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Iron and magnesium isotope fractionation in oceanic lithosphere and sub-arc mantle: Perspectives from ophiolites

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ABSTRACT

We present high-precision Fe and Mg isotopic data for the Purang ophiolite, southwestern Tibet, representing the first combined Fe and Mg isotopic study of the oceanic lithosphere hitherto. The δ^{56}Fe and δ^{26}Mg values of the ophiolitic peridotite, dunite and gabbro vary from -0.209 to $0.187‰$ and from -0.28 to $-0.14‰$, respectively. The average δ^{56}Fe of the peridotites is $-0.030 \pm 0.143‰$ (2SD, $n = 17$), a value indistinguishable from abyssal peridotites and chondrites, and lower than oceanic basalts. The average δ^{26}Mg value of the peridotites is $-0.20 \pm 0.10‰$, a value slightly higher than both chondrites and oceanic basalts. Correlations between δ^{56}Fe and indices of partial melting indicate fractionation of $0.323‰$ in δ^{56}Fe between the oceanic lithospheric mantle and the overlying mafic crust during an early episode of partial melting, presumably beneath a spreading centre. Subsequent metasomatism in a supra-subduction zone caused elevated oxygen fugacity and heavy Fe isotopic compositions in the oceanic lithospheric mantle. The dunite with high Ba/La, a proxy for oxygen fugacity, and high δ^{56}Fe values was likely formed during this process of sub-arc mantle-melt interaction. The negatively coupled Fe–Mg isotopic variations of the Purang ophiolite indicate that Mg isotope fractionation may also occur during high-temperature mantle processes. The observed isotopic variations among different lithologies in the ophiolite may satisfactorily account for the isotopic differences between arc lavas and mantle peridotites with respect to oceanic basalts, thus providing implications for crust–mantle differentiation.

1. Introduction

Studies of peridotite xenoliths and komatiites indicate that the Earth's mantle might have chondritic Fe and Mg isotopic compositions (e.g., Weyer et al., 2005; Weyer and Ionov, 2007; Dauphas et al., 2009a, 2010; Handler et al., 2009; Yang et al., 2009; Bourdon et al., 2010; Teng et al., 2010a). By contrast, oceanic basalts (MORBs and OIBs), partial melting products of the mantle, have chondritic Mg (Teng et al., 2007, 2010a; Bourdon et al., 2010) and non-chondritic, heavier Fe isotopic compositions (Beard et al., 2003; Weyer and Ionov, 2007; Teng et al., 2008, 2013; Schuessler et al., 2009). The difference in Fe isotopic composition between oceanic basalts and mantle peridotites implies that partial melting fractionates Fe isotopes. As ferric iron (Fe^{3+}) is more incompatible (e.g., Canil et al., 1994) than ferrous iron (Fe^{2+}) (e.g., Polyakov and Mineev, 2000; Polyakov et al., 2007; Dauphas et al., 2009a), heavy Fe isotopes are preferentially concentrated in the melts, leaving an isotopically light residue (Williams et al., 2005; Weyer and Ionov, 2007; Nebel et al., 2013). However, the lack of measurable Fe isotope fractionation in abyssal peridotites (Craddock et al., 2013) implies that Fe isotope fractionation of peridotite residues is limited during partial melting and thus the mechanism causing enrichments of heavy Fe isotopes in oceanic basalts relative to their source regions requires further investigation. On the other hand, boninites and island arc basalts, both of which originate from a

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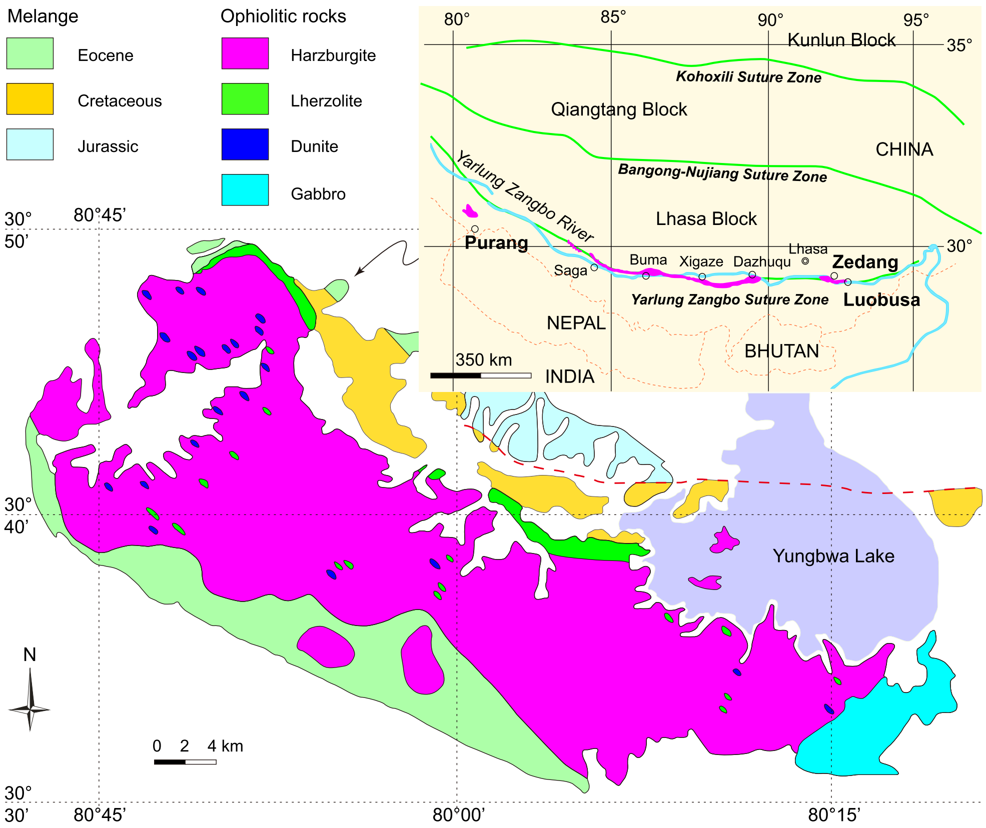

Fig. 1. Sketch geological map of the Purang ophiolite and its surrounding lithological units.

more oxidized environment than the MORBs, display lighter Fe isotopic compositions (Dauphas et al., 2009a). This discrepancy is not yet fully understood, although some studies suggested that redox variations and fractional crystallization might play an important role (Williams et al., 2005; Dauphas et al., 2009a, 2014; Nebel et al., 2013).

Unlike Fe isotopes, Mg isotopes appear to be insensitive to the partial melting processes described above. However, recent studies have revealed that some cratonic eclogites and subduction-related basalts have lighter Mg isotopic compositions relative to the lithospheric mantle (Wang et al., 2012; Yang et al., 2012). These abnormal δ^{26}Mg signals thus raise an important question on the mechanisms responsible for transferring the light Mg isotopes in the recycled eclogitic slab to the overlying mantle wedge, and their subsequent manifestation on Earth's surface as continental volcanic rocks. Oceanic lithosphere represented by ophiolites that commonly involve recycled materials during subduction may record recycling process of light Mg isotopes. However, the lack of relevant data on oceanic lithosphere impedes our understanding of the above question.

In order to further constrain the behavior of Fe and Mg isotope fractionation in oceanic and sub-arc lithosphere, we present, to our knowledge, the first combined Fe and Mg isotopic study on the well-studied Purang ophiolite complex in southwestern Tibet. This ophiolitic massif was considered to have formed after melt extraction at a mid-ocean ridge setting, followed by percolation of arc magmas in a supra-subduction zone (e.g., Liu et al., 2014; Li et al., 2015), thus being the ideal samples to study Fe and Mg isotope fractionation during the evolution of the upper mantle. Specifically, we aim at constraining the Fe and Mg isotopic compositions of the oceanic lithospheric mantle and revealing the influence of various mantle processes on fractionating Fe and Mg isotopes. Our results show that the Purang ophiolite has variable, but negatively correlated, Mg and Fe isotopic compositions, which suggests that partial melting and melt-peridotite interaction may have played an important role in fractionating Fe and Mg isotopes in the upper mantle.

2. Geological background and sample descriptions

The Tibetan Plateau has been formed by collision between different blocks. The Yarlung Zangbo Suture Zone is the youngest suture, which marks the final collision of the Indian with Eurasian plates (Fig. 1). This suture zone is marked by Cretaceous ophiolites that represent remnants of the Neo-Tethyan oceanic lithosphere (Hébert et al., 2012 and references therein). The Purang ophiolite complex in the western segment of the Yarlung Zangbo Suture Zone consists mainly of a large ultramafic massif with limited exposures of crustal rocks (Fig. 1). The outcrops are dominated by harzburgites, with local occurrence of lherzolites and subordinate dunites. Chromitites are occasionally observed in dunites (Liu et al., 2015). Mafic rocks commonly occur as dykes or veins in the peridotites with MORB-like composition (Miller et al., 2003; Liu et al., 2014, 2015).

Lherzolites and harzburgites in the Purang ophiolite commonly display coarse equigranular to porphyroclastic textures and have a mineral assemblage of olivine, orthopyroxene, clinopyroxene and spinel (Fig. 2a). Olivine is subhedral to euhedral and displays kink bands. Some olivine grains are locally replaced with serpentine (Fig. 2b). Olivine grains in harzburgites are commonly large and fresh (Fig. 2c). Orthopyroxene occurs as coarse porphyroclasts and is surrounded by fine-grained orthopyroxene, olivine and spinel (Fig. 2d). Clinopyroxene generally displays irregular forms with curved grain boundaries. Both orthopyroxene and clinopyroxene show exsolution lamellae. Anorthitic plagioclase and pargasitic amphibole are also observed in Purang peridotites (Liu et al., 2010). Dunites in the Purang ophiolite occur as pods and lenses in the harzburgite bodies (Fig. 1), and occasionally host small banded