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Geochimica et Cosmochimica Acta 143 (2014) 34–48

Geochimica et Cosmochimica Acta

www.elsevier.com/locate/gca

Magnesium isotopic systematics of mafic rocks during continental subduction

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Available online 3 April 2014

Abstract

Magnesium isotopic compositions of a set of prograde metamorphosed rocks (greenschists, amphibolites, and eclogites) from East China were measured in order to understand the behavior of Mg isotopes during continental subduction. The δ^{26}Mg values of the greenschists vary from -0.269 ± 0.057‰ to -0.133 ± 0.042‰ (2SD), and correlate negatively with the MgO contents and Nb/U ratios, possibly due to the assimilation of isotopicallly heavy felsic schists (δ^{26}Mg up to -0.099‰) during the genesis of MORB-like protoliths. The two subgroups of amphibolites have slightly different Mg isotopic compositions. The group I amphibolites with cumulate origin have δ^{26}Mg values ranging from -0.243 ± 0.061‰ to -0.192 ± 0.050‰, which reflects clinopyroxene accumulation nature of the protolith. The group II amphibolites have relatively light δ^{26}Mg values varying from -0.358 ± 0.061‰ to -0.224 ± 0.056‰, which may result from either source contamination or crustal assimilation of isotopically light components (e.g., carbonates). Eclogitic garnet and clinopyroxene display large inter-mineral Mg isotope fractionations ($\Delta^{26}Mg_{Cpx\text{-}Grt} = 1.097 \pm 0.056$‰ to 1.645 ± 0.081‰) equilibrated at peak metamorphic temperatures. The δ^{26}Mg values of the eclogites vary from -0.348 ± 0.041‰ to -0.137 ± 0.063‰, overlapping the ranges of greenschists and amphibolites. Such Mg isotopic variations are not related to unrepresentative sampling nor host–eclogite chemical interactions, instead, they reflect the protolith heterogeneities. Collectively, the similarity of Mg isotopic compositions among the greenschists (-0.196 ± 0.044‰), amphibolites (-0.271 ± 0.042‰), and eclogites (-0.226 ± 0.044‰), suggests that Mg isotope fractionation during continental subduction, if any, is limited.
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1. INTRODUCTION

Magnesium (Mg) is a major element in earth's mantle, crust, and hydrosphere. Over geological time-scales, Mg is continuously extracted from the mantle to form crust by igneous processes, transferred from the continents to the hydrosphere via continental weathering, and returned to the mantle through subduction or delamination. These processes comprise a long-term Mg cycle, which contributes to

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http://dx.doi.org/10.1016/j.gca.2014.03.029
0016-7037/Published by Elsevier Ltd.

the compositional evolution of continental crust (Rudnick, 1995). Magnesium has three stable isotopes (^{24}Mg, ^{25}Mg, and ^{26}Mg), with the relative mass difference > 8% between ^{24}Mg and ^{26}Mg. Previous studies have found limited Mg isotope fractionations during high-temperature igneous process (Teng et al., 2007, 2010a; Handler et al., 2009; Yang et al., 2009; Bourdon et al., 2010; Huang et al., 2011; Pogge von Strandmann et al., 2011), but large during low-temperature processes, e.g., chemical weathering drives light Mg isotopes into the hydrosphere (e.g., Tipper et al., 2006a,b; Foster et al., 2010; Ling et al., 2011), leaving the weathered residues enriched in ^{26}Mg (Tipper et al., 2006a; Brenot et al., 2008; Pogge von Strandmann et al., 2008; Li et al., 2010; Teng et al., 2010b; Wimpenny et al., 2010; Huang et al., 2012, 2013b), and carbonate precipitation preferentially uptakes ^{24}Mg from the ambient aqueous solutions (e.g., Galy et al., 2002). Therefore, surface-processed materials may have Mg isotopic compositions significantly distinct from that of normal mantle (δ^{26}Mg = −0.25 ± 0.07‰; Teng et al., 2010a), making Mg isotopes a potential tracer for crustal recycling (e.g., Ke et al., 2011). For example, previous studies have found δ^{26}Mg values of certain mantle derivates are deviated significantly from the "normal" mantle value of −0.25 ± 0.07‰ (Teng et al., 2010a), and these Mg isotopic signatures were attributed to the incorporation of subducted materials in their mantle sources (Yang et al., 2012; Wang et al., 2012b; Xiao et al., 2013).

A primary assumption for the above geochemical hypotheses and interpretations is that Mg isotopic systematics of the subducting rocks suffer little change during metamorphic dehydration. However, to date, the extent to which Mg isotopes fractionate during this process remains largely unknown. Li et al. (2011) has found that bulk-rock δ^{26}Mg values of ten orogenic eclogites from Dabie orogen are relatively homogeneous (on average −0.32 ± 0.08‰), although there is large inter-mineral Mg isotope fractionation between coexisting garnet and clinopyroxene. Based on the assumption that the gabbroic protoliths of the eclogites have δ^{26}Mg values around "normal" mantle value of −0.25 ± 0.07‰, Li et al. (2011) concluded that eclogite-facies metamorphism produced limited Mg isotope fractionations. Despite all these, direct assessments on the behaviors of Mg isotopes during prograde metamorphism are still absent.

To address the above issue, a straightforward method is to compare the protoliths to their prograde metamorphic counterparts for Mg isotopic compositions. In this study, a set of genetically related meta-basaltic rocks including greenschists, amphibolites, and eclogites from South China Block and Dabie–Sulu orogen, East China, were analyzed for Mg isotopic ratios. The main purpose of this work is: (1) to assess the behaviors of Mg isotopes during continental subduction; and (2) to evaluate the origin and extent of Mg isotopic variations in metamorphic rocks.

2. GEOLOGICAL SETTINGS AND SAMPLES

2.1. Geological background

The Dabie–Sulu orogen was formed by continent–continent collision between the South China Block (SCB) and the North China Block (NCB) in the Triassic (Li et al., 1989, 1993, 2000; Hacker et al., 1998; Zheng et al., 2003), and was later separated into two terranes by the left-lateral movement of the Tan–Lu fault (Fig. 1a). The Dabie orogen to the west of the Tan–Lu fault is divided into five litho-tectonic unites (Fig. 1a; Li et al., 2001; Zheng et al., 2005). They are, from south to north, the Susong-Hongan blueschist-facies metamorphic zone (SH zone), the south Dabie ultra-high pressure (UHP)/low-temperature eclogite-facies zone (SD zone), the central Dabie UHP/middle-temperature eclogite-facies zone (CD zone), the north Dabie UHP/high-temperature eclogite-facies zone (ND zone), and the Beihuaiyang greenschist- to amphibolite-facies zone (BHY zone). To the southwest of Dabie orogen are the SCB rocks that were not involved into the Triassic continental subduction, as represented by the Wudang terrane (Fig. 1a).

The SH zone is composed of Proterozoic metamorphic volcano-sedimentary rocks, overprinted by Triassic blueschist-facies metamorphism (Li et al., 1993, 2001). The SD, CD and ND zones are mainly composed of UHP metamorphic rocks including eclogite, gneiss, marble and mafic–ultramafic rocks, and represent respectively independent crustal slices decoupled during continental subduction and exhumation (Li et al., 2003; Liu et al., 2007; Liu and Li, 2008; Wang et al., 2012a). Eclogites from SD and CD zones occur as fresh blocks or lenses within gneisses, marbles and ultramafic massifs. Coesite and/or diamond inclusions preserved in zircons and garnets from the eclogites support that these rocks were subducted to mantle depths of at least 90–120 km (Okay et al., 1989; Xu et al., 1992; Ye et al., 2000; Liu et al., 2001; Li et al., 2004). Previous studies show that the eclogites from the SD zone experienced peak metamorphism at temperature of ∼650 °C, whereas the eclogites from the CD zone recorded the peak metamorphic temperature of ∼750 °C (e.g., Xiao et al., 2000; Li et al., 2004). Eclogites from the ND zone are overprinted by high-temperature granulite-facies retrograde metamorphism and later Cretaceous migmatization (Wang et al., 2012a, 2013), leading to the intensive retrogression of eclogitic minerals. Geochemical, stable and radiogenic isotopic evidence indicates that the protoliths of eclogites and surrounding gneisses are Neoproterozoic bimodal volcanic suites in SCB with the formation ages of 750–800 Ma (e.g., Zheng et al., 2006; Liu and Liou, 2011).

The BHY zone is mainly composed of meta-sedimentary and meta-igneous rocks, and represents a passive-margin accretionary wedge formed during Triassic continental subduction (Fig. 1b; Li et al., 2001; Zheng et al., 2005). It is subdivided into two complexes: Fuziling and Luzhenguan complexes (Fig. 1c; Li et al., 2001; Zheng et al., 2005). The Fuziling complex is made of Paleozoic flysch sediments overprinted by greenschist-facies metamorphism, and the Luzhenguan complex is mainly composed of granitic gneisses, amphibolites, and graywackes that are overprinted by Triassic peak amphibolite-facies metamorphism (Li et al., 2001; Faure et al., 2003; Zheng et al., 2005). Previous geochronological studies have shown that amphibolites from Luzhenguan complex share the common feature of Neoproterozoic intrusive ages (∼750 Ma; Wu et al., 2004), which are comparable to the protolith ages of UHP metamorphic rocks from the