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Thermal evolution and core formation of planetesimals

Taichi Suwa (1) and Hiroko Nagahara (2)

(1) The University of Tokyo, Department of Earth and Planetary Science, Tokyo, Japan (suwa@eps.s.u-tokyo.ac.jp), (2) The University of Tokyo, Department of Earth and Planetary Science, Tokyo, Japan (hiroko@eps.s.u-tokyo.ac.jp)

Planetesimals did not get an adequate thermal energy by accretion to form large scale magma ocean because of smaller radii, masses, gravity and accretion energy, however, there are various evidences for the presence of core in planetesimals: 4-Vesta has a core and non-magmatic iron meteorites were segregated metal in bodies that did not experience silicate melting. It has been pointed out that accretion time of planetesimals controls melting and differentiation, because short lived nuclides are plausible heat source. Other factors such as radiative cooling from the surface and thermal conductivity, would also affect thermal evolution of planetesimals. Furthermore, percolation of Fe-S melt through silicate matrix is controlled by the porosity and grain size of silicates and dihedral angle between the melt and silicates. Therefore, the interior structure of planetesimals should be considered by taking the accretion, growth, and thermal evolution of the interior simultaneously.

We make a numerical simulation with a spherical 1D model on the basis of the model by Neuman, which is a non-stationary heat conduction equation. We specifically pay attention to the process at temperatures between eutectic temperature Fe-FeS (1213K) and silicate solidus (1425K) and the surface tension of the melt that governs percolation. The model contains three free parameters, formation time, accretion duration, and final size of the planetesimals.

The results show that the interior structure can be divided to four types: Type A is undifferentiated, Type B is differentiated to core and mantle of which core was formed by Fe-S melt percolation, Type C is partially differentiated to FeS core and mantle, where mantle retains residual Fe metal, and Type D is differentiated to core and mantle by metal separation in silicate magma. Type A would correspond to the parent bodies of chondrites, and Type B (and Type C?) core would be the source of non-magmatic iron meteorites. Type D would be parent bodies for 4 Vesta and angrites.

The conditions for the four types of planetesimals are throuly investigated as a function of the three parameters, accretion time, accreting duration, and palnetesimal size. We found that the planetesimal interior is strongly controlled by the formation time: planetesimals formed after 3 Ma after CAIs would be undifferentiated (Type A) regardless of the planetary size, whereas most of them formed within 1 Ma are Type D (differentiated bodies with magmatically formed core). Types B and C bodies are preferentially formed between 1 and 3 Ma after CAIs. Longer accretion duration tends to be resulted in formation of Types A, B and C.

The present work predicts the planetesimal interior structure if we know the formation age with the isotopic measurements of samples and the size of the body, which would be a very powerful tool for future explorations of small bodies except for very small ($< \sim 20$ km) bodies.