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Partitioning of Fe, Ni and Co and Si behavior between liquid metal and lower mantle minerals

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Partitioning of Fe, Ni and Co between liquid metal and lower mantle minerals has been investigated at 27 GPa and 2773-3373 K in order to estimate the depth of magma ocean, which covered the surface of the glowing earth. It implies that magma ocean was deeper than 27 GPa and temperature of its base was higher than 3373 K because mantle abundance calculated from experimental results is lower than that of the earth. We found that Mg-perovskite reacted with metallic iron to form (Mg,Fe)O and Fe-Si metallic liquid.

1. Introduction

Recently core formation model with deep magma ocean is widely accepted. During accretion surface of proto-earth must have been molten with energy generated by collisions. Metallic component was also molten and segregated from magma. The liquid metal sank through the magma ocean and ponded its base. Then it sank through proto-mantle toward center of the earth. The liquid metal must have reacted with magma and minerals of the proto-mantle. Most of Fe, Ni and Co was distributed in liquid metal and silicate was depleted in these elements. Therefore mantle is about tenth less abundant in Fe, Ni and Co than CI chondrites when these abundances are normalized by Mg. Partitioning between liquid metal and silicate has been investigated at high-pressure to account for this depletion and estimate a depth of magma ocean and temperature at its base. Previous study has mainly investigated the effect of temperature, pressure and oxygen fugacity on partitioning between liquid metal and liquid silicate. This study has investigated effect of temperature, pressure and oxygen fugacity on partitioning between liquid metal and lower mantle minerals. The effect of Al_2O_3 content in Mg-perovskite on partitioning was also investigated.

Earth's core is supposed to have a small amount of light elements. These light elements must have desolved into liquid metal during core formation described above. Mantle is depleted in Si and it is one of candidates for light element in the core. Therefore it has been investigated whether Si can desolve into the liquid metal or not at the condition where liquid metal contacted with the lower mantle minerals.

2. Experimental method

Experiments have been performed with Kawai-type high pressure apparatus at Tohoku University. We used WC second anvil whose truncated edge length is 2.0 mm.

After sample is pressurized, it is kept at high temperature for 30 minutes to 2 hours and quenched. Next it is decompressed and recovered. Finally it is mounted with epoxy and analyzed with EPMA with wave dispersive mode.

3. Result and discussion

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 85 to 161, from 38 to 83 and from 8.6 to 35.6, respectively. And those of Ni, Co and Fe between liquid metal and (Mg,Fe)O are form 11.3 to 28.9, from 7.5 to 22.9 and from 2.9 to 10.0, respectively. Partitioning coefficients decrease with increasing oxygen fugacity and temperature. Those between liquid metal and (Mg,Fe)O decrease with increasing pressure. Those between liquid metal and Mg-perovskite decrease with increasing content of Al_2O_3 in Mg-perovskite and the effect increases with decreasing oxygen fugacity. As a result it is supposed that magma ocean was deeper than 810 km and temperature at its base was higher than 3373 K because mantle abundances of Fe, Ni and Co calculated from experimental results are lower than that of the earth.

It is observed that Mg-perovskite reacted to form (Mg,Fe)O and liquid Fe-Si alloy at 27 GPa and 2773-3373 K. This implies that liquid metal containing some amount of Si was able to sink through proto-mantle. It is needed to investigate effect of pressure on this reaction in order to discuss whether this reaction occurred or not during sinking of the liquid metal through the deep proto-mantle.