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A synthesis of mineralization styles with an integrated genetic model of carbonatite-syenite-hosted REE deposits in the Cenozoic Mianning-Dechang REE metallogenic belt, the eastern Tibetan Plateau, southwestern China

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A B S T R A C T

The Cenozoic Mianning–Dechang (MD) rare earth element (REE) belt in eastern Tibet is an important source of light REE in southwest China. The belt is 270 km long and 15 km wide. The total REE resources are >3 Mt of light rare earth oxides (REO), including 3.17 Mt of REO at Maoniuping (average grade = 2.95 wt.%), 81,556 t at Dalucao (average grade = 5.21 wt.%), 0.1 Mt at Muluozhai (average grade = 3.97 wt.%), and 5764 t of REO at Lizhuang (average grade = 2.38 wt.%). Recent results from detailed geological surveys, and studies of petrographic features, ore-forming ages, ore forming conditions, and wallrock alteration are synthesized in this paper. REE mineralization within this belt is associated with carbonatite–syenite complexes, with syenites occurring as stocks intruded by carbonatitic sills or dikes. The mineralization is present as complex vein systems that contain veinlet, stringer, stockwork, and brecciated pipe type mineralization. Carbonatites in these carbonatite-related REE deposits (CARDs) are extremely rich in light REEs, Sr (>5000 ppm), and Ba (>1000 ppm), and have low Sr/Ba and high Ba/Th ratios, and radiogenic Sr–Nd isotopic compositions. These fertile magmas, which may lead to the formation of REE deposits, were generated by the partial melting of sub-continental lithospheric mantle (SCLM) that was metasomatized by REE- and CO_2-rich fluids derived from subducted marine sediments. We suggest that this refertilization occurred along cratonic margins and, in particular, at a convergent margin where small-volume carbonatitic melts ascended along trans-lithospheric faults and transported REEs into the overlying crust, leading to the formation of the CARDs. The formation of fertile carbonatites requires a thick lithosphere and/or high pressures (>25 kbar), a metasomatized and enriched mantle source, and favorable pathways for magma to ascend into the overlying crust where REE-rich fluids exsolve from cooling magma. The optimal combination of these three factors only occurs along the margins of a craton with a continental root, rather than in modern subduction zones where the lithosphere is relatively thin.

U–Pb zircon dating indicates that the Maoniuping, Lizhuang, and Muluozhai alkali igneous complexes in the northern part of the belt formed at 27–22 Ma, whereas the Dalucao complex in the southern part of the belt formed at 12–11 Ma. Biotite and arfvedsonite in Lizhuang and Maoniuping REE deposit have $^{40}Ar/^{39}Ar$ ages of 30.8 ± 0.4 Ma (MSWD = 0.98) and 27.6 ± 2.0 Ma (MSWD = 0.06), respectively. Biotitaion alteration in syenite and fenitization caused by the relatively amount of carbonatite on syenite and host rocks is the main alteration along the whole belt.

Initial Sr (0.7059–0.7079), $^{143}Nd/^{144}Nd$ (0.5123–0.5127), and $^{207}Pb/^{204}Pb$ (15.601–15.628) and $^{208}Pb/^{204}Pb$ (38.422–38.604) isotopic compositions of fluorite, barite, celestite, and calcite in the MD belt are similar to those of the associated syenite and carbonatite. Given the relatively high contents of Cl, F, SO_4^{2-}, and CO_2 in the rocks of the complexes, it is likely that the REEs were transported by these ligands within hydrothermal fluids, and the presence of bastnäsite indicates that the REEs were precipitated as fluorocarbonates. Petrographic, fluid inclusion, and field studies of the ores indicate that bastnäsite and other REE minerals formed during the final stages (<300 °C) of the evolution of magmatic–hydrothermal systems in the belt.

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The mineralization formed from magmatic and meteoric fluids containing CO_2 derived from the decarbonation of carbonatite, as indicated by C–O isotopic values of hydrothermal calcite and bastnäsite ($\delta^{13}C$ = −4.8 to −8.7 and $\delta^{18}O$ = 5.8 to 12.5‰) and O–H isotopic values of quartz (330 °C) and arfvedsonite (260 °C), which correspond to fluid isotope compositions of $\delta^{18}O$ = 0.3–9.8‰ and δD = −70.0 to −152.8‰ in the belt. This study indicates that formation the largest REE deposits are related to voluminous carbonatite–syenite complexes, compositionally similar ore-forming fluids, extensive alteration, multiple stages of REE mineralization, and tectonic setting.

1. Introduction

More than 500 carbonatite intrusions have been found on all of Earth's continents (Bell and Tilton, 2001), and they largely occur as circular to ovoid complexes in rift belts (e.g., East Africa), but are also associated with large igneous provinces (e.g., Deccan) and/or alkaline provinces (e.g., Greenland and Kola Peninsula). Giant carbonatite-related rare earth element (REE) deposits (CARDs) are rare, and have only been discovered in China, North America, and the Kola Peninsula (Fig. 1). The REEs are essential for high-technology industries and defense systems. China hosts one-third of the world's known REE reserves and produces 97% of global REE + Y (Weng et al., 2013, 2015). A wide variety of REE deposits are found in China (Chakhmouradian and Wall, 2012; Kynicky et al., 2012), including CARDs that formed from REE-rich fluids exsolved from carbonatitic melts. This type of deposits is the most significant form of REE mineralization in China, accounting for ca. 65% of China's REE reserves. The known CARDS in China include Bayan Obo (Yang et al., 2009, 2016, 2011a,b; Ling et al., 2013; Lai et al., 2012, 2015, 2016; Lai and Yang, 2013) and deposits in the Mianning–Dechang (MD) belt (Hou et al., 2009; Liu et al., 2015a, b,c). All of these deposits are located along cratonic margins (Fig. 2) and share a number of similarities (Tables 1 and 2).

The Cenozoic MD REE belt in eastern Tibet (Figs. 3 and 4) and western Sichuan Province, southwest China, is 270 km long and 15 km wide (Fig. 5). The belt contains total resources of >3 Mt of light rare earth oxides (REO), including those at Maoniuping (3.17 Mt of REO; average grade at 2.95 wt.%), Dalucao (81,556 t; average grade at 5.21 wt.%), Muluozhai (0.1 Mt; average grade at 3.97 wt.%), and Lizhuang (5764 t; average grade at 2.38 wt.%). The MD belt contains REE deposits that all formed under the same geological conditions, but these deposits have various grades, reserves, and REE mineralization styles. As such, study of these deposits with regards to REE mineralization may improve our understanding of the formation of giant CARDs.

Most previous studies have focused on the carbonatite petrogenesis, fluorite geochemistry, fluid inclusions, formation ages of carbonatite-syenite complex or individual deposits in the MD deposits (Yuan et al., 1995; Pu, 2001; Huang et al., 2003; Xu et al., 2004, 2008, 2012, 2015; Hou et al., 2006a, 2015; Song et al., 2016a,b; Tian et al., 2008a,b; Xie et al., 2009, 2015; Liu et al., 2015a,b,c). However, their field relations are largely based on old geological survey reports, and the ages of the deposits and host rocks, wallrock alteration styles, and REE mineralogy have not been reported in detail and compared with each other even in one belt. Moreover, the paragenetic sequences of these ore

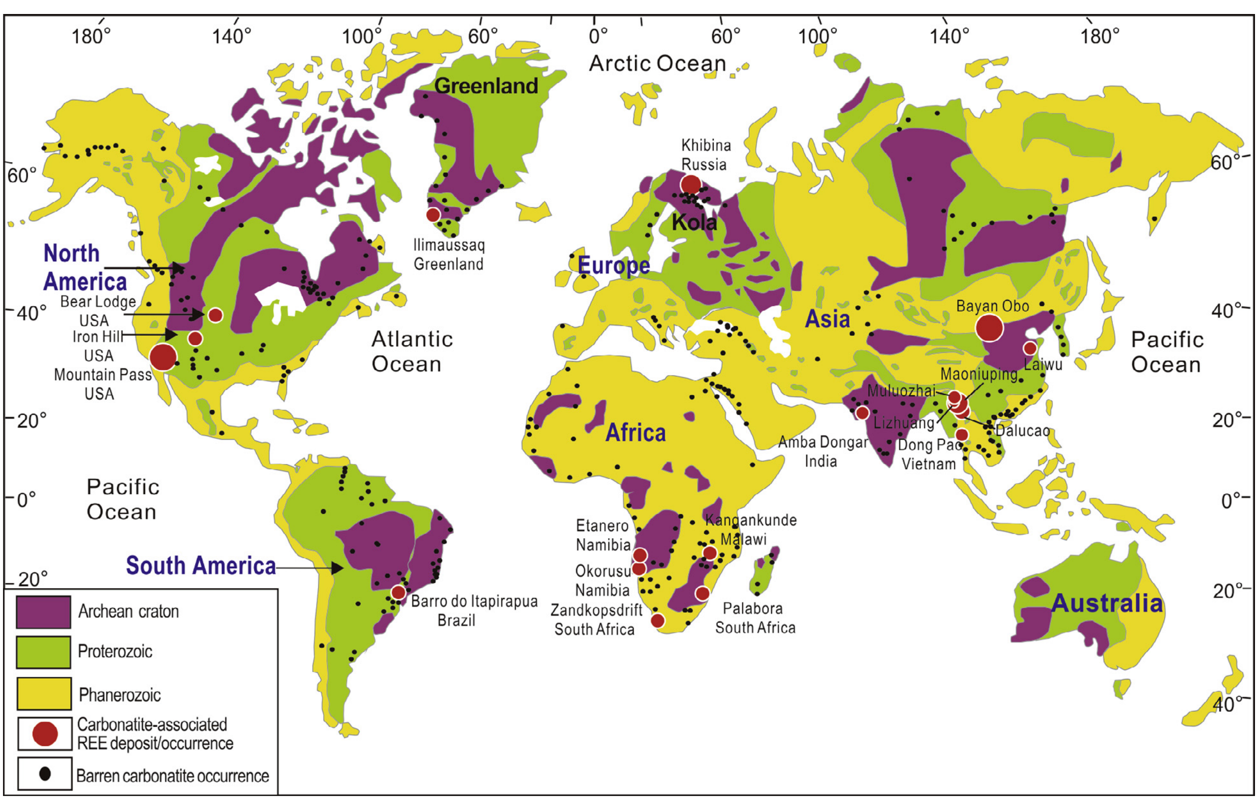

Fig. 1. Main global occurrences of carbonatites and carbonatite-related REE deposits in the world.