EFFECTS OF MAGMA-GENERATION AND TRANSPORT OF HEAT AND HEAT PRODUCING ELEMENTS BY MIGRATING MAGMA ON THE THERMAL HISTORY OF THE MOON. Kenyo U1, Masaki Ogawa*, Hiroki Hasumi*, "Department of Earth Sciences and Astronomy, University of Tokyo at Komaba, Meguro, Tokyo 153–8902, Japan, Correspondence: u-kenyo0822@g.ecc.u-tokyo.ac.jp, *Only U is family name for first author.

Introduction & model description: Previous geological and geophysical observations of the Moon indicate its radial expansion in its early history (e.g., [1]) and radial contraction in the later history (e.g., [2]). The best fit models that explain this history commonly start from a low initial temperature in the deep mantle (e.g., [3]). However, this cold origin model is at odds with the giant-impact hypothesis (e.g., [4]). To resolve this difficulty, we numerically studied the thermal history of the spherically symmetrical mantle of the Moon, taking account of thermal diffusion, magma-generation, and the transport of heat and heat-producing elements (HPEs) by migration of the generated magma.

Migration of magma is calculated in the energy equation as a transport of the latent heat of melting by melt [5] as,

$$\frac{\partial (\rho_0 h)}{\partial t} = -\nabla \cdot [\rho_0 \phi h (1 + G) \mathbf{u} - \kappa_{edd} \nabla (\rho_0 h)]$$

$$- \frac{\Delta V}{V_0} \rho_0 g \phi u + \nabla \cdot (k \nabla T) + \rho_0 H.$$  

The first and second terms on the right-hand side are the contribution of advection; the third term that of diffusion; the fourth term that of internal heating. To take account of the blanket effect of the lunar crust and regolith layer [6], the thermal conductivity $k$ in the crust is about half that of the mantle. $\kappa_{edd}$ is the eddy diffusivity in largely molten regions ($\kappa_{edd} = 10 \ell cm$ at $\phi < 0.4$, where $\kappa$ is the thermal diffusivity). Enthalpy $h$ is written as

$$h = C_p T + \phi h (1 + G),$$

and $h_1 = h (\phi = 1)$. Here, $C_p$ is the specific heat; $\phi$ the melt-content (0–1); $\Delta h$ the latent heat of melting; $G$ a function of the pressure as

$$G = \frac{1}{\rho_0 \Delta h} \int_{P}^{P} \frac{\Delta V}{V_0} dP,$$

where $P$ is the lithostatic pressure, and $\Delta V/V_0$ is the normalized difference in molar volume between the melt and solid phases.

The equation for HPE-transport is

$$\frac{\partial H}{\partial t} = -\nabla \cdot [H \phi \mathbf{u} / \phi + D / (1 - D)] - \kappa_{edd} \nabla H],$$

where $D$ is the partition coefficient of HPEs between melt and solid, and $\mathbf{u}$ is the velocity of magma [7]. We also took account of decay of HPEs.

The initial conditions: The initial temperature in the deep mantle is high enough to make the temperature in the shallow mantle equal to the solidus temperature [4]. The temperature is fixed at 270K on the surface boundary, while the core is modeled as a heat bath of uniform temperature. The initial temperature on the CMB is about 1900 K (see the green line in Figure 1). We also assume that the mantle is depleted in HPEs relative to the crust by a factor of 8, as suggested from studies of the Th concentration in the putative primary magmas of mare basalts [8].

Results: Figure 1, 2 shows an example of the thermal history and the evolution of $\phi$-distribution we calculated. The temperature first increases and then remains equal to the solidus for billions of years due to the contribution from the latent heat of melting, and then decreases due to decay of HPEs (Fig. 1). The melt-content increases at first and then gradually decreases; magma migrates upward and accumulates at the top of the partially molten region (Fig. 2). The globally averaged temperature first decreases due to conductive cooling at the base of the mantle, then increases due to internal heating, and after that, gradually decreases owing to the cooling from the surface boundary (Fig. 3). The radius first increases mostly by melting and then decreases due to cooling (Fig. 4).

Discussions: The calculated temperature distribution at 4.4 Gyr (see the black line in Figure 1) is consistent with the thermal structure inferred in the literature (e.g., [9]). The calculated history of radial change (Fig. 4) is consistent with that inferred from observations of the lunar gravity field [1] and lobate scarps [2]. Realistic modeling of generation and migration of magma as well as HPE-transport by migrating magma are crucial for understanding the thermal history of the Moon.

Figure 1 The thermal history of the lunar mantle; the initial temperature in the deep mantle is 1650 K.

Figure 2 Melt-content evolution in the lunar mantle for the case shown in Fig. 1.

Figure 3 The average temperature plotted against time.

Figure 4 Radial change of the Moon dR plotted against time (the purple line). Also shown are the contributions from thermal expansion (the green line) and that from melting/solidification (the blue line).