Evolution of D/H ratios on rocky proto-planets growing in the solar nebula

*Hiroaki Saito[1], Kiyoshi Kuramoto[2]

1. School of Systems Engineering, Kochi University of Technology, 2. Department of Cosmosciences, Graduate School of Sciences, Hokkaido University

The D/H ratio of Martian mantle estimated from the analysis of Martian meteorites (Usui et al., 2012) is close to that of carbonaceous chondrite ($1.3–1.7\times10^{-4}$, Robert, 2003), which implies the chondritic origin of water in the interior of Mars. On the other hand, the precise Hf-W chronology suggests that Mars reached about half of its present mass within the 1.8 ±1.0 Myr or less after the formation of CAI with core-mantle differentiation (Dauphas and Pourmand, 2011). Since this timescale is much shorter than the estimated lifetime of the solar nebula, the accretion of Mars mostly proceeded within the solar nebula. The D/H ratio of the solar nebula is estimated to be as low as 2.1×10^{-5} (e.g., Geiss & Gloeckler, 1998), which is 10 times lower than the typical value of carbonaceous chondrite. Besides, the energy released by planetesimal collisions becomes large enough to induce degassing of the volatile compounds such as H_2O when the proto-planet exceeds the lunar size (0.1 M_M). Therefore, growing proto-planets may have a proto-atmosphere that consists of nebula gas and degassed gas.

We analyze the thermal structure of a hybrid-type proto-atmosphere where the solar nebula component dominates the upper layer, and the degassed component dominates the lower layer, by developing a 1D radiative-equilibrium model (Saito & Kuramoto, 2018). As a result, we found that when the volatile fraction in the planetary building blocks is lower than about 1 wt%, the solar nebula component layer and the degassed component layer would be mixed due to the opaque and convective solar nebula layer. This tendency becomes strong when the planetary mass is large.

Our preliminary analysis suggests that the mean D/H ratio of planetary atmosphere would become close to that of the solar nebula due to the convective mixing on a rocky proto planet larger than Mars. In addition, the surface temperature would increase up to the melting temperature of the rock. Hence, the D/H ratio of the interior of such a proto-planet would get close to that of the solar nebula. This result may account for the low D/H ratio of the Earth's volcanic rock likely originated from deep mantle (Hallis et al., 2015).

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