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Geological and sulfur–lead–strontium isotopic studies of the Shaojiwan Pb–Zn deposit, southwest China: Implications for the origin of hydrothermal fluids

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ABSTRACT

Located on the western Yangtze Block, SW China, the Sichuan–Yunnan–Guizhou Pb–Zn metallogenic (SYG) province, contains known total Pb and Zn metals more than 20 million tons (Mt) grading >10% Pb+Zn and is a well known producer of base metals in China. The Shaojiwan carbonate-hosted Pb–Zn deposit is a representative deposit in this province with 0.5 Mt metals of 0.71 to 10.56% Pb and 2.09 to 30.27% Zn. Its ore bodies are hosted in Devonian and Permian carbonate rocks and structurally controlled by the Yadu–Mangdong thrust fault. Lead–zinc ores composed of pyrite, sphalerite, galena, calcite and dolomite occur as brecciated, veinlets and disseminations in dolomitized limestone rocks.

The S–Pb–Sr isotope compositions of sulfide minerals have been analyzed to trace the sources of sulfur and metals for the Shaojiwan Pb–Zn deposit. $\delta^{34}S$ values of sulfide minerals range from +8.4 to +11.6‰, suggesting that sulfur in the hydrothermal fluids was derived predominantly from evaporite rocks in the host strata. Sulfide minerals have a small range of Pb isotope compositions ($^{206}Pb/^{204}Pb = 18.616$ to 18.686, $^{207}Pb/^{204}Pb = 15.682$ to 15.728 and $^{208}Pb/^{204}Pb = 39.067$ to 39.181) that are close to upper crust Pb evolution curve and similar to Proterozoic basement in the SYG province. This implies that the lead metal originated mainly from the basement rocks. $^{87}Sr/^{86}Sr$ ratios of sphalerite range from 0.7114 to 0.7130, and $^{87}Sr/^{86}Sr_{200\ Ma}$ ratios range from 0.7113 to 0.7129, higher than Sinian to Permian sedimentary rocks and Permian Emeishan flood basalts, but lower than basement rocks. This implies a mixed strontium source between the older basement rocks and the younger cover sequences. Therefore, the fluids' mixing is a possible mechanism for sulfide precipitation in the Shaojiwan Pb–Zn deposit.

1. Introduction

Carbonate hosted Pb–Zn deposits are widely distributed around the world, including major districts in southeast Missouri, USA (Sverjensky, 1981), Pine Point, Canada (Powell and Macqueen, 1984), Upper Silesia in Europe (Wilkinson et al., 2005), and Sichuan, Yunnan and Guizhou (SYG) provinces in SW China (Leach et al., 2010; Zheng and Wang, 1991). The SYG Pb–Zn metallogenic province contains total Pb and Zn metals more than 20 million tons (Mt) at grades of >10% Pb+Zn (Table 1) and has been the major source of base metals in China (e.g., Cromie et al., 1996; Han et al., 2007; Zheng and Wang, 1991; Zhou et al., 2001). There are 408 Pb–Zn deposits of this type in the region, including the world class Huize Pb–Zn deposit (e.g., Han et al., 2007; Huang et al., 2003; Zhou et al., 2001), hosted in Sinian (Late Proterozoic) to Late Permian carbonate rocks (e.g., Cromie et al., 1996; Han et al., 2007; Liu and Lin, 1999; Zheng and Wang, 1991; Zhou et al., 2001, 2011, in press).

A close spatial association with Permian Emeishan flood basalts has been used to classify them as the distal magmatic–hydrothermal deposits (Xie, 1963). In addition, the Emeishan flood basalts were thought to be an important source of metals and heat (e.g., Han et al., 2007; Huang et al., 2003, 2010; Liu and Lin, 1999). On the other hand, these deposits have been interpreted as strata-bound and generated during the reworking of sedimentary rocks (Tu, 1984). Liao (1984) proposed a hypothesis of diverse sources of metals and thought that all Pb–Zn deposits in this region belonged to the same genetic type of hydrothermal deposits associated with post-diagenetic sulfate brines. However, other researchers have attributed the Pb–Zn deposits in the region to be Mississippi valley-type (MVT) deposits (e.g., Zheng and Wang, 1991; Zhou et al., 2001), with metals sourced from the carbonate host rocks (Jin, 2008) and Neoproterozoic igneous rocks (Zhou et al., 2001). Despite these controversies and a large number of publications in Chinese, it is still unclear how these metals became so highly concentrated in the SYG province.

S–Pb–Sr isotopes are powerful tool for fingerprinting ore-forming fluids and metals (e.g., Carr et al., 1995; Gromek et al., 2012; Haest et al., 2010; Huston et al., 1995; Wilkinson et al., 2005; Zheng and Wang, 1991; Zhou et al., 2001, 2010). In this paper, we describe the geology of the Shaojiwan Pb–Zn deposit in detail and report new S–Pb–Sr isotope

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Table 1
Host strata, grade and tonnage of representative Pb–Zn deposits in the SYG province, SW China.

Deposits	Strata	Location	Metal association	Tonnage	Grade
Huize	C	Yunnan	Zn–Pb–Ge–Cd–Ag	>5 Mt	Pb+Zn >25%
Maozu	S	Yunnan	Zn–Pb–Cd–Ag	>1 Mt	Pb+Zn >12%
Maoping	D–C	Yunnan	Zn–Pb–Ag	>2 Mt	Pb+Zn >25%
Fule	P	Yunnan	Zn–Pb–Cd–Ge–Ga–In	>0.4 Mt	Pb+Zn >15%
Lemachang	D, P	Yunnan	Pb–Ag–Zn	>0.3 Mt	Pb+Zn >10%
Tianbanshan	S	Sichuan	Zn–Pb–Cd–Ag	>1 Mt	Pb+Zn >10%
Daliangzi	S	Sichuan	Zn–Pb–Ge–Cd–Ga–Ag	>1 Mt	Pb+Zn >10%
Xiaoshifang	S	Sichuan	Zn–Pb–Cd–Ag	>1 Mt	Pb+Zn >15%
Yinchanggou	S	Sichuan	Pb–Zn–Ag	>0.3 Mt	Pb+Zn >14%
Paoma	S	Sichuan	Pb–Zn	>0.2 Mt	Pb+Zn >10%
Tianqiao	D–C	Guizhou	Zn–Pb–Cd–Ag–Ge	>0.3 Mt	Pb+Zn >15%
Yinchangpo	C	Guizhou	Pb–Zn–Ag–Ge	>0.2 Mt	Pb+Zn >20%
Shanshulin	C	Guizhou	Zn–Pb–Ag–Cd–As	>0.5 Mt	Pb+Zn >20%
Shaojiwan	D, P	Guizhou	Zn–Pb–Cd–Ag	>0.4 Mt	Pb+Zn >15%
Maomaochang	C	Guizhou	Zn–Pb–Cd–Ag	>0.3 Mt	Pb+Zn >12%
Zhazichang	C	Guizhou	Zn–Pb–Cd–Ag	>0.2 Mt	Pb+Zn >10%
Qingshan	C	Guizhou	Zn–Pb–Cd–Ag–In	>0.3 Mt	Pb+Zn >15%
Yadu	P	Guizhou	Zn–Pb–Cd–Ag	>0.5 Mt	Pb+Zn >15%
Mangdong	D	Guizhou	Zn–Pb–Cd–Ag	>0.3 Mt	Pb+Zn >15%

Note: P = Permian; C = Carboniferous; D = Devonian; S = Sinian. The Huize and Maoping deposits are from Han et al. (2007); the Maozu, Fule, Tianbanshan, Daliangzi, Xiaoshifang and Yinchanggou Pb–Zn deposits are from Zheng and Wang (1991); Liu and Lin (1999); Huang et al. (2004); other deposits are from Zhou et al. (in press) and Jin (2008).

data of sulfide minerals. This new dataset, together with previously published results, is utilized to constrain the sources of the ore-forming fluids and metals for the Shaojiwan Pb–Zn deposit, and providing evidence as to how these metals concentrated highly in the SYG province.

2. Geological background

The Yangtze Block is composed of ~2.9 to ~3.3 Ga crystalline basements (Qiu et al., 2000), Meso- to Neoproterozoic folded basements (Sun et al., 2009; Zhao et al., 2010) and Paleozoic to Mesozoic cover sequences. In the western Yangtze Block, the folded basement rocks include the ~1.7 Ga Dongchuan and ~1.1 Ga Kunyang Groups and equivalents (Sun et al., 2009; Zhao et al., 2010) that consist of greywackes, slates and other carbonaceous to siliceous sedimentary rocks. These rocks are overlain unconformably by shallow marine Paleozoic and Lower Mesozoic cover sequences (Yan et al., 2003). Jurassic to Cenozoic strata are composed entirely of continental sequences (Liu and Lin, 1999). A major feature of the western Yangtze Block is the mantle plume-derived Emeishan Large Igneous Province (ELIP), which covers an area of more than 250,000 km^2 (Zhou et al., 2002). This igneous province is dominantly composed of Emeishan flood basalts.

The Pb–Zn deposits in the western Yangtze Block (Fig. 1A) are distributed in a large triangular area of 170,000 km^2 in NE Yunnan, NW Guizhou and SW Sichuan (Liu and Lin, 1999). More than four hundred Pb–Zn deposits have been reported in the province (Liu and Lin, 1999). They are characterized by irregular ore bodies with simple mineralogy, weak wall-rock alteration and high Pb + Zn grades of ores (more than 10%; Table 1), usually associated with Ag, Ge, Cd, Ga and In (e.g., Han et al., 2007; Zhou et al., 2011). They are mainly hosted in Sinian to Permian carbonate rocks, which are below the Permian Emeishan flood basalts (e.g., Han et al., 2007; Zheng and Wang, 1991; Zhou et al., 2001, 2011).

In the SE SYG province, the cover sequence includes Devonian to Triassic sedimentary rocks and Permian Emeishan flood basalts (Fig. 1B). Diabase dykes, also probably associated with the ELIP, are locally present. The Devonian strata consist of sandstone, siltstone, limestone and dolostone, and the Carboniferous strata are composed of shale, limestone, and dolostone. The Early Permian sedimentary sequence consists of sandstone, shale, coal and limestone, all of which are overlain by Permian Emeishan flood basalt. The basalt is overlain by Late Permian sandstone, siltstone and coal measures. The Triassic strata are composed of siltstone, sandstone, dolostone and limestone. The Pb–Zn ore bodies are hosted in Devonian to Permian carbonate rocks and controlled by the NW-trending tectonic belts, particularly the Yadu–Mangdong (F_1) and Weining–Shuicheng (Fw-s) faults (Fig. 1B).

3. Geology of the Shaojiwan deposit

3.1. The host rocks

The Shaojiwan Pb–Zn deposit occurs in the NW-trending Yadu–Mangdong fault in the SE SYG province (Fig. 1B). The ore bodies occur mainly in a thrust fault (F_1) that marks the contract between the Lower Permian Qixia Formation in the structural footwall and the Middle Devonian Dushan Formation in the hanging wall (Fig. 2A). Although Devonian to Permian sedimentary rocks are present through the mining district, Carboniferous carbonate rocks are poorly exposed to the southwestern (Fig. 1B). The host rocks are mainly Qixia, Dushan and Longdongshui Formations limestone, dolomitic limestone and dolomite (Fig. 2A and B). The detailed features of exposed rocks in the Shaojiwan ore field are shown in Fig. 3.

3.2. Structures in the mining district

Multiple stages of NW-trending faults and folds constitute the pre-Mesozoic Yadu–Mangdong tectonic belt. The ore deposit is situated on the SE segment of the asymmetrical Yadu–Mangdong anticline, which trends 310°, with axial plane dipping to the SW. Exposed in the axial part of the anticline are Devonian sedimentary rocks, with the Carboniferous and Permian sedimentary rocks exposed on both the limbs. The rocks on the SW limb have a dip angle of 25° to 56°. As the NE limb was destroyed by the Yadu–Mangdong fault, only Permian carbonate rocks have been preserved. Both limbs are characterized by a number of second-ordered anticlines and synclines. The faults within the mining district are composed of a series of high-angle thrust faults, forming an imbricate thrust–nappe structure (Fig. 2B). The strike of the faults is consistent with that of the folds. These structure elements extend through the whole region and have a close spatial connection with Pb–Zn mineralization.

3.3. Ore body characteristics

The ore bodies are classified into two types–the steeply dipping vein echelon and the gently dipping strata–bound types (Fig. 2A and B). A