

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

**LONG-LONG GOU<sup>1</sup>, MING-GUO ZHAI<sup>1,2,\*</sup>, CHENG-LI ZHANG<sup>1</sup>, P.M. GEORGE<sup>1</sup>, KANG-JUN HUANG<sup>1</sup>,  
XIAO-FEI XU<sup>1</sup>, JUN-SHENG LU<sup>1</sup>, YAN ZHAO<sup>1</sup>, WEN-HAO AO<sup>1</sup>, YU-HUA HU<sup>1</sup>, AND FENG ZHOU<sup>1</sup>**

<sup>1</sup>State Key Laboratory of Continental Dynamics, Department of Geology, Northwest University, Xi'an 710069, China

<sup>2</sup>State 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  $\delta^{26}\text{Mg}$  values of  $-0.04$  to  $-0.07\text{‰}$ , and  $-0.65$  to  $-0.64\text{‰}$ , respectively, with  $\Delta^{26}\text{Mg}_{\text{Cpx-Grt}} = \delta^{26}\text{Mg}_{\text{Cpx}} - \delta^{26}\text{Mg}_{\text{Grt}} = 0.62$  and  $0.57\text{‰}$ . The  $\delta^{26}\text{Mg}$  values of the coexisting clinopyroxene and garnet in the high-pressure mafic granulites are  $0.03$  to  $0.07\text{‰}$  and  $-0.54$  to  $-0.55\text{‰}$ , respectively, with  $\Delta^{26}\text{Mg}_{\text{Cpx-Grt}} = 0.57$  and  $0.62\text{‰}$ . 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  $994 \pm 60$  °C and  $1048 \pm 89$  °C for the garnet pyroxenites, and  $1048 \pm 89$  °C and  $994 \pm 65$  °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