Validation of clinopyroxene-garnet magnesium isotope geothermometer to constrain the peak metamorphic temperature in ultrahigh-temperature ultramafic-mafic granulites

LONG-LONG GOU¹, MING-GUO ZHAI¹,²,*, CHENG-LI ZHANG¹, P.M. GEORGE¹, KANG-JUN HUANG¹, XIAO-FEI XU¹, JUN-SHENG LU¹, YAN ZHAO¹, WEN-HAO AO¹, YU-HUA HU¹, AND FENG ZHOU¹

¹State Key Laboratory of Continental Dynamics, Department of Geology, Northwest University, Xi’an 710069, China
²State Key Laboratory of Lithospheric Evolution, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China

ABSTRACT

Conventional Fe-Mg exchange geothermometers generally are not effective means to measure the peak metamorphic temperatures of granulites because of Fe-Mg diffusion during the re-equilibration during the exhumation and cooling. Therefore, it is essential to find alternative geothermometers. In this study, we investigated the magnitude of Mg isotope fractionation between the coexisting clinopyroxene and garnet in garnet pyroxenites and high-pressure mafic granulites from southern India. The clinopyroxene and garnet from the garnet pyroxenites have δ²⁶Mg values of −0.04 to −0.07‰, and −0.65 to −0.64‰, respectively, with Δ²⁶MgCpx-Grt = δ²⁶MgCpx − δ²⁶MgGrt = 0.62 and 0.57‰. The δ²⁶Mg values of the coexisting clinopyroxene and garnet in the high-pressure mafic granulites are 0.03 to 0.07‰ and −0.54 to −0.55‰, respectively, with Δ²⁶MgCpx-Grt = 0.57 and 0.62‰. The inter-mineral Mg isotope fractionations between the clinopyroxene and garnet of the garnet pyroxenites are similar to those of the high-pressure mafic granulites and more or less fall within the equilibrium fractionation lines at peak metamorphic temperatures. The measured peak temperatures for all four samples indicate equilibrium Mg isotope fractionations between the clinopyroxene and garnet. The clinopyroxene-garnet Mg isotope geothermometer of Li et al. (2016) yields temperatures of 994 ± 60 °C and 1048 ± 89 °C for the garnet pyroxenites, and 1048 ± 89 °C and 994 ± 65 °C for the high-pressure mafic granulites, which are slightly lower than those at both 10 and 12 kbar from the clinopyroxene-garnet Mg isotope thermometer of Huang et al. (2013). Compared with the peak metamorphic conditions from phase equilibrium modeling, the clinopyroxene-garnet Mg isotope thermometry yielded temperatures corresponding to the peak metamorphic conditions of the garnet pyroxenites and the high-pressure mafic granulites, whereas the conventional clinopyroxene-garnet Fe-Mg exchange thermometry yielded lower temperatures corresponding to the retrograde metamorphism. These results underscore the inter-mineral Fe-Mg exchange between clinopyroxene and garnet during the retrograde cooling of the ultrahigh temperature (>900 °C), which, however, did not disturb their Mg isotope fractionation equilibrium attained during the ultrahigh-temperature metamorphic condition. Therefore, we conclude that clinopyroxene-garnet Mg isotope thermometry, together with phase equilibrium modeling, is a valid tool to constrain the peak metamorphic temperature conditions even for ultramafic-mafic granulites that have undergone ultrahigh-temperature metamorphism.

Keywords: Clinopyroxene-garnet Mg isotope geothermometer, Mg isotope fractionation, garnet pyroxenites, high-pressure mafic granulites

INTRODUCTION

It is well known that granulites provide a window to understand the accretion and eventual stabilization of new crust and hence continental growth (Bohlen and Mezger 1989; Harley 1989; Sawyer et al. 2011; Cipar et al. 2020). However, conventional Fe-Mg exchange geothermometers generally underestimate the peak metamorphic temperatures of granulites (Frost and Chacko 1989; Harley 1989, 1998; Fitzsimons and Harley 1994; Pattison et al. 2003; Usuki et al. 2017), due to the fast Fe-Mg diffusion during retrograde cooling obliterated initial mineral compositions. Therefore, it is important to look for alternative geothermometers to estimate the peak metamorphic temperature, unaffected by the late re-equilibrium processes. Several attempts have been made in this regard in the past decade, and the Mg isotope geothermometer is a potential candidate, as described below. A large inter-mineral Mg isotope fractionation of Δ²⁶MgCpx-Grt = 1.14 ± 0.04‰ was found in a set of eclogites from Bixiling in the Dabie orogen, China (Li et al. 2011). The constant inter-mineral Mg isotope fractionation, together with homogeneous mineral chemistry and equilibrium oxygen isotopic partitioning between clinopyroxene and garnet, suggests an equilibrium Mg isotope fractionation (Li et al. 2011). Later analyses of coexisting clinopyroxene and garnet in cratonic eclogites (Wang et al. 2012, 2015) and orogenic eclogites (Wang et al. 2014a, 2014b; Li et al. 2016) also found large equilibrium inter-mineral Mg isotope fractionation. This large equilibrium Mg isotope fractionation is controlled by different coordination numbers of Mg in the structures of these two minerals, six in clino-

* E-mail: mgzhai@mail.iggcas.ac.cn