LOW-VELOCITY AND LOW-VISCOSITY ZONE AT THE LOWERMOST MANTLE OF THE MOON.
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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. A large amount of seismic information was brought by the near-side network consisting of four seismometers of Apollo 12, 14, 15, and 16. The Apollo seismic data have contributed to internal structure modeling, but the structure below the deepest moonquake about 1,200 km depth was uncertain.

The Moon is also observed by selenodetic techniques such as Lunar Laser Ranging (LLR), satellite gravimetry, and satellite altimetry. Lunar properties obtained from these observations include the mass, mean radius, moments of inertia (MOI), frequency-dependent quality factor, and tidal Love numbers.

Here we report on the progress of investigation of lunar deep interior which focuses on the connection between viscoelastic property and tidal response of the Moon by complementing the Apollo seismic analysis with recent selenodetic observations.

Forward analysis: In the forward approach of [1], the quantitative effect of the low-viscosity zone located at the lowermost mantle on the frequency-dependent dissipation was investigated. By using the model of [2] as a reference, the quality factor and the complex Love number of the Moon with respect to the monthly and annual periods are calculated by changing the outer radius and viscosity of the lowermost mantle layer. After that, the viscosity of this specific zone was determined by comparing the model value with pre-GRAIL (Gravity Recovery and Interior Laboratory) observations. It was found that the existence of the low-viscosity layer leads to a value of the quality factor which is consistent with the LLR results [3].

With the viscosity of 2×10^{16} Pa s and outer radius of 500 km, the model value satisfies the observed quality factor for both monthly and annual periods at the same time. The resulting viscosity value is extremely low considering that of the bottom part of the lunar mantle estimated by previous studies [4, 5]. The Love number corresponding to the viscosity value restricted by the quality factor is also consistent with SELENE and Chnag'e-1 gravity results [6, 7]. Such an existence of an ultralow-viscosity layer in the lowermost part of the lunar mantle indicates that strong tidal dissipation is induced there.

Inverse analysis: Following the result of [1], explored by a Bayesian inversion approach were lunar internal structure models [8] which are consistent with both the seismic [9] and the recent selenodetic data. These models also include the low-velocity/viscosity zone (LVZ) at the base of the mantle. The selenodetic constraints includes the recent estimate of k_2 from GRAIL [10] which is accurate to 1% as well as updated estimates of the quality factors from LLR [11]. The seismic data mainly constrain the structure down to about 1200 km depth, while the selenodetic data have contributed to constraining the remaining deeper parts.

The inversion result shows that the thickness of the LVZ has a negative correlation with the radius of the fluid outer core and needs to be larger than 170 km to fit the observational data. The S-wave velocity and viscosity in the LVZ are estimated to be about 3×10^{16} Pa s and 2.9 ± 0.5 km/s, respectively. The viscosity value strengthens the deep-seated dissipative property observed as a severe attenuation of seismic waves. The density of the LVZ is estimated to be larger than 3450 kg/m^3. If we assume that the TiO_2 content in the bulk silicate moon is 0.4 wt.% [12] and that the LVZ contains all the TiO_2, its content in the LVZ is larger than 11 wt.%, which supports a mantle overturn scenario.

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