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Major element composiiton of the missing reservoir: Implication for the early Earth differentiation

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The Earth has been considered to form through the accumulation of the chondritic materials. In this assumption, the bulk silicate Earth (BSE), sum of the mantle and crust, should have chondritic abundance of lithophile elements. In terms of some lithophile elements, however, it has been revealed that present accessible silicate Earth (ASE) has different isotopic ratio or trace element composition from chondrites (^{142}Nd/^{144}Nd, Nb/Ta). Therefore there should exist an unfound reservoir that complements the compositional differences between ASE and chondrites, if we assume the chondritic BSE. This unfound reservoir is called "missing reservoir" . In ^{142}Nd/^{144}Nd, the ASE has significantly larger value than the chondrites (Boyet & Carlson, 2005). Sm is less incompatible than Nd, and the parent nuclide ^{146}Sm is an extinct radionuclide (half life = 68 Myr). Therefore the ^{142}Nd/^{144}Nd difference between ASE and chondrites suggests that the low ^{146}Sm/^{144}Nd melt formed in the early era of the Earth's history and then it has isolated from the mantle convection. Numerous scenarios about the formation and fate of the ^{142}Nd/^{144}Nd missing reservoir have been proposed by previous studies (Boyet & Carlson, 2005; Lee et al., 2007; Labrosse et al., 2007; Korenaga et al., 2009; Nebel et al., 2010). In these scenarios, it is crucial whether the missing reservoir sunk or rose in the mantle. However, the density of the missing reservoir has been poorly constrained, and this is one of the reasons why there has been no conclusive scenario. The density depends on the major element composition. Therefore we estimated the major element composition of the missing reservoir and calculate its density in order to propose a more plausible scenario about the formation and fate of the missing reservoir.

In Kondo & Kogiso (2014), we estimated the formation age and the melt fraction of the missing reservoir, which satisfies the Sm/Nd difference between the ASE and chondrites obtained from the ^{142}Nd/^{144}Nd difference. The formation age was estimated to be less than 33.5 Myr after the solar system formation, and the melt fraction was estimated to be quite small at an upper mantle pressure (1GPa: $<$2.8%, 3 GPa: $<$2.5%, 7 GPa: $<$1.0%). In this study, we determined the major element composition of the melt formed at the small melt fraction (solidus melt), using melting experiments of primitive pridotite. In the early Earth, the mantle probably hotter than in present, therefore we must know the solidus melt composition at high temperature and high pressure. However, there is no previous experiment that determined the solidus melt composition at more than 3 GPa, so we performed the Modified Iterative Sandwich Experiment (MISE) (Hirschmann & Dasgupta, 2007) and determined the solidus melt composition at 7 GPa. As a result, the solidus melt composition was revealed to be Fe-rich komatiite. Then, we calculated the density of the solidus melt at 7 GPa with the method from Matsukege et al. (2005). The density of the solidus melt is smaller than the density of the primitive peridotite, therefore the 7 GPa solidus melt ascends in the mantle. From these results, we concluded that the missing reservoir formed as the solidus melt at high pressure and high temperature and ascended in the mantle. The formation age of the missing reservoir is earlier than the age of the last giant impact estimated by previous studies. The giant impact is considered to melt the whole mantle region, therefore if the missing reservoir had been isolated in the mantle, it probably also melted and was re-mixed with surrounding mantle at the giant impact. Therefore the more plausible scenario is that in the early Earth the solidus melt at high pressure and high temperature ascended in the mantle to form the komatiitic crust, and then spattered into the space at a giant impact. Thus, the komatiitic crust was lost from the Earth, and ASE came to have non-chondritic composition.

Keywords: missing reservoir, 144Nd/144Nd, Hadean, solidus melt, melting experiment