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Mineralization by mantle fluids in the Miaoniuping REE deposit, Sichuan Province, China

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Abstract

The Miaoniuping REE deposit, Sichuan Province, China is the second largest primary LREE deposit which is a little smaller than the world's largest Bayan Obo REE deposit, Inner Mongolia, China. The REE mineralization is spatially and temporally associated with carbonatites and syenites. This deposit is characterized by its tectonic setting of deep faults, the accompanying mantle-derived magmatic activity, the multiple of wall-rock alteration, the moderately high temperature of formation, H_2O and CO_2 being the important components of the ore-forming fluids, and the mantle source for the ore-forming materials and fluids. These features evidenced that this deposit is the product of the mineralization by mantle fluids.

Keywords: Mantle fluids; Mineralization; Miaoniuping REE deposit; China

1. Introduction

Mineralization by mantle fluids (or their involvement in the ore-forming processes) has been proved for many of superlarge metallic and nonmetallic deposits (Pirajno, 2000; Liu et al., 2001). Liu et al. (2001) summarized the characteristics of the mineralization by mantle fluids as follows: *a*. a tectonic setting of deep faults, *b*. accompanying mantle-derived magmatic activity, *c*. often forming large–superlarge deposits or mineralized district, *d*. multiple types of wall-rock alteration, *e*. moderately high temperature, *f*. H_2O and CO_2 being the important components of the ore-forming fluids, and *g*. a mantle source for the ore-forming materials and fluids. The Miaoniuping REE deposit, Sichuan Province, China is the second largest primary LREE deposit which is a little smaller than the world's largest Bayan Obo REE deposit, Inner Mongolia, China. Although many scholars have studied this deposit with focus on its regional geology (Zhang et al., 1988; Yuan et al., 1995; Wang et al., 2001), ore geology (Yuan et al., 1995), ore-controlling structures (Wang et al., 2001), ore-forming ages (Yuan et al., 1995), and fluid inclusion (Niu et al., 1997; Xu et al., 2001; Yang et al., 2001), the genesis of the deposit is still under debate. Systematic study of the geology and geochemistry, in combination with the previous results, leads us to suggest that the Miaoniuping REE deposit is the product of mineralization by mantle fluids.

2. Geology

Yuan et al. (1995) and Wang et al. (2001) described the geological setting of the Miaoniuping deposit.

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Devonian–Permian (D–P) argillaceous clastic rocks and carbonates and Tertiary (T) diluvium talus outcrop in the orefield (Fig. 1). The magmatic rocks include Yanshanian granites (Mianxi granites), Himalayan syenites and carbonatites, and a few basalts and rhyolites of unknown age (Fig. 1). The REE ore types are mainly pegmatite-type and subordinate thin-network-type. The major ore mineral is bastnaesite and the

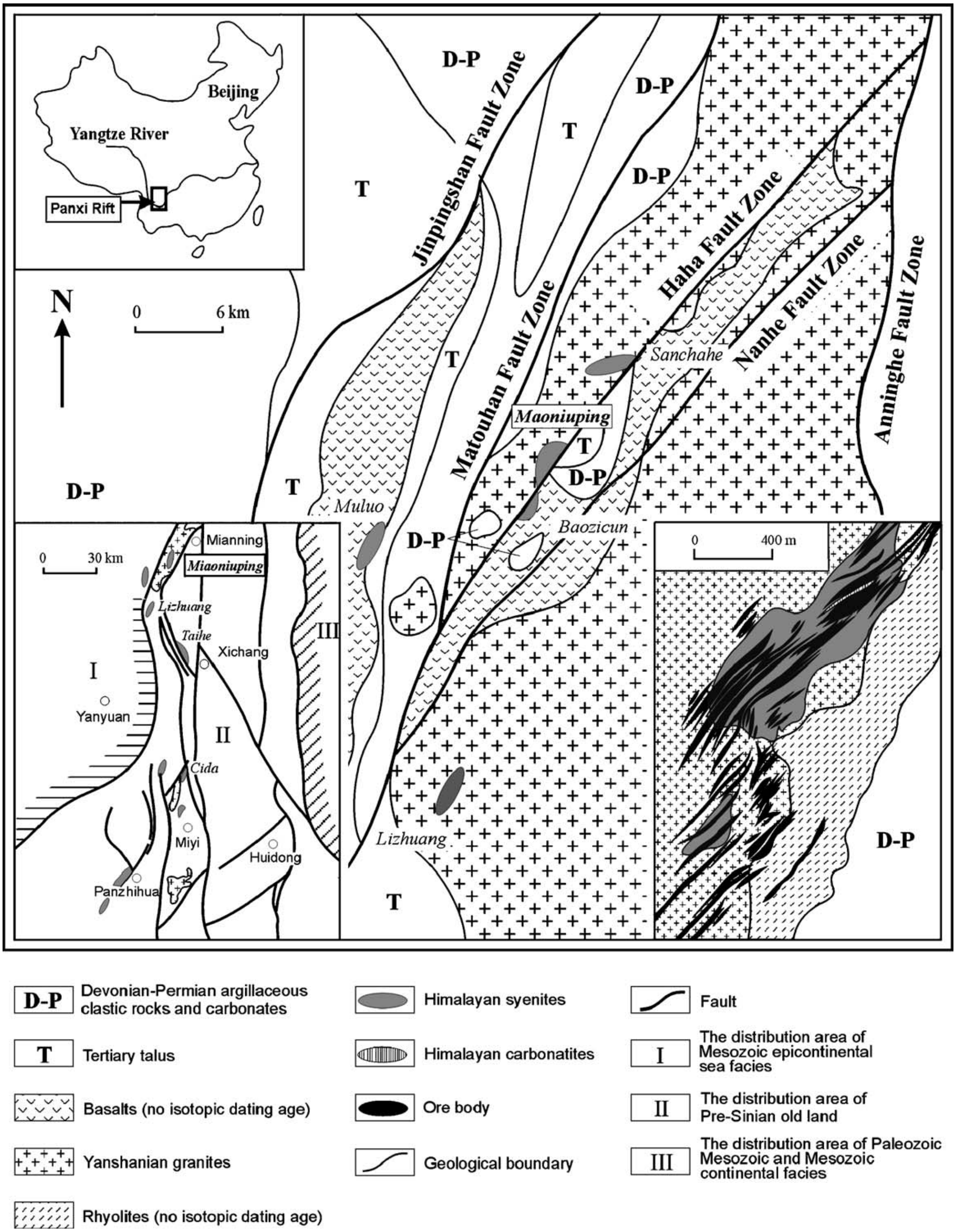

Fig. 1. The geological map of the Miaoniuping REE deposit.

vein minerals are mainly fluorite, barite, calcite, feldspar, quartz, mica and aegirine–augite.

Syenites and carbonatites in the Miaoniuping REE deposits 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 the two types of rocks and ore bodies is controlled by the NE Haha fault zone (Fig. 1; Yuan et al., 1995; Wang et al., 2001). In time, the two types of rocks and REE mineralization are all Himalayan in age. The K–Ar ages of syenites and carbonatites in the orefield vary from 28 Ma to 48 Ma (Luo and Yu, 2001; Pu, 2001) and the age of ore formation varies from 23 Ma to 40 Ma (Yuan et al., 1995).

3. Evidences for the mineralization of mantle fluids

3.1. Tectonic setting of deep faults

The Miaoniuping REE deposit is located in the north of the Panxi rift which has with north–south striking (Fig. 1). Although the Panxi rift had closed during the age of mineralization of the Miaoniuping REE deposit (Zhang et al., 1988), due to the collision between the Indian plate and the Yangtze plate, which formed many of northeast striking tensional fractures in the district (Luo and Yu, 2001), such as the Jinpingshan, Matoushan, Haha and Nanhe fracture zones (Fig. 1). The Haha deep fracture zone specifically controlled the mantle-derived magmatic activity and the mineralization of the Miaoniuping REE deposit (Yuan et al., 1995; Wang et al., 2001).

3.2. Mantle-derived magmatic activity

Many types of magmatic rocks occur in the Miaoniuping region, but only the carbonatites and syenites are spatially and temporally associated with REE mineralization. Xu et al. (2003) systematically studied the geology, petrology, geochemistry, and genesis of the carbonatites in the orefield. The main characteristics of the carbonatites are as follows: *a*. the rock association is carbonatite and syenite and the mineral assemblage is calcite, aegirine, augite, arfvedsonite, mica and orthoclase; *b*. they have very rich incompatible elements such as Sr, Ba, REE, etc.; *c*. their $\delta^{13}C_{PDB}$ and $\delta^{18}O_{SMOW}$ vary from −6.6‰ to −7.0‰ and from 6.3‰ to 7.4‰, respectively, which are the features of C and O isotopic compositions of primary carbonatite (Taylor et al., 1967); *d*. the $(^{87}Sr/^{86}Sr)_0$ and $(^{143}Nd/^{144}Nd)_0$ varies from 0.70602 to 0.70615 and 0.51239 to 0.51242, respectively, and all of the samples plot into the narrow range between EM1 and EM2 in the $(^{87}Sr/^{86}Sr)_0$ vs $(^{143}Nd/^{144}Nd)_0$ diagram (figure is left out); *e*. $^{206}Pb/^{204}Pb$, $^{207}Pb/^{204}Pb$ and $^{208}Pb/^{204}Pb$ range from 17.877 to 18.471, 15.362 to 15.587 and 38.083 to 38.683, respectively, all of the data plot into the narrow range between EM1 and EM2 in the $^{206}Pb/^{204}Pb$ vs $^{207}Pb/^{204}Pb$ and $^{206}Pb/^{204}Pb$ vs $^{208}Pb/^{204}Pb$ diagram also (figure is left out). All of these features show that the rocks were derived from a metasomatic enriched mantle. Xu et al. (2003) suggested that the crustal materials with an EM2 signature subducted and metasomatized EM1 type sub-continental lithosphere to form the metasomatic enriched mantle of carbonatites, and the carbonatites and syenites were generated from the liquid immiscibility of the CO_2-rich alkalic silicate melts, which were formed from the partial melting of the metasomatic enriched mantle.

3.3. Large–superlarge deposits or ore-concentrating district

There is a south–north REE mineralization belt with the length of about 270 km in the Panxi area, Sichuan Province, which begins in Miaoniuping, through Xichang, Dechang, Huili and Huidong, and ends in Panzhihua (Fig. 1). At present, more than 50 REE ore deposits or ore showings have been found in this belt (Pu, 2001). Many of them are spatially and temporally associated with carbonatites and syenites of Himalayan age and their features of geology and geochemistry are similar to that of the Miaoniuping REE deposit. We conclude that the REE mineralization in relation to carbonatites and syenites of Himalayan age in Panxi area has formed the large–superlarge deposit or ore-concentrating district.

3.4. Wall-rock alteration

The wall-rock alteration of the Miaoniuping REE deposit is very intense and many types of alteration and ore-forming stages can be identified. The type of alteration is depended on the mineral assemblage of the host rocks and the mineral assemblages of alteration for different type of ores. Yuan et al. (1995) divided the wall-rock alteration in the orefield into four phases: *a*. the K and Na metasomatism of late magmatic stage or postmagmatic stage including biotitization, aegirine-augitization, arfvedsonitization and albitization; *b*. the low–moderate temperature hydrothermal metasomatism of postmagmatic stage including aegirine-augitization, calcitization, baritization, fluoritization, chevkinite-bastnaesitization and sulfidationl; *c*. the low temperature hydrothermal metasomatism including sericitization, kaolinization and biotitization; and *d*. the epigenization including oxidation and dissolved eluviation.

3.5. Moderately high hydrothermal deposit

A great number of primary inclusions are found in the Miaoniuping REE deposit. These primary inclusions can be grouped into fluid and fluid-melting inclusions. The fluid inclusions can be further distinguished into gas–liquid ($L+V$) two-phase, gas–liquid–CO_2 ($L+L_{CO_2}+V_{CO_2}$) three-phase, pure gas fluid (V) and solid (S) inclusions. The homogenization temperature (T_h) of the fluid-melting inclusions is usually higher than 450 °C. However, the T_h of fluid inclusions in the different host minerals are different. The T_h of fluid inclusions in quartz, fluorite and bastnaesite is usually higher than 250 °C, T_h of fluid inclusions in calcites are about 200 °C. So, the Miaoniuping REE deposit is a moderately high temperature hydrothermal deposit.

3.6. Component of ore-forming fluids

Freezing method determined that the trip point temperature of CO_2 in different types of inclusions in gangue minerals from the Miaoniuping REE deposit varied from −59 to −50 °C. This temperature shows that CO_2 is the main gas component of the ore-forming fluids. The analytical data of Yuan et al. (1995) and Yang et al. (2001) suggested also that H_2O and CO_2 were the main gas components of different types of inclusions in the orefield. Niu et al. (1997) suggested that the ore-forming fluid in this deposit was a Na^+–K^+–Cl^-–F^-–SO_4^{2-}–CO_2–H_2O solution. The data also show that H_2O and CO_2 are important components of the ore-forming fluids in the Miaoniuping REE deposit.

3.7. Sources of ore-forming materials and fluids

The primary REE deposits in the world are often associated with carbonatite complex in time and space (Mariano, 1989). Studies have indicated that the LREE-rich fluids could have been separated from the carbonatite–silicate magmatic system in the processes of evolution (Wendlandt and Harrison, 1979; Ngwenya, 1994; Bulakh et al., 2000; Nasraoui et al., 2000; Zaitsev et al., 2002). On the basis of the REE contents, Sr–Nd–Pb and C–O–H isotopic compositions, Huang et al. (submitted for publication to Chinese J Geochem) has confirmed that the ore-forming materials and fluids in the Miaoniuping REE deposit originated mainly from the mantle and that carbonatite–syenite magmatic activity provided the ore-forming materials and fluids during the processes of REE mineralization.

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