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Mineralogical and sulfur isotopic evidence for the incursion of evaporites in the Jinshandian skarn Fe deposit, Edong district, Eastern China

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ABSTRACT

Evaporites have played important role in the formation of diverse metallic ore deposits, especially in the case of magmatic–hydrothermal deposits. However, the relationship between evaporites and skarn Fe deposit remains poorly constrained. In this contribution, we present new sulfur isotope data of pyrite, as well as the composition of halogen-rich minerals (scapolite and amphibole) in the Jinshandian skarn Fe deposit. The data are used to evaluate the evidence for incursion of evaporites in the skarn Fe deposit. The $\delta^{34}S$ values for pyrite from the early and late retrograde stage range from +17.4‰ to +18.7‰ ($n = 4$) and +16.4‰ to +19.4‰ ($n = 13$), respectively. Both these values are markedly heavier than the common $\delta^{34}S$ values of sulfides from magmatic–hydrothermal fluid, indicating that sulfur in the Jinshandian ore-forming system was mostly derived from evaporites. Compared to the amphibole from endoskarn, the scapolite and amphibole from exoskarn show high Cl content up to 4.04% and 3.01%, respectively, suggesting that the hydrothermal fluid with high NaCl content was probably derived from evaporites. The amphiboles from endoskarn are more enriched in F which is probably of magmatic in origin. The data presented in our study suggest that the hydrothermal system of the Jinshandian skarn Fe deposit probably experienced significant incursion of evaporites before or during the late prograde stage.

1. Introduction

Evaporites are dominantly composed of alkali earth carbonates and halite, gypsum, anhydrite, and other salts mineral (Warren, 1996), and have played important role in the formation of diverse metallic ore deposits. For example, evaporites provide Cl^- and other anions or reduced S, which are required for the transport and concentration of metals, resulting in the formation of sediment-hosted mineral deposits including Mississippi Valley-type (MVT) Pb–Zn deposits, sandstone Cu and U deposits, and sedimentary exhalative (SEDEX) Pb–Zn–Cu deposits (Sverjensky, 1986; Hanor, 1994; Warren, 1996, 1997, 2000; Broadbent et al., 1998; Chetty and Frimmel, 2000; Hitzman and Valenta, 2005; Leach et al., 2005; Selley et al., 2005). In addition, evaporites also offer active components and volatile constituents, such as Na^+, K^+, Ca^{2+}, and Cl^-, necessary for the voluminous alteration of magmatic–hydrothermal deposits including the iron oxide copper–gold (IOCG) deposits (Barton and Johnson, 1996, 2000; Hitzman, 2000; Benavides et al., 2007; Soloviev, 2010; Chen, 2013), skarn Fe–Cu deposits (Cai, 1980, 1981; Rose et al., 1985; Chang et al., 1991; Zhai et al., 1996; Pan and Dong, 2003; Zhou et al., 2000, 2005, 2011; Li et al., 2013; Zhang et al., 2014a, 2014b), magnetite–apatite deposits (Ningwu Research Group, 1978; Zhang, 1986; Fan et al., 2012; Li et al., 2014; Zhou et al., 2014; Li et al., 2015), and even some porphyry deposits (Field et al., 2005). They also serve as a possible source for providing excess S to trigger the immiscibility of sulfide liquid form silicate melt and precipitate sulfides to produce Cu–Ni(–PGE) deposits (Grinenko, 1985; Arndt et al., 2003; Li et al., 2003; Hryciuk et al., 2012). However, it is not always easy to identify the presence of evaporites in the magmatic–hydrothermal systems since most of the evaporite minerals are highly soluble and could be easily transformed to other minerals. Therefore, whether the hydrothermal system had experienced the incursion of evaporites remains a matter of debate due to the absence of critical evidence (Barton and Johnson, 1996).

The Middle–Lower Yangtze River metallogenic belt (MLYRMB) is one of the important evaporite-bearing sedimentary province in China (Fig. 1), with hundreds of meters of thick evaporite

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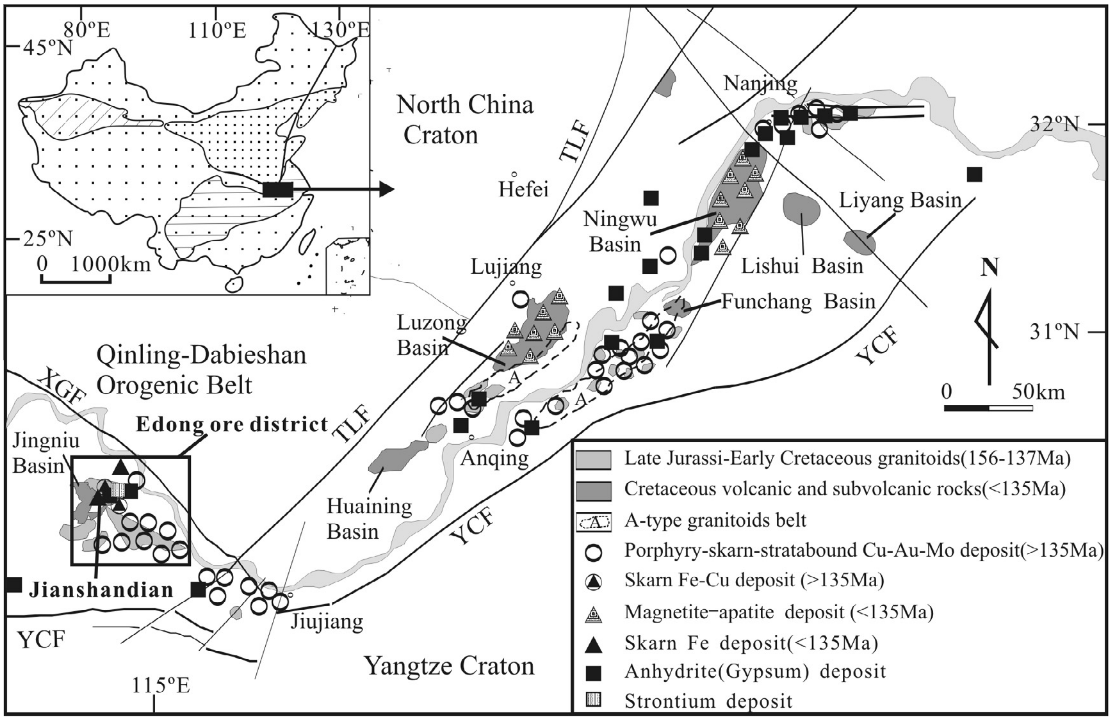

Fig. 1. Sketch map showing the distribution of Fe–Cu polymetallic, anhydrite (gypsum) and strontium deposits in the Middle–Lower Yangtze River metallogenic belt (modified from Shu et al., 1992; Fan et al., 1995; Mao et al., 2011).

deposited within carbonate formations (Zhai et al., 1996; Pan and Dong, 1999). The extensive interaction between widespread Late Mesozoic magmatism and carbonate formations resulted in abundant skarn Fe–Cu–Au, porphyry Cu–Au, and magnetite–apatite deposits, as well as some large anhydrite (gypsum) and Sr deposits (Fig. 1) (Zhai et al., 1996; Pan and Dong, 1999; Mao et al., 2006, 2011; Xie et al., 2007, 2012). Some preliminary studies proposed that evaporites were associated with some skarn deposits in the MLYRMB (Cai, 1980, 1981; Shu et al., 1992; Zhai et al., 1996). However, the robust evidence of evaporites in the ore-formation process has not yet been recognized, in spite of the possibility that evaporites served as a critical controlling factor for the formation of high-grade (total Fe > 50 wt.%) skarn Fe deposits (Li et al., 2013; Zhang et al., 2014b).

The Edong ore district within the southeastern Hubei Province is located in the westernmost part of the MLYRMB, and contains abundant skarn Fe–Cu deposits, with variable amounts of hydrothermal evaporitic minerals and extensive sodic alteration (Fig. 1) (Cai, 1980, 1981; Shu et al., 1992), which were considered as evidence for the incursion of evaporites into the ore-forming system (Ningwu Research Group, 1978; Chang et al., 1991; Barton and Johnson, 1996; Zhai et al., 1996; Benavides et al., 2007; Li et al., 2013; Zhang et al., 2014a). Recently, a preliminary study of sulfur isotopes of sulfate–sulfide pairs in the Jinshandian skarn Fe deposit in the Edong ore district (Fig. 1), showed that hydrothermal sulfates had similar isotopic characteristics to that of the Triassic sedimentary anhydrite in the MLYRMB, suggesting a genetic relationship between evaporites and skarn Fe mineralization (Zhu et al., 2013). Considering that sulfur from multiple sources might cause δ^{34}S variability within IOCG system, including that from the incursion of evaporites (such as Raúl-Condestable IOCG deposit, De Haller and Fontboté, 2009, and IOCG deposits in the Mantoerde district, Benavides et al., 2007), the sulfur isotopes of pyrite that does not coexist with sulfate and that of the early generation is a potential tracer. In addition, Cl-rich minerals (scapolite and amphibole) also provide important clues on the incursion of evaporites into the ore-forming system (Barton and Johnson, 1996, 2000).

In this contribution, we present new S isotope of pyrite and the composition of halogen-rich mineral (scapolite and amphibole) in the Jinshandian skarn Fe deposit. Integrating the results from this study with those from previous sulfur isotope investigation of sulfate–sulfide pairs, we evaluate the process of incursion of evaporites in the Jinshandian skarn Fe deposit.

2. Geological setting

2.1. Regional geological setting

The Middle–Lower Yangtze River metallogenic belt is one of the important mineralized belts in China with seven Fe–Cu ore districts, namely, Edong, Jiurui, Anqing, Luzong, Tongling, Ningwu, and Ningzhen from west to east, which extend along the northern margin of the Yangtze Craton and the southeastern margin of the North China Craton, and the Dabieshan orogenic belt (Zhai et al., 1996; Mao et al., 2011; Goldfarb et al., 2014; Mao et al., 2014) (Fig. 1). The strata of this belt are characterized by three tectonostratigraphic units, including Archean–Proterozoic metamorphic rocks as the basement, Cambrian to Middle Triassic submarine sedimentary cover, and Middle Triassic to Cretaceous terrigenous clastic and volcanic rocks (Chang et al., 1991). The rock types of Lower–Middle Triassic includes dolomite, limestone, marl, and gypsum-bearing beds and siltstone (Chang et al., 1991).

The ore deposits related to igneous rocks in the MLYRMB can be divided into three types (Mao et al., 2011): (1) 156–137 Ma K-rich calc-alkaline granitoids associated with porphyry-related, skarn, and stratabound Cu–Au–Mo–Fe mineralization, including diorite, granodiorite, granite, and granodiorite porphyry; (2) 135–123 Ma calc-alkaline granitoids consisting of gabbro, pyroxene diorite, quartz diorite, quartz monzonite, granodiorite, granite, diorite porphyry, granodiorite porphyry, and their corresponding extrusive