has experienced several cycles of orogenesis, forming an early Paleozoic accretion-dominated North Qinling belt in the north and a Mesozoic collision-dominated South Qinling belt in the south (e.g., Zhang et al., 1995; Ratschbacher et al., 2003, 2006; Wang et al., 2009a, 2009b; Dong et al., 2011a, 2011b; Liu et al., 2013; Bader et al., 2013; Chen et al., 2014).

The North Qinling belt contains the Kuanping, Erlangping, Qinling and Danfeng groups from north to south (Fig. 1b), which are separated from each other by large-scale thrust faults or ductile shear zones. The emplacement of syn- and post-collision granitoids and the major regional deformation and metamorphism took place in this belt between 440 and 400 Ma (Chen et al., 1991; Lerch et al., 1995; Zhai et al., 1998; Wang et al., 2009a, 2009b, 2011; Liu et al., 2011; Xiang et al., 2012; Xue et al., 1996; Bader et al., 2013).