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Geodynamic setting of mineralization of Mississippi Valley-type deposits in world-class Sichuan–Yunnan–Guizhou Zn–Pb triangle, southwest China: Implications from age-dating studies in the past decade and the Sm–Nd age of Jinshachang deposit

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ABSTRACT

The Sichuan–Yunnan–Guizhou (S–Y–G) Zn–Pb triangle is a world-class metallogenic belt in southwestern China that contains hundreds of carbonate-hosted giant-to-small epigenetic Zn–Pb deposits. Here, we provide an overview of the ore geology, geochemistry and ore-forming fluids of the major Zn–Pb deposits in this area. These deposits are most likely Mississippi Valley-type (MVT) deposits that formed as a result of the regional migration of basinal brines along large fault systems and more minor secondary structures. The Sm–Nd age (201 ± 6.2 Ma) of ore-stage fluorite from the Jinshachang Zn–Pb deposit, within northeast Yunnan province, China, reveals this deposit formed during the Late Triassic, consistent with the majority of the published isotopic ages for other Zn–Pb deposits in the S–Y–G MVT triangle. These fluorite samples have initial $^{87}Sr/^{86}Sr$ ratios of 0.711385–0.711463 and ε_{Nd} values of −8.4 to −8.7, confirming the basin-related nature of the mineralizing fluids. Published geochronological data combined with basic features of MVT deposits (e.g., geology, geochemistry, and ore-forming fluids) and the geological evolution of the study area has enabled us to develop a model for the Zn–Pb mineralization, where this word-class MVT belt has formed as a result of the regional-scale migration of basinal fluids coincident with tectonic activity along ore-controlling structures (e.g., thrust–fold systems). Both the fluid migration and the tectonic activity were probably triggered by the late Indosinian Orogeny, which in turn was a response to the closure of the Paleo-Tethys Ocean.

1. Introduction

The Sichuan–Yunnan–Guizhou (S–Y–G) Zn–Pb triangle is located along the southwestern margin of the Yangtze Platform and hosts the majority of known Pb and Zn resources in China in addition to significant resources of other metals such as Ag, Cd, Ge, and Ga. A total of 408 Zn–Pb deposits containing more than 26 million tons of Zn + Pb had been reported within the S–Y–G triangle up to the end of 1999 (Liu and Lin, 1999). In addition, the resources identified in this area over the past decade represent some 27% of the total Zn + Pb resources in China (Zhang et al., 2013), and a world-class Zn–Pb belt is gradually unfolding in front of the world.

Studies on these Zn–Pb deposits can be traced back to 70 years ago. Similar to some other well-known Mississippi Valley-type (MVT) deposits (e.g., MVT districts in North America), the Zn–Pb deposits in this region were originally thought to have magmatic-hydrothermal origins (Xie, 1941; 1963). This model was superseded by a syngenetic or syngenetic plus overprinting epigenetic model, primarily as a result of the development of the sedimentary-exhalative (SEDEX) metallogenic model during the 1980s and 1990s, leading to the proposal of SEDEX (Zhang, 1984) or "sedimentary reworking-type" (Tu, 1984; Chen, 1986; Zhao, 1995; Liu and Lin, 1999) for the mineralization. More detailed recent research has found the most of these Zn–Pb deposits are clearly epigenetic, but different ideas have been proposed on the genesis of them (Zhou et al., 2001; Li et al., 2007; Hu and Zhou, 2012; Wu et al., 2013). The most representative hypotheses are as follows. 1. The Permian Emeishan mantle plume-related Zn–Pb deposits (Huang et al., 2001; Li et al., 2007). 2. The Mississippi

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Valley-type (MVT) deposits resulted from the regional migration of basinal brines (Zhou et al., 2001; Zhang et al., 2007; Han et al., 2007; Hu and Zhou, 2012; Wu et al., 2013). 3. The unique SYG-type Zn–Pb deposits which are different from the typical MVT deposit (Zhou et al., 2013a). One of most significant obstacle for us to understand the genesis of these deposits is it remains ambiguous as to which tectonic event probably triggered the hydrothermal activity leading to such large-scale Zn–Pb mineralization. For example, Huang et al. (2001) suggested the giant Huize MVT deposit was generated by the eruption of the Emeishan flood basalts, which provided metal-bearing hydrothermal fluids that formed the deposits themselves as well as a heat source that drove hydrothermal circulation. However, this hypothesis was discounted after the study which indicated the metals within the Huize deposit could not have been derived from the Emeishan basalts (Zhou et al., 2001). One approach that is ideally suited to improving our understanding of the formation of this world-class Zn–Pb belt is the high-precision dating of mineralizing events. Although a small number of metallogenic ages have been determined for some of the deposits in this area over the past decade, the geodynamic setting of these MVT deposits is still controversial, primarily because the lack of comparison of a single mineralization age to the others and correlation within the regional tectonic evolution.

Here, we report a new high-precision Sm–Nd isochron age for the Jinshachang Zn–Pb deposit, which is located in the northeastern part of the S–Y–G triangle. We combine this age with the known timing of mineralization of Zn–Pb deposits within the S–Y–G triangle and the geological evolution of this region to identify the geodynamic setting of these MVT deposits and to develop a possible model for the mineralization.

2. Geological background and MVT deposits

2.1. Geological setting

The S–Y–G triangle is located within the southwestern margin of the Yangtze Platform (South China Craton) (Fig. 1A). This area covers some ~170,000 km^2 and consists of northeastern Yunnan Province, northwestern Guizhou Province, and southwestern Sichuan Province (Fig. 1B). The triangle is confined by three regional fault belts that extend deep into basement rocks, namely, the NW–SE-trending Weining–Shuicheng, the N–S-trending Anninghe, and the NE–SW-trending Mile–Shizong fault belts, and contains the deep-seated N–S-trending Xiaojiang fault belt (Fig. 1B). These long-lived fault belts have been activated and reactivated by a number of tectonic events and may have acted as conduits for the Emeishan basalt and other hydrothermal fluids (Zhang, 2008). The area also contains numerous secondary NE–SW- and NW–SE-trending faults and thrust–fold belts (Fig. 1B).

The stratigraphy of the S–Y–G triangle consists of a pre-Sinian basement, Sinian (Neoproterozoic) to lower Mesozoic submarine sedimentary sequences, and Jurassic to Cenozoic terrigenous sediments. The crystalline basement of the Yangtze Platform is thought to consist of Archean (~3.3–2.9 Ga) metamorphic rocks (Qiu et al., 2000; Gao et al., 2011). The late Paleoproterozoic to early Mesoproterozoic Dongchuan (~1.7–1.5 Ga) and Mesoproterozoic Kunyang (~1.2–0.9 Ga) groups are widely distributed throughout the study area and are dominated by siltstones, slates, sandstones, and dolostones interbedded with tuffaceous units (Zhao et al., 2010). These rocks form the basement, which is tightly folded but only weakly metamorphosed (Zhou et al., 2013b).

The southwestern Yangtze Platform was a passive continental margin between the Sinian and Middle Triassic, leading to the deposition of thick submarine sedimentary sequences that cover the basement rocks and are dominated by carbonates and clastic sediments (Wu et al., 2013). The lower Sinian units are dominantly coarse volcanic clastic sediments, with the uppermost Sinian unit consisting of a very thick dolostone layer. Cambrian rocks are dominantly clastic sediments, including black shales, sandstones interlayered with dolostones, and limestones. Ordovician sediments are dominantly limestones, dolostones, marls, and shales, with Silurian sediments being dominated by fine-grained sandstones, shales, dolostones, and limestones. Devonian sediments are dominated by quartz sandstones, calcareous sandstones, shales, limestones, dolomitic limestones, and dolostones, all of which are overlain by Carboniferous limestones, oolitic limestones, dolomitic limestones, and dolostones. Lower Permian sediments include microcrystalline limestones, brecciated limestones, dolomitic limestones, dolostones, and argillaceous siltstones, which are overlain by the voluminous Permian Emeishan flood basalts, which were erupted and emplaced at ~263–251 Ma (Zhong and Zhu, 2006; He et al., 2007; Xu et al., 2008). The closure of the Paleo-Tethys Ocean was followed by tectonism relating to the Indosinian Orogeny and post-Late Triassic completion of the suturing between the Indochina and South China blocks around the study area (Cai and Zhang, 2009). This led to the development of a series of thrust belts and foreland basins in the periphery of this region, including the Longmenshan (Yong et al., 2003; Jia et al., 2006) and Nanpanjiang (Yang et al., 2012) foreland basins, which formed at the northeastern and southeastern boundaries, respectively. The S–Y–G triangle was also affected by subsequent continuous intracontinental deformation and the deposition of terrigenous sandstones, conglomerates, and freshwater marls of Jurassic to Cenozoic age. Moreover, at the northeastern boundary of the study region, the Longmenshan thrust belt was reactivated during the late Miocene, caused by the India–Asia collision (Wu et al., 2013).

2.2. MVT deposits in the Sichuan–Yunnan–Guizhou Zn–Pb triangle

A significant amount of research on the Zn–Pb deposits within the S–Y–G triangle has been published in the Chinese literature, complemented by a few English publications. Here, we summarize the ore geology, geochemistry and the composition of hydrothermal fluids associated with major Zn–Pb deposits (Table 1).

The giant Huize deposit in northeastern Yunnan Province in China is the largest Zn–Pb deposit within the S–Y–G triangle. This deposit contains ~7 Mt of contained metal in reserves with an average grade of 25–35% Pb + Zn (Table 1). Several additional large Zn–Pb deposits are present, including, from north to south, the Chipu, Maoping, Maozu, Lehong, Tianbaoshan, and Daliangzi deposits, which have grades of 10–30% Pb + Zn and contain between 0.65 and 4.2 Mt of metal resources (Table 1). In addition to these giant and large Zn–Pb deposits, the S–Y–G triangle contains hundreds of medium-to-small deposits, e.g., the Paoma deposit in southern Sichuan Province, the Jinshachang deposit in northeastern Yunnan Province, and the Tianqiao, Shaojiwan, and Qingshan deposits in northwestern Guizhou Province (Fig. 1B and Table 1).

These carbonate-hosted Zn–Pb deposits are epigenetic and mainly hosted by the rocks ranged in age from Sinian to Permian, while the dolostone of Sinian Formation and Early Carboniferous Formation are the two major ore-bearing rocks accounting for more than 62% of the known Zn–Pb deposits and ~70% of the Pb + Zn reserves (Wu et al., 2013). A small number of Zn–Pb mineralized veins are also present within Emeishan basalts and Triassic limestones (Han et al., 2012), indicating that at least one post-late Permian Zn–Pb mineralization event occurred in the S–Y–G triangle.

The Zn–Pb deposits are usually located near deep-seated regional faults and are often spatially associated with fault intersections