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On low-velocity zone at the bottom of the lunar mantle

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Introduction: The knowledge of internal structure of the Moon is a key to understand the origin and the evolution of our nearest celestial body. Some analyses of the Apollo seismic data have indicated the existence of low-velocity zone (LVZ) at the bottom of the lunar mantle, e.g., [1], [2], but some models do not include the LVZ, e.g., [3]. The recent Gravity Recovery and Interior Laboratory (GRAIL) mission has provided a degree-2 potential Love number k_2 accurate to 1% [4], [5]. This level of k_2 accuracy has a potential to better characterize the lunar deep interior [6]. One of the recent studies which used the GRAIL-derived k_2 indicates the existence of the LVZ [7].

Data and inversion: In order to infer the deep structure of the Moon, we employed four selenodetically observed data of mean radius (R), mass (M), normalized mean solid moment of inertia (I_s/MR^2), and the GRAIL-derived k_2 which are recently summarized by [8], together with the seismic travel time data which are selected by [9], i.e., 318 data (183 P-wave and 135 S-wave) from 59 sources (24 deep quakes, 8 shallow quakes, 19 meteoroid impacts, and 8 artificial impacts). The Love number k_2 is corrected for the anelastic contributions following [7]. We used Markov chain Monte Carlo (MCMC) algorithm to infer the parameters of the lunar internal structure. The solutions of the parameters and their uncertainties are obtained from the posterior distribution which is sampled by the MCMC algorithm.

Results: The inferred mean crustal and mantle structures are basically consistent with previous studies (e.g., [2], [3], [10]). Our model, however, has larger lower-mantle density. P and S wave velocities in the LVZ are estimated to be 6.9 +0.9/-0.5 km/s and 2.6 $\pm$ 1.4 km/s, respectively. A two-dimensional posterior probability function clearly shows a negative correlation between the outer core size and the LVZ thickness; a smaller outer core should be accompanied by a thick LVZ and vice versa. The outer core radius is estimated to be 310 +90/-200 km. The thickness of the LVZ is inferred as 220 $\pm$ 170 km, so provided that the anelastic correction is appropriate, the LVZ is required from the observations. The plausible inference from the existence of the LVZ is that the LVZ is partially molten where viscosity is also low and most of the tidal dissipation occurs [11, 7]. Although the uncertainty is large, the estimated LVZ density at the pressure near the core mantle boundary ($\sim$4.5 GPa) indicates that this zone is typically high-Ti basalt which might have originated black glass with TiO2 content $\sim$16 wt% [12]. The deep Ti-rich composition is consistent with a lunar evolution model involving lunar mantle overturn in which ilmenite-bearing cumulate layer sank with trapped incompatible heat-producing elements [13]. The above discussions support the idea that both tidal heating and radiogenic heating have maintained the partially molten region up until the present.

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