Tidal Dissipation of the Solid Earth with an Internal Structure Including a Low-Viscosity Layer

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Tidal dissipation in the solid Earth is one of the important geophysical phenomena. Because tidal dissipation in a solid body depends on its internal structure, especially its viscosity structure, the dissipation can be a constraint on the interior. If the viscous structure can be constrained, it may provide one of the useful clues to learn the mantle dynamics.

The tidal response of the solid Earth, particularly the dependence of the theoretical Love number on the tidal period and viscosity structure, has been investigated in a few previous studies already. As a result, it has been considered that the presence of a low-viscosity layer inside the mantle, especially at its bottom part, is important for successfully interpreting the frequency-dependence of the observational Love number derived geodetically.

On the other hand, based on a similar idea to that of the above-mentioned research, the authors examined the dependence of the tidal quality factor on the frequency and the internal structure, assuming that such a low-viscosity layer exists also in the mantle of the Moon. This result also indicates that, as well as the Earth, the frequency-dependence of the quality factor obtained from the selenodetic observation can be explained if a low-viscosity layer exists at the base of the mantle. In addition, the characteristic timescale corresponding to the viscoelastic property of this layer is discovered to be very close to the main tidal periods. That is, it also implies a possibility that the viscosity which leads to efficient tidal heating in the layer is controlled through self-regulation.

Returning the viewpoint to the Earth tide with considering the implication from the lunar tide, it is unknown whether the above low-viscosity layer of the Earth possesses viscosity which is consistent with the dominant tidal periods. The previous research on the Earth have mainly illustrated the frequency-dependence of the complex Love number. Indeed, the uncertainty of the viscosity of the layer was systematically taken into consideration also in the previous analysis. However, the viscosity structure dependence of the quality factor obtained from the complex Love number was not explicitly specified. It is meaningful to survey this point in terms of both geophysics and comparative planetology.

Therefore, in the present study, in order to quantitatively estimate the effect of the low-viscosity zone at the bottom of the mantle on the tidal dissipation of the solid Earth, especially on the quality factor, the viscoelastic tidal deformation was calculated for several actual tidal periods. The typical reference structure for the density and elastic profiles is given in here based on the observation of seismic observation. Also, concerning the viscosity profile, for the sake of simplicity in order to roughly understand the dependence on the layered structure, just the four layers of a lithosphere, asthenosphere, mesosphere, and low-viscosity layer are set from the top to the bottom. Among them, only the viscosity of the low-viscosity layer is adjusted whereas those of the remaining three layers are uniform and constant. In the computation of the complex Love number in finding the quality factor, the stress-strain relation follows the rheological law of the Maxwell material. Then, the viscosity of the layer was estimated by comparing this theoretical value of the quality factor with the observational value.

The calculation result demonstrate that, like the Moon, the relaxation time of the low-viscosity layer is close to the tidal periods with respect to the deformation of the Earth. It is basically the same as the previous result that the numerical value matches with the geodetic observation if adding the influence of the low-viscosity layer. What is further clarified in this work is that the Maxwell relaxation time of the viscosity satisfying the frequency-dependent quality factor for the semidiurnal and diurnal tides, which is particularly prominent at the Earth tide, approaches the tidal period. In other words, a similar implication to that of the Moon described above were obtained here also in the case of the Earth.

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