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Iron isotope systematics of magnetite: Implications for the genesis of Makeng iron deposit, southern China

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The high-precision Fe isotope analyses of magnetite samples from Makeng ore rocks yielded a range of δ^{56}Fe values (per mil deviations in ^{56}Fe/^{54}Fe ratios) in nature from +0.028‰ to +0.178‰ (average +0.10‰), and a narrow range of δ^{57}Fe values (per mil deviations in ^{57}Fe/^{54}Fe ratios) from +0.04‰ to +0.26‰ (average +0.15‰). The results, comparing with the compositions of the banded iron formation type deposits and sedimentary rock, upper mantle, and intermediate-acid magmas, indicate that the Fe of magnetite in Makeng ore rocks probably was generated from the intermediate-acid magmas with involving of some metal materials coming from Hercynian diabases.

Key words: Fe isotope; δ^{57}Fe values; Magnetite; Makeng deposit; Iron source; Geochemistry

1 Introduction

Makeng deposit is the largest iron deposit in the southwestern Fujian depression belt, even in all over the south China. The mineralization of the deposit has been widely studied since it was discovered. However, there are different viewpoints for the mineralization process and genesis type of this deposit: (1) Marine sedimentary type (Chen et al., 2002; Lin et al., 2008); (2) Marine volcanic sedimentary – hydrothermal transformation type (Ge et al., 1981; Wang et al., 1981; Zhu et al., 1982; Han and Ge, 1983; Chen et al., 1985; Jiang, 2009); (3) Skarn type (Zhao et al., 1983; Chen, 2010; Zhang, 2012; Zhang et al., 2012a). The cruxes of these different viewpoints are the origin of iron. In this study, the Fe isotope was used to constrain the origin of Fe and explain the genesis of Makeng Fe deposit.

The isotopic composition of Fe is a powerful index to trace geochemical and mineralizing processes since the advent of modern MC-ICP-MS instruments. Johnson et al. (2003), Dauphas et al. (2004), Whitehouse and Fedo (2007), Li et al. (2008a, b), and Yan et al. (2010) studied the Fe isotopic composition in the banded iron formation (BIF) type ore rocks and suggested that the Fe sourced from sea water and clastic, and Fe isotopic compositions in the BIF type ore rocks are extremely different because of the multiple sources of the clastic. Graham et al. (2004) inferred that the iron of the Grasberg porphyry type Cu–Au deposit is probably a mixture source between sedimentary and igneous sources through analyzing the Fe isotope. Wang et al. (2011) researched the source of mineralizing components in Xinqiao skarn type polymetallic deposit via introducing the Fe isotopic systematics, and indicated that the dominant Fe source of deposit is magmatic. Hofmann et al., (2009) analyzed the Fe isotope composition of detrital pyrite in Archaean conglomerate-type gold deposit and suggested that the fluid exsolution from siliceous hydrous magmas produce porphyry-style Cu, Mo, or Cu–Au mineralization, which could be traced using Fe isotopes. Therefore, the advent of modern Fe isotopic systematics analysis technology could directly trace the metal materials in the mineralizing processes. In this work, we found the Fe isotopic of vital importance to the study of Makeng deposit.

2 Geology

Makeng iron deposit is situated in the southeastern of early Hercynian Yong'an-Meixian fold belt upon the Caledonide basement (Ge et al., 1981). Several late Paleozoic strata outcropped in this region; the dominated ore-hosted strata are middle-lower carboniferous marine volcanic-carbonate formations that are discontinuously distributed along the regionally NE-NNE controlling basement faults (Han and Ge, 1983). Meanwhile, voluminous Indosinian and Yanshanian granites were emplaced in the region and few Hercynian diabases were

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Table. 1. Fe isotopic data for magnetite samples from Makeng deposit.

Sample number	Location*	Test type	δ^{56} Fe (‰)	SD (‰)	δ^{57} Fe (‰)
MKO-2 Mt	D283	magnetite	0.086	0.045	0.127
MKO-3 Mt	D283	magnetite	0.059	0.056	0.087
MKO-4 Mt	D106, 80m	magnetite	0.096	0.038	0.142
MKO-6 Mt	D106, 145m	magnetite	0.178	0.064	0.263
MKO-10 Mt	D214, 40m	magnetite	0.028	0.039	0.041
MKO-11 Mt	D200, 300m	magnetite	0.155	0.106	0.229

also exposed (Zhang et al., 2012a).

The dominated rock units in the deposit district are Carboniferous and Permian sequences. They composed of several formations (or groups), which are mainly dominated by marine sedimentary rocks including, marine detrital rocks, pyroclastic rocks, carbonates, sandstone, argillite, siltstone, mudstone, and shale. Yanshanian granitic Juzhou and Dayang intrusions are emplaced in two sides of the deposit. Hercynian diabases dikes or stocks intruded into the Carboniferous and Permian sequences. The major faults of the deposit district were also NE-NNE oriented.

Major ore bodies were hosted in Carboniferous Lindi and Jingshe formations. Several smaller ones were generated in the contact zones between two formations. The metal minerals, primarily containing magnetite as well as molybdenite and the gangue minerals consisted of mainly quartz, feldspar, diopside, garnet, and calcite. Skarnization, albitization, K-feldspar alteration, and other calc-silicate-carbonate alterations are widespread in the deposit district.

3 Sampling and analytical methods

We collected several ore-rock specimens from Makeng deposit and pure magnetite separates were hand-picked from the ore-rock chips of 60–80 mesh size that were initially crushed in a steel-faced jaw crusher. Then, the pure magnetite separates were ground to 200 mesh size in a motor-driven agate mortar and were prepared using microwave assisted sample digestion in HNO_3 + HCl + HF acid mixture. The magnetite samples isotopic analyses were carried out with MC-ICP-MS (NEPTUNE, Thermo Scientific, Germany) technique in ALS Scandinavia's laboratory in Luleå, Sweden, and were calibrated against international standards.

4 Results

The data for δ^{56}Fe were obtained and the Fe isotopic standard IRMM-14 with $\delta^{56}\text{Fe} = [(^{56}\text{Fe}/^{54}\text{Fe})_{\text{sample}}/(^{56}\text{Fe}/^{54}\text{Fe})_{\text{standard}} - 1] \times 1000$ was used. Standard deviation (SD) was calculated from two independent consequent measurements. Results of δ^{56}Fe values for samples are summarized in Table 1. As for mass fractionation, the $\delta^{57}\text{Fe} = 0.678 \times \delta^{56}\text{Fe}$ was used from literature (Wang and Zhu, 2012). The δ^{57}Fe values are listed in Table 1. According to the result, the δ^{57}Fe values of magnetite samples have a narrow range of 0.04‰ to 0.26‰ (average 0.15‰).

5 Discussions

According to the researches on the banded iron formation (BIF) and sedimentary rock, the Fe sourced from the sediments has δ^{57}Fe values ranged from –3.02‰ to 4.65‰ (Wang and Zhu, 2012) with a big difference between two samples in the same deposit. Thus, the narrow range of magnetite samples in Makeng deposit suggested that the Fe of the magnetite should not be entirely generated from the sedimentary rocks.

Williams et al. (2004, 2005), Weyer et al. (2005), Weyer and Ionov (2007), Weyer (2008), Huang et al. (2009, 2011), Zhao et al. (2010, 2011) investigated the distribution characteristics of δ^{57}Fe values in the upper mantle. In their research, Wang and Zhu (2012) authenticated that the δ^{57}Fe values in basalts changed within a narrow range and the average was found +0.01 ± 0.22 ‰. Previous study of diabases in Makeng deposit (Zhang, 2012) indicated that they were generated from the upper mantle, so the δ^{57}Fe values of these diabases also changed within a narrow range. However, in contrast with the diabases, the δ^{57}Fe values of these magnetite samples were much larger. Thus, the Fe of the magnetite should not be entirely generated from the diabases.

Former studies (Beard et al. 2003; Dauphas et al. 2004; Poitrasson et al. 2004; Poitrasson and Freydier 2005; Heimann et al. 2008; Schuessler et al. 2009) indicated that the δ^{57}Fe values in intermediate-acid intrusive rocks were in the range of 0.01‰ to 0.54‰ (average 0.18‰), and the latter residual magma was enrich in the heavier isotopes (Wang and Zhu, 2012). Thus, when the magnetite (generally differentiated from the latter process of intermediate-acid magmatism) is entirely generated from the magmas, the δ^{57}Fe values of the magnetite samples should be greater than 0.18‰. However, in our observations the δ^{57}Fe values changed from 0.04‰ to 0.26‰ (average 0.15‰), therefore we could conclude that the Fe in the magnetite should not be entirely sourced from the intermediate-acid magmas.

Based on the above discussions, we can imply that the δ^{57}Fe values of the magnetite samples have a similar narrow distribution characteristic to those of granites and diabases. But, the δ^{57}Fe values of the magnetite samples are distributed between granites and diabases, and much close to the granites. As a result, we assume that metal materials (Fe) are mainly generated from the intermediate-acid magmas and Fe, coming from Hercynian diabases, was involved in the mineralizing process. Moreover, some Fe may come from the sedimentary rocks. Further detailed research should be performed to provide a better understanding of the matter.

6 Conclusions

From the results of this study we conclude that the origin of the metal materials in Makeng deposit is complex. According to the characteristics of the Fe isotopes, we infer that they may have been generated from the intermediate-acid magmas with similar distribution characteristics. But, because of the relatively small δ^{57}Fe values, we determine that metal materials coming from Hercynian diabases were involved in the mineralizing process, and also some Fe may be generated from the sedimentary rock.

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