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Dependence of the tidal response on the internal structure of the Moon: Geodetic implication to the partial melt layer

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Generally, internal energy dissipation associated with tidal deformation and physical libration of a planetary body depends on its internal structure, especially viscosity structure. Here magnitude of the tidal dissipation is mainly represented by the quality factor (Q) and the Love number (k_2). These values inevitably depend on its viscosity structure, and thus, give us clues of its thermal state and history.

Although dependence of the tidal dissipation on the viscosity structure of the Moon has already been demonstrated by previous research, its parameter study unfortunately has certain limitations. First, it assumes the lunar interior as a uniform sphere. However, the realistic interior on the Moon has been revealed to be differentiated by observation of the moonquakes. Therefore, it should be based on the seismic velocity structure instead of a homogeneous body. Second, Only Q has been calculated. However, geodetic observation actually show us not only Q but also k_2. Therefore, both of them need to be estimated. Third, in the past, there are no observational values which correspond to the calculation results. However, both Q and k_2 on the Moon has been derived from rotation and gravity field measurements by lunar laser ranging and precise orbit determination of the orbiters, respectively. Therefore, the parameter study should be confronted with the current result of Q and k_2.

By resolving the above issues, we would be able to put a new constraint on the interior structure on the Moon. That is, it allows us to consider what kind of viscosity structure can explain both Q and k_2 with no contradiction. Moreover, such consideration further enables us to tell what should be investigated in the framework of the lunar exploration project in the next generation.

Therefore, parameter studies on visco-elastic deformation are performed based on more realistic interior structure, and then, its calculation results are compared with pre-existing results derived from selenodetic observation. Concretely speaking, by employing the density and elasticity structures from seismic inversion, and by defining the viscosity of the asthenosphere as a free parameter, Q and k_2 are calculated. The knowledge of seismology also indicates the presence of a strong attenuation zone at the lower-most part of the lunar mantle. The viscosity in this zone is probably lower than that in the upper part. Therefore, this study prepares two extreme viscosity structures for the sake of simplification. One is the case in which the viscosity of the asthenosphere is regarded to be uniform and changed over several orders of magnitude in this parameter study. The other is the case in which just the viscosity of the high attenuation zone is changed over the same range. After that, by comparing the result for each of the above cases with the observational values obtained from Kaguya, Chang'e-1, and LRO, it is examined whether the viscosity value satisfying Q and k_2 at the same time is admissible or not.

As a result, it is clarified that the viscosity solution consistent with geodetic observations of both rotation and gravity field exists only if the interior structure includes the specific low viscosity zone, and also if the value from Kaguya or Chang'e-1 is referred. This case defines only one narrow range of viscosity corresponding to the observational Q. This viscosity range determines a numerical k_2 which is consistent with each of the observed values. On the other hand, this determined value is not consistent with the observed value from LRO because it is slightly larger than the others. In contrast to the above case, if it does not include the low viscosity zone, this case defines two ranges of corresponding to the observational Q. However, both these ranges are not consistent with any of the values from either Kaguya, Chang'e-1, or LRO.

As a conclusion, the seismic attenuation zone inside the lunar interior is probably equivalent to the low viscosity zone.

Keywords: the Moon, tidal response, internal structure, partial melt, quality factor, Love number