Partitioning of Ni and Co between liquid metal and lower mantle minerals: Implication for a core formation of the Earth

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1.Introduction

The formation of the Earth's core is one of the most important events of in Earth history. Recently, a core formation model with a deep magma ocean, extended to the lower mantle depth, was proposed by several authors [Ohtani et al., 1997; Righter et al., 1997; Li and Agee, 2001]. Liquid metal separated in the magma ocean, and then ponded at its bottom, where the liquid metal coexisted with lower mantle minerals, and subsequently sank through the solid lower mantle to form the core. We can obtain evidence for the core formation from mantle abundance of Ni and Co, which resulted from a distribution of these elements between liquid metal and mantle during the core formation process [McDonough and Sun, 1995]. Partitioning experiments between liquid metal and magma at elevated temperatures and pressures were performed in order to account for the mantle abundance. It was found that the partitioning is affected by pressure, temperature, oxygen fugacity (fO2) and compositions [e.g., Ohtani et al., 1997; Righter et al., 1997; Li and Agee, 2001]. There are a few studies on partitioning between liquid metal and Mg-perovskite, which is the most dominant mineral at the lower mantle [Ohtani et al., 1997; Ito et al. 1998; Tschauner et al., 1999]. However, there are no reported experiments on the effects of oxygen fugacity and temperature on the partitioning, which is essential in order to understand distribution of these elements throughout the mantle at a plausible oxygen fugacity and temperature in the core formation process. Here we report the effects of the oxygen fugacity and temperature on partitioning of Ni and Co between liquid metal and lower mantle minerals, Mg-perovskite and magnesiowüstite, at 26-27 GPa and up to 3100 K.

2. Experimental method

Experiments were performed with a Kawai-type multi-anvil apparatus at Tohoku University. In order to produce different fO2 conditions of samples, three orthopyroxene powders and two sets of metallic mixture were used as starting materials. A set of the pyroxene and the metallic power was packed into an MgO capsule. A sample was heated by a cylindrical Re heater with a LaCrO3 thermal insulator. Temperature at the sample was monitored by a W97Re3-W75Re25 thermocouple, whose junction was in contact with the outside and midpoint of the heater. Recovered samples were analyzed with an EPMA with the wave length dispersive mode (JEOL JXA-8800).

3. Result and discussion

The experiments have been done at 26 and 27 GPa and 2700, 2900 and 3100 K. A logfO2 relative to iron-wüstite buffer was varied from -1.15 to -1.84. A partitioning coefficient is determined as ratio of weight fractions of Fe, Ni and Co in liquid metal and lower mantle minerals. Partitioning coefficients of Ni, Co and Fe between liquid metal and Mg-perovskite are from 81 to 161, from 41 to 94 and from 10.8 to 35.6, respectively. And those of Ni, Co and Fe between liquid metal and magnesiowüstite are from 11.3 to 23.2, from 8.1 to 16.2 and from 3.1 to 6.4, respectively. All partition coefficients decrease significantly with increasing fO2 and do not change with increasing temperature.

In a magma ocean stage, the mantle was partially molten and liquid metal must have coexisted with the lower mantle minerals at a bottom of a partially molten layer. Partitioning of Ni and Co between liquid metal and lower mantle minerals at the bottom of the partially molten layer also plays an important role for determination of their abundance in the primitive mantle. It is likely that the depth of the magma ocean was deeper than that proposed by previous authors, taking the fO2 dependency in this study and pressure dependency of the partition coefficients between metal and the lower mantle minerals reported by Tschauner et al. [1999] and Gessmann et al. [2000] into account.