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Frequency-dependence of the tidal dissipation on the Moon: Effect of the low-viscosity zone at the lowermost mantle

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In the present study, in order to estimate the effect of the low-viscosity zone at the lowermost mantle exerted on the frequency-dependence of the tidal dissipation on the Moon quantitatively, model calculation of the viscoelastic tidal deformation was performed with respect to the monthly and annual periods. Here the seismologically-derived internal structure is given concerning the density and elasticity structure. Concerning the viscosity structure, on the other hand, although not only the existence of the low-viscosity layer but also those of the lithosphere and asthenosphere is taken into consideration, only the viscosity value of the low-viscosity layer is adjusted while those of the remaining two layers are regarded as uniform and constant. Moreover, the mechanical constitutive relation in this calculation follows the rheological law of Maxwell body. And finally, the interior structure, particularly the viscosity of this specific zone is determined by comparing the present numerical result with the preexisting observational result.

As a result of the present calculation, the additional influence of the low-viscosity layer successfully provides the viscosity structure which has no inconsistency with the geodetic observables on the tidal dissipation. More specifically, its viscosity satisfies the quality factor derived from the lunar laser ranging for both monthly and annual periods. This viscosity value is extremely low, which Maxwell relaxation time is close to the tidal periods. Also, the theoretical range of the complex tidal Love number corresponding to this viscosity structure restricted through the quality factor almost corresponds at the same time to the observational range based on the precision orbit determination of the historical lunar orbiters.

This result reveals that, as far as the low-viscosity layer is assumed to exist, even such simple linear rheology can easily interpret the frequency-dependence of the lunar tidal dissipation. One of the former attempts suggested that the observed frequency-dependence on the tidal dissipation is not necessarily interpretable even if following, instead of the Maxwell model, more complicated rheological model like the Burgers model. However, the low-viscosity layer as a simple and natural precondition leads to the different suggestion.

The conclusion obtained from the present result is that the low-viscosity layer certainly exists at the lowermost part of the lunar mantle, and also that this layer induces tidal energy dissipation very effectively. The most important knowledge clarified through this work is that the high seismic attenuation zone is equivalent also to the low-viscosity zone. That is, it is thought that the portion of exceedingly low viscosity exists adjacent to the core-mantle boundary on the Moon as well as on the Earth. The fact that the relaxation time of this ultralow-viscosity zone is close to the tidal periods means that the tidal heating is nearly the maximum within the range of the internal structure defined in the above calculation. Moreover, there is a possibility that partial melting occurs in the deeper part as has previously been pointed out. Perhaps substantial amount of melt is created, even suggesting the rheologically critical state.

Keywords: the Moon, tidal dissipation, mantle, viscosity