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Internal structure and thermal evolution of Mercury with highly reduced composition

Akifumi Nakayama[1*], Kiyoshi Kuramoto[2]

[1]Department of Earth Sciences, School of Science, Hokkaido University, [2]Department of Cosmosciences, Graduate School of Sciences, Hokkaido University

According to topography, surface composition and gravity data obtained by MESSENGER, a new internal structure model of Mercury have been proposed (Smith et al., 2012). The core radius and solid mantle density have been estimated on the basis of the moment of inertia are 2030 +/- 37 km and 3650 +/- 225 kg m^{-3}, respectively. To explain the high mantle density, the presence of FeS layer at the bottom of mantle is suggested. The observed surface composition (Nittler et al., 2011) is poor in FeO. This suggests Mercury formed from highly reduced precursors like enstatite (E) chondrite (Wasson, 1998). Because these results are very different from the previous model, it is necessary to reestimate the precursors and thermal evolution of Mercury.

E chondrite contains significant amount of S in metal components. If such a significant amount of light element is also contained in the Mercurian core, silicate mantle layer should be very thin in order to explain the higher average density of Mercury. In previous thermal evolution models assumed the relatively thick silicate mantle (e.g. Stevenson et al., 1983), the fluid core is not thermally convective today, because heat transport through the mantle sufficiently decreases. If this is the case, no FeS is solidified in the core. However if Mercury has a thin mantle, the heat transport efficiency through the mantle does not decrease so much and the core could be cooled to allow FeS solidification. In this study we calculate the thermal evolution of Mercury with supposing new internal structure and discuss thermal state of the core and thermal history of Mercury.

Assuming spherical symmetry, the heat balance calculation of silicate mantle and core performed in accordance with the mixing length theory (Abe, 1997) and box model (Stevenson et al., 1983), respectively. The silicate and metal components have chemical compositions similar to those of E chondrite, respectively. The thickness of silicate mantle and the core density are 170-340 km and 6000-6981 kg m^{-3}, respectively, which agree with the core radius and solid mantle density estimated by Smith et al. (2012). In this calculation we varied the mantle thickness while adjusted the concentration of sulfur in the core, so as to keep the mean density of Mercury. The viscosity of a silicate mantle assuming enstatite composition is about 1000 times that of the Earth's upper mantle, hence the heat transport efficiency by convection is weaker than previous models. We give the solidus temperature of enstatite for the initial temperature of mantle, and the adiabatic temperature distribution continuous with the temperature of the core-mantle boundary (CMB) for the initial temperature of the core. Initial temperature of the core is higher than the melting curve of Fe-S alloy, so the core is entirely molten.

In all the models of different mantle thickness, heat transport by convection is weakened rapidly and dominant heat transport mechanism is switched to thermal conduction during the first 1 billion year. Heat is still efficiently transported by thermal conduction, because the silicate mantle is thinner than previous models. When the silicate mantle is thinner than 270 km, the temperature of the CMB drops below the eutectic point of Fe-FeS binary within 4.5 billion years. This explains the formation of solid FeS layer. In addition, the heat flow across CMB after 4.5 billion years exceeds the value achieved by the thermal conduction in the core with adiabatic temperature profile. This suggests that it is possible to drive the liquid outer core dynamo by the thermal convection even today.

Keywords: Mercury, thermal evolution