



The anomalous lithium isotopic signature of Himalayan collisional zone carbonatites in western Sichuan, SW China: Enriched mantle source and petrogenesis

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Abstract

Lithium concentrations and isotopic compositions of 38 carbonatites and associated syenites from the Maoniuping, Lizhuang, and Dalucao in western Sichuan, along with previously published and new Pb–Sr–Nd–C–O isotope data and whole-rock analyses, are used to constrain their mantle source and genesis. Carbonatites and syenites are characterized by extremely varying Li concentrations (0.8–120 ppm) and highly variable Li isotopic compositions (−4.5‰ to +10.8‰). Among them, the majority of the carbonatites and syenites have $\delta^7\text{Li}$ values between +0.2‰ and +5.8‰, which overlap with the reported values for MORB and OIB; 3 carbonatites have higher $\delta^7\text{Li}$ values between +8.7‰ and +10.8‰; 5 carbonatites and 4 syenites have lighter $\delta^7\text{Li}$ values between −4.5‰ and −0.3‰. These highly variable $\delta^7\text{Li}$ compositions could not have been produced by diffusive-driven isotopic fractionation of Li and thus may record the isotopic signature of the late Proterozoic subcontinental lithospheric mantle (SCLM). This paper demonstrates the existence of anomalous $\delta^7\text{Li}$ within the late Proterozoic subcontinental lithospheric mantle, suggesting that the ancient SCLM beneath western Sichuan was modified by interaction with fluids derived from the subducted oceanic crust and marine sediments.

The modeling curves of fluids derived from a dehydrated slab (ratios: $\text{AOC}_{80}\text{--SED}_{20}$ to $\text{AOC}_{40}\text{--SED}_{60}$) with a representative mantle composition can account for the majority of lithium compositional variations. Some samples with unusual Pb–Sr–Nd–O isotopic compositions and highly variable $\delta^7\text{Li}$ compositions are affected by significant involvement of marine sediments in their source region, not contaminated by crustal materials. The carbonatites and syenites in western Sichuan were

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generated by the partial melting of subcontinental lithospheric mantle, which was metasomatized by the Li-rich fluids derived from the subducted oceanic crust and marine sediments. This melting was most likely triggered by a Cenozoic asthenospheric mantle diapir related to Indian-Asian continental collision and post- or late-collisional stress relaxation in the Oligocene. © 2015 Elsevier Ltd. All rights reserved.

1. INTRODUCTION

Lithium stable isotopes are increasingly being used to study recycling processes in the mantle (e.g., Aulbach and Rudnick, 2009; Vlastélic et al., 2009; Tang et al., 2014), because of their moderate incompatibility during magmatic processes (Ryan and Langmuir, 1987), strong fluid mobility (You et al., 1996), and highly variable Li isotopic compositions (up to 80‰) in terrestrial samples (Tomascak, 2004). In contrast to the relatively uniform lithium isotopic composition of the convecting mantle (+2‰ to +6‰, as inferred from relatively pristine olivine and fresh MORB; Chan et al., 1992; Moriguti and Nakamura, 1998; Tomascak, 2004; Magna et al., 2006a; Tomascak et al., 2008), the lithospheric mantle has highly variable $\delta^7\text{Li}$ values (40‰; Tomascak, 2004), primarily because subducted sediments, altered basaltic and ultramafic rocks on the ocean floor have high Li contents (up to 80 ppm) and diverse Li isotopic compositions ($\delta^7\text{Li} = -12‰$ to +21‰) (Chan et al., 1992; Bouman et al., 2004; Rudnick et al., 2004) and therefore fluid/melt derived from the subducting slabs can strongly affect Li isotopic compositions in the overlying mantle wedge (Magna et al., 2006b, 2008; Tomascak et al., 2000).

Equilibrium fractionation of lithium isotopes occurs in igneous systems at the low temperatures associated with pegmatite formation (Teng et al., 2006a), but not significantly at the high temperatures and high degrees of partial melting associated with basalt generation and differentiation (>1050 °C; Tomascak et al., 1999). This indicates that Li isotopes undergo negligible fractionation during magmatic processes, suggesting that the Li isotopic compositions of mantle-derived magmas may directly record the compositions of their source materials (e.g., Zhang et al., 2010; Tang et al., 2012, 2014; Su et al., 2012). Several studies have suggested that the anomalous $\delta^7\text{Li}$ values in the mantle, including high $\delta^7\text{Li}$ values (up to 7.9‰) of HIMU lavas (Chan et al., 2009; Vlastélic et al., 2009), and low $\delta^7\text{Li}$ values (lower than -27.0‰) of mantle-derived minerals (Tang et al., 2012, 2014) and lavas (Agostini et al., 2008), are related to isotopic fractionation associated with fluid loss during the dehydration of subducted oceanic crust (e.g., Zack et al., 2003; Elliott et al., 2004; Wunder et al., 2007). However, recent analyses of peridotites and phenocrysts within lavas indicate that Li isotopes can be strongly fractionated during diffusive kinetic fractionation associated with high-temperature igneous processes (e.g., Lundstrom et al., 2005; Teng et al., 2006b; Marschall et al., 2007; Rudnick and Ionov, 2007). This indicates that it is important to determine whether the non-MORB-like $\delta^7\text{Li}$ values of the mantle-derived samples are the result of

kinetic effects or the recycling of crustal components (Aulbach and Rudnick, 2009).

Carbonatites are mantle-derived, intraplate magmas that provide a means of documenting the isotopic secular evolution of Earth's mantle (Halama et al., 2008, 2011), and are usually interpreted to reflect the recycling of oceanic lithosphere (Hou et al., 2006a). This indicates that carbonatites may also provide useful evidence of crustal recycling. In addition, carbonatites form from extremely low-temperature, low-density, and low-viscosity magmas compared to typical silicate melts (Genge et al., 1995), which means that these carbonatitic magmas rapidly rise to Earth's surface and undergo only limited interaction with continental crustal material (Bell and Tilton, 2002). This implies that carbonatites can provide robust evidence for the composition of the lithospheric mantle. Moreover, carbonatite-related rare-earth-element (REE) deposits are the most significant source of the world's REEs, accounting for 50% of all global REE reserves (Hou et al., 2015). A wide variety of carbonatite-associated REE deposits in China, including Bayan Obo (the world's largest LREE–Fe–Nb deposit; Yang et al., 2009; Lai et al., 2012; Ling et al., 2013), Maoniuping (the giant LREE deposit; Hou et al., 2009) and numerous medium-large LREE deposits (Ying et al., 2004; Hou et al., 2009; Xu et al., 2010), account for approximately 65% of China's REE reserves. Carbonatites in rift zones are generally thought to be derived from the melting of sublithospheric mantle triggered by mantle plume activity (Bell and Simonetti, 2010); however, the genesis of the carbonatite in a collisional zone remains unclear.

Halama et al. (2007, 2008) presented the Li isotopic compositions of carbonatites and associated silicate rocks in rift zones, but to date no Li isotope data have been reported from carbonatites and associated silicate rocks in a collisional zone. Here, we present the first anomalous Li isotope compositions of carbonatites and spatially associated syenites from three districts in the eastern Indian-Asian collisional zone (EIACZ), and use these data to provide new constraints not only on the nature of the source region and the petrogenesis of these carbonatitic magmas but also on the processes that occurred during crust–mantle interaction related to the Indian-Asian continental collision. In addition, lithium stable isotopes are an effective method to make a difference between the collisional zone carbonatites and rift zone carbonatites.

2. GEOLOGICAL BACKGROUND AND SAMPLES

Cenozoic carbonatite–alkalic complexes within the EIACZ are located on the western margin of the Yangtze

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