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The thermal evolution of the lunar farside inferred from viscoelastic deformation of impact basins

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The viscoelastic evolution of large-scale topography strongly depends on the thermal history of a planet since the dynamic viscosity of silicate is mainly controlled by temperature. Thus, the viscoelastic state of lunar farside basins may retain the record of the ancient thermal history of the Moon. In order to extract such record, we developed a new viscoelastic numerical calculation code and compare its results and Kaguya data in this study.

The selenodetic analysis of farside lunar basins is important from two points of view. First, most of them are not covered with thick mare basalt lava flows unlike the nearside counter part. This makes selenodetic analysis much easier on the farside than the nearside. Second, because the farside of the Moon is known to be very different from the nearside in many aspects (i.e., lunar dichotomy), the thermal history of the lunar farside may also be very different from the nearside. However, because the lunar farside gravity field, which is necessary to estimate the viscoelastic state of the lunar farside, was not directly measured until recently, no detailed analysis of the thermal history of the lunar farside has been conducted. The relay satellite observation by Kaguya mission resolved this problem [1]. Nevertheless, we still cannot conduct selenodetic analyses of the farside of the Moon readily, because conventional numerical approaches have a problem in applying to the long thermal history of the Moon. More specifically, heat flux, which is proportional to thermal gradient and is one of the most important parameter to constrain the thermal history, has not been explicitly incorporated into viscoelastic models since continuously stratified viscosity profiles require extremely long calculation time with conventional approaches. In addition, conventional viscoelastic calculation schemes have a couple of problems in handling temporal variation in viscosity. We proposed a new formulation of the constitutive equation of a Maxwell viscoelastic body to resolve these problems [2]. Compared with conventional time-domain schemes involving first-order approximation in time, our second-order-approximation scheme for the constitutive equation shows improved accuracy and stability for long time steps. Consequently, the cost of time-consuming calculations, such as a simulation of planetary thermal history would greatly reduced.

Using this code, we investigate the dependences of (1) basin size, (2) heat flux, and (3) crustal thickness on basin relaxation in a Maxwell viscoelastic model. Specifically, the degrees and the timescales of two major modification stages for basin (i.e., isostatic compensation and crustal lateral flow) are quantitatively examined. According to the results, the heat flux < 10 mW/m^{2}is required to prevent Moho deformation for a basin > 500 km diameter. Based on the SGM100h gravity model and the STM-359_grid03 topography model, this is the case for basins dated later than pre-Nectarian (PN) 6 and located outside of South Pole-Aitken (SP-A), such as Lorentz and Hertzsprung. In contrast, the positive uplift in Bouguer anomaly for Coulomb-Sarton (PN5, outside of SP-A) requires the heat flux > 50 mW/m^2. Consequently, for outside of SP-A, the lunar farside heat flux is significantly decreased at PN5. This result indicates that the cooling of the farside is much earlier than that of the nearside suggested by previous studies [e.g., 3]. Moreover, Schrodinger, the newest basin considered in this study and located inside of SP-A, shows mantle uplift, indicating the heat flux about 30 mW/m^2at the formation age of Schrodinger. Due to a large amount of impact heat produced by such a gigantic impact, the inside of SP-A may have been kept significantly warmer than outside for a long time.

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