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Abstract

Sr and Nd isotope geochemistry of fluorites from the Maoniuping REE deposit, Sichuan Province, China: implications for the source of ore-forming fluids

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Abstract

Fluorites are one of the main vein minerals in the Maoniuping REE deposit, Sichuan Province, China. This paper analyzes the Sr and Nd isotopic compositions of fluorites in the orefield. Their $(^{87}Sr/^{86}Sr)_0$ and $(^{143}Nd/^{144}Nd)_0$ (0.706031–0.706237 and 0.512370–0.512412, respectively) are similar to those of carbonatites (0.706074–0.706149 and 0.512383–0.512406, respectively) and syenites (0.705972–0.706302 and 0.512378–0.512405, respectively) in the orefield and all lie in the narrow range between EM I and EM II in the diagram of $(^{87}Sr/^{86}Sr)_i$ vs. $(^{143}Nd/^{144}Nd)_i$. In combination with other geological and geochemical data, we suggested that the ore-forming fluids of the Maoniuping REE deposit mainly came from syenite–carbonatite magmas.

Keywords: Maoniuping REE deposit; Fluorites; Sr and Nd isotope; Ore-forming fluids

1. Introduction

Fluorites are common vein minerals in many deposits. Studies have shown that the Sr and Nd isotope geochemistry of fluorites play an important role in constraining the source and evolution of ore-forming fluids (Halliday et al., 1990; Galindo et al., 1994, 1997; Simonetti and Bell, 1995; Menuge et al., 1997). The Maoniuping REE deposits, Sichuan Province, China, is a large-scale primary REE deposit. In China, this REE deposit is only smaller in scale (primary REE deposit) than the Bayan Obo REE deposit, Inner Mongolia. Fluorites not only are one of the main vein minerals in the Maoniuping REE deposit, but also themselves are potentially recovered as by-products. Although some scholars studied the fluorites in the orefield from inclusions (Niu et al., 1997; Xu et al., 2001; Yang et al., 2001) and REE geochemistry (Yuan et al., 1995; Niu et al., 1996; Xu et al., 2002), few Sr and Nd isotopic compositions of fluorites were reported. Thus, the geochemistry of fluorites in the orefield was not used to discuss the source and evolution of ore-forming fluids. This paper analyzes the Sr and Nd isotopic compositions of fluorites in the Maoniuping REE deposits, summarizes the Sr and Nd

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Table 1

The Sr and Nd isotopic compositions of fluorites in the Maoniuping REE deposits

Sample	Ore-6-1	MNP-135	MNP-127	Ore-5-1	MNP-69	MNP-151	Carbonatite[a]	Syenite[a]	Granite[a]
REE-type[b]	LRE-rich	LRE-rich	LRE-flat	LRE-flat	LRE-depleted	LRE-depleted			
Color	purple	colorless	green	purple	green	colorless			
Rb (ppm)	0.037	0.056	0.331	0.084	0.038	0.026	0.178–0.438	145–169	141–177
Sr (ppm)	3,329	3,980	3,025	3,119	6,173	2,374	9,527–27,815	276–467	48.1–82.1
$^{87}Rb/^{86}Sr$	3.25e − 05	6.35e − 05	3.13e − 04	7.96e − 05	1.83e − 05	2.62e − 05		0.897–1.77	4.97–10.6
$^{87}Sr/^{86}Sr$	0.706031	0.706213	0.706027	0.706208	0.706237	0.706084	0.706074–0.706149	0.706719–0.706863	0.733631–0.744731
$(^{87}Sr/^{86}Sr)_i$	0.706031	0.706213	0.706027	0.706208	0.706237	0.706084	0.706074–0.706149	0.705972–0.706302	0.725747–0.736017
ε_{Sr}	22.2	24.8	22.2	24.7	25.2	23.0	22.9–23.9	21.4–26.1	304–449
Sm (ppm)	26.0	33.8	18.0	32.6	33.0	26.1	55.0–93.7	15.1–99.5	3.78–18.3
Nd (ppm)	129	98.0	85.2	99.8	102	81.2	332–601	157–1,022	19.7–179
$^{147}Sm/^{144}Nd$	0.09511	0.1544	0.1287	0.2199	0.2377	0.1586	0.0888–0.1001	0.0568–0.0780	0.0619–0.1161
$^{143}Nd/^{144}Nd$	0.512431	0.512409	0.512422	0.512413	0.512437	0.512412	0.512405–0.512427	0.512391–0.512427	0.512419–0.512494
$(^{143}Nd/^{144}Nd)_i$	0.512412	0.512379	0.512397	0.512370	0.512390	0.512381	0.512383–0.512394	0.512378–0.512405	0.512370–0.512403
ε_{Nd}	− 3.7	− 4.3	− 4.0	− 4.0	− 4.1	− 4.3	− 3.7 to − 4.2	− 3.7 to − 4.2	− 1.6 to − 2.2

Isotope results normalized to $^{146}Nd/^{144}Nd = 0.7219$ and $^{86}Sr/^{86}Sr = 0.1194$; uncertainties are given at the 2σ level; $(^{87}Sr/^{86}Sr)_i$, $(^{143}Nd/^{144}Nd)_i$, ε_{Sr} and ε_{Nd} values have been calculated for $t = 30$ Ma.

[a] After Xu et al. (2003).

[b] After Xu et al. (2002).

isotopic features of fluorites, and in combination with the REE geochemistry of fluorites and the REE geochemistry and isotope data of rocks and other vein minerals in the orefield, discusses the source of ore-forming fluids.

Wang et al. (2001) and Xu et al. (2003) described the geological setting of the Maoniuping REE deposit. Devonian–Permian (D-P) argillaceous clastic rocks and carbonates and Tertiary (T) diluvium talus outcrop in the orefield. The magmatic rocks in the orefield include Yanshanian granites (Mianxi granites), Himalayan syenites and carbonatites, and a few age-unknown basalts and rhyolites. The Himalayan syenites and carbonatites are closely associated with REE mineralization in time and space. The ore types are mainly barite–pegmatite-type and calcite–pegmatite-type and subordinate thin-network-type. The major ore mineral is bastnaesite and the vein minerals are mainly fluorite, barite, calcite, feldspar, quartz, mica and aegirine–augite.

Fluorites diverse in color and different in grain size occur in every ore type. On the basis of the REE distribution patterns, Xu et al. (2002) divided the fluorites in the orefield into three types, i. e., LRE-rich, LRE-flat and LRE-depleted and suggested that the three types of fluorites may be the products of the same source but at different stages of evolution.

Presented in this paper are the Sr and Nd isotopic compositions of fluorites of every REE-type and different color from every ore-type in the Maoniuping REE deposit. The Sr, Nd isotopic compositions of fluorites were analyzed at the Institute of Geology and Geophysics, Chinese Academy of Sciences. The analytical procedures are described by Xu et al. (2003). The analytical result of standard sample NBS987 is $^{87}\mathrm{Sr}/^{86}\mathrm{Sr} = 0.710234 \pm 7$ and La Jolla is $^{143}\mathrm{Nd}/^{144}\mathrm{Nd} = 0.511838 \pm 8$.

2. Results

Listed in Table 1 are the Sr and Nd isotopic compositions of fluorites in the Maoniuping REE deposits. Five fluorites with different REE-type and

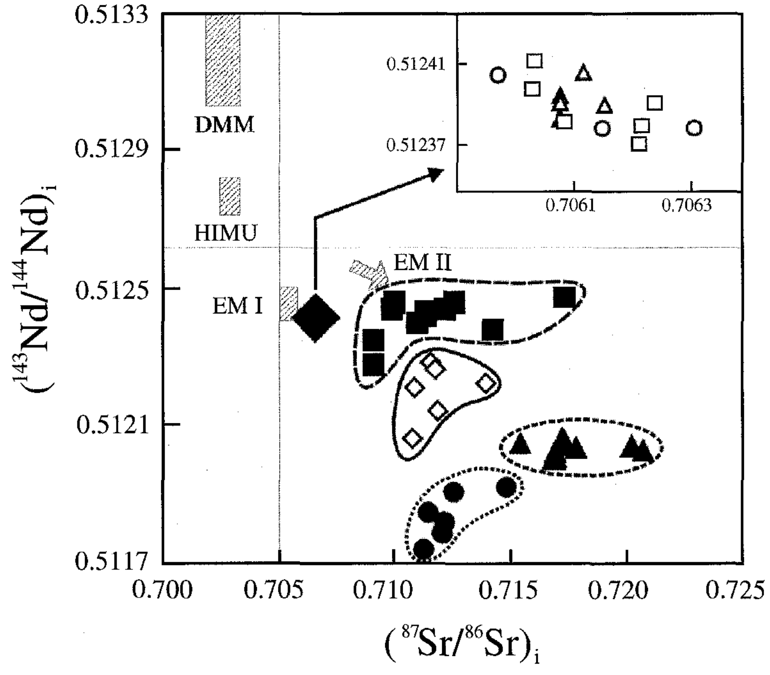

Fig. 1. $(^{87}\mathrm{Sr}/^{86}\mathrm{Sr})_i$ vs. $(^{143}\mathrm{Nd}/^{144}\mathrm{Nd})_i$ diagram of fluorites in the Maoniuping REE deposit. ◇, fluorites in Galway, Ireland (Menuge et al., 1997); ▲, Sierra del Guadarrama, Spain (Galindo et al., 1994); ●, Sierras Pampeanas, Argentina (Galindo et al., 1994; ■, fluorites in Amba Dongar, India, which are host-carbonatites (Simonetti and Bell, 1995); ♦, fluorites, carbonatites and syenites in Maoniuping REE deposits (△, fluorites; □, carbonatites; ○, syenites); DMM, HIMU, EM I and EM II after Zindler and Hart (1986).

different color from every ore-type are generally consistent with each other in Sr and Nd isotopic compositions. Their $(^{87}Sr/^{86}Sr)_i$ range from 0.706031 to 0.706237, $(^{143}Nd/^{144}Nd)_i$ from 0.512370 to 0.512412, ε_{Sr} from 22.22 to 25.2 and ε_{Nd} from -4.3 to -3.7. The Sr and Nd isotopic compositions of one fluorite far away from the orebody (sample MNP-151) are similar to those of fluorites from the ores (Table 1). These characteristics show that all fluorites in the orefield come from the same source. The result is consistent with Xu et al. (2002).

As can be seen from Fig. 1, the Sr and Nd isotopic compositions of fluorites in the Maoniuping REE deposit are different from those of fluorites in Galway, Ireland (Menuge et al., 1997), Sierra del Guadarrama, Spain (Galindo et al., 1994), and Sierras Pampeanas, Argentina (Galindo et al., 1994), which are granite-hosted and those of fluorites in Amba Dongar, India, which are carbonatite-hosted (Simonetti and Bell, 1995). From Table 1, it can be seen that the Sr and Nd isotopic compositions of fluorites are similar to those of carbonatites and syenites, but are different from those of granites in the orefield. In Fig. 1, the values of fluorites, carbonatites and syenites in the orefield lie in the narrow range between EM I and EM II, relatively close to EM I mantle end-member. This feature shows that the ore-forming fluids of the Maoniuping REE deposit are related to the magmatism of syenite–carbonatite.

3. Discussion and conclusions

Fluorites are one of the main vein minerals in the Maoniuping REE deposit and their growth occurred throughout the paragenetic sequence . The Sr and Nd isotope geochemistry of fluorites in the orefield have recorded some important information about the source of the ore-forming fluids. Because the $(^{87}Sr/^{86}Sr)_i$ of fluorites in many deposits lie in between those of two (or more than two) geological bodies, lots of previous investigations have shown that the fluorites (or relevant ores) are the origin of fluid mixing (Deans and Powell, 1968; Ruiz and Richardson, 1988; Ruiz et al., 1985; Barbieri et al., 1987; Halliday et al., 1990; Canals and Cardellach, 1993; Galindo et al., 1994, 1997; Simonetti and Bell, 1995; Menuge et al., 1997). For example, the $(^{87}Sr/^{86}Sr)_i$ of fluorites in Amba Dongar, India (0.70910–0.71729), lie in between those of the carbonatites (0.70549–0.70628) and the host Bagh sandstones (0.75359–0.78274), and Simonetti and Bell (1995) suggested that the fluorites in Amba Dongar, India, were the products of mixing between carbonatite-derived, F-rich fluids and crustal-derived fluids. The $(^{87}Sr/^{86}Sr)_i$ of fluorites in the Maoniuping REE deposit are similar to those of carbonatites and syenites but are different from those of granites in the orefield (Table 1; Fig. 1), showing that the fluids of fluorites in the orefield are relatively simple fluids which were derived mainly from the magmas of syenite–carbonatite. This conclusion can be supported by the following evidence.

(1) Syenites and carbonatites in the Maoniuping REE deposit are closely related to REE mineralization in time and space. In space, the syenites and carbonatites are the main host rocks and the distribution of two types rocks and ore bodies are controlled by the NE Haha fault zone (Wang et al., 2001; Xu et al., 2003). In time, the two types of rocks and REE mineralization are Himalayan in age. Yuan et al. (1995) reported that the K–Ar ages of syenites and carbonatites in the orefield were 28–48 Ma and 31.7 ± 0.7Ma, respectively, and the isotopic age of the vein minerals arfvedsonite and biotite in the ores were 23 and 27 Ma–40 ± 0.7Ma, respectively.

(2) It is confirmed by many investigations that carbonatite magmas can differentiate F-rich fluids (Deans and Powell, 1968; Gittins et al., 1990; Jago and Gittins, 1991; Simonetti and Bell, 1995). The Nd isotope can be used to trace the source of F in fluorites (Ronchi and Touray, 1993; Simonetti and Bell, 1995). In Fig. 1, although the $(^{87}Sr/^{86}Sr)_i$ of fluorites in the Mainiuping REE deposit are different from those of fluorites in Amba Dongar, India, the $(^{143}Nd/^{144}Nd)_i$ values are similar to the latter. The $(^{143}Nd/^{144}Nd)_i$ of fluorites (0.51240–0.51247) are similar to those of fluorites (0.51248–0.51253) in Amba Dongar, India, and Simonetti and Bell (1995) suggested that the F in fluorites from this orefield is mainly derived from carbonatites. So, we consider that the F in fluorites from the Maoniuping REE deposit is mainly derived from magmas of syenite–carbonatite.

(3) Xu et al. (2003) reported that the REE contents of syenites (ΣREE: 369–3,354 ppm; six samples) and carbonatites (ΣREE: 2,207–3,808 ppm; eight samples) in the orefield are obviously higher than those of

basalts (ΣREE: 131–216 ppm; three samples), rhyolites (ΣREE: 112–200 ppm; three samples) and granites (ΣREE: 132–432 ppm; 17 samples). It is shown that syenites and carbonatites in the orefield have the potential of providing ore-forming materials. Studies have indicated that the LRE-rich fluids could be separated from the silicate–carbonatite magmatic system in the processes of evolution (Wendlandt and Harrison, 1979; Ngwenya, 1994; Bulakh et al., 2000; Nasraoui et al., 2000; Groves and Vielreicher, 2001; Zaitsev et al., 2002).

(4) The $\delta^{13}C_{PDB}$ and $\delta^{18}O_{SMOW}$ values of the vein mineral calcites in the Maoniuping REE deposit are − 6.6‰ to − 7.0‰ and 6.4–7.4‰ respectively (eight samples; Xu et al., 2003). These values are within the range of $\delta^{13}C_{PDB}$ and $\delta^{18}O_{SMOW}$ for primary carbonatites (− 4‰ to − 8‰ and 6–10‰, respectively). Moreover, the $\delta D_{H_2}O$ and $\delta^{18}O_{H_2}O$ values of the vein mineral quartz in the orefield are − 52‰ to − 77‰ and 7.8–9.4‰, respectively (three samples; unpubl.). These values also are within the range of $\delta D_{H_2}O$ and $\delta^{18}O_{H_2}O$ for magmatic waters (− 50‰ to − 90‰ and 6–10‰, respectively). These stable isotopic compositions showed that the ore-forming fluids of the Maoniuping REE deposit are characterized as being of mantle source. This conclusion is also supported by the results of inclusion studies by Niu et al. (1997) and Yuan et al. (1995).

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