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Concentrations of radioactive elements in the lunar crust constrained from relaxation of impact basins

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Concentrations of long-lived radioactive elements (Th, K, and U) are among the most important heat sources for the long-term thermal evolution of the Moon. These elements also tend to be concentrated in melt because these elements are incompatible elements. Thus, their distribution may reflect the solidification process of the lunar magma ocean (LMO). In order to understand such an early, pre-mare thermal evolution of the Moon, a detailed study of the lunar farside is necessary.

The lunar farside is geologically classified into the Farside Highland Terrane (FHT) and the South Pole-Aitken Terrane (SPAT), and the FHT is depleted in radioactive elements compared to the SPAT [e.g., 1]. Lunar topography and gravity field data indicate that crustal thickness at the FHT is ~70 km while that at the SPAT is ~30 km [2]. Based on these results, hypotheses have been proposed for spatial variation in concentrations of radioactive elements. One is that their concentrations in the FHT crust are much smaller than the SPAT crust. The other is that the SPAT crust is similar to lower part of the FHT crust [3]. Since the column density of radioactive elements are significantly different between two hypotheses, constraining concentrations of radioactive elements deep in the FHT crust is necessary to understand the lunar farside thermal history.

Rheology of the lunar crust and mantle strongly depends on temperature. Thus, long-term viscous relaxation of lunar major impact basins would reflect the upper part of the early Moon [4]. A Japanese lunar explorer KAGUYA revealed that no significant isostatic compensation occurred for many farside impact basins [5]. This result indicates that, at the timing of basin formation, the lunar Moho had been cold [5]. In this study, we constrain concentrations of radioactive elements, which are consistent with topography and gravity field data obtained by KAGUYA from thermal evolution calculation and viscoelastic deformation calculation.

We calculate thermal evolution and viscoelastic deformation independently. For the former calculation, we solve the thermal conduction equation, using the solidus of peridotite for the initial condition at 4.5 Ga. Here we only consider radiogenic heat for heat production. For the latter calculation, we use a time-integration scheme we developed recently in order to use time-dependent temperature profile calculated in thermal evolution calculation [6]. Parameters are concentrations of radioactive elements in the crust, crustal thickness, harmonic degree, and basin formation age. For each parameter setup, we calculate the time evolutions of surface and Moho topographies induced by a surface load and by a Moho load.

We compare our calculation results with KAGUYA topography data and a latest crustal thickness model [2], and estimate initial surface and Moho topographies of farside basins. We estimated the upper limit of the initial surface heat flux based on the requirement that crustal thickness should be non-negative. We found that the initial heat flux < 33 mW/m^2 is required for Freundlich-Sharonov (Crustal thickness ~67 km). The absolute age of Nectaris, which is fresher than Freundlich-Sharonov, is estimated to be 4.14-3.84 Ga. We found that Th < 0.5 ppm is necessary to satisfy the heat flux constrained from the non-negative crustal thickness requirement for formation age older than 3.84 Ga. This upper limit is much smaller than Th on the SPAT. Thus, the SPAT crust may be significantly different from the lower part of the FHT crust, suggesting regional variation in solidification processes of the LMO.

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