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Constraints on the Moon's deep interior from tidal deformation

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The Moon deforms in response to tidal forcing exerted by the Earth, the Sun and, to a lesser extent, by other planetary bodies. Their observations from ground-based and space-borne instruments, as well as Lunar surface missions, provide one of the most significant constraints that can be employed to unravel the deep interior (Williams et al. [2014], Williams and Boggs [2015]). The tidal forcing generates periodic variations of the harmonic degree-2 shape and gravity that depend on the internal composition and structure of the Moon. These changes in shape and gravity of the Moon are described by three geodetic parameters, called Tidal Love numbers (TLNs). Because of their low degree, these TLNs are sensitive to the structure of the deep interior (e.g., Khan et al. [2004]). Apart from the geodetic constraints, the Moon and Mars (e.g. Zweifel et al. [2021]) are the only other bodies besides the Earth for which seismic data are available. Seismic studies using the Apollo Passive Seismic Experiment (PSE) constrain the seismic wave velocity distribution and therefore give a glimpse of the Moon's interior structure (Garcia et al. [2011], Weber et al. [2011]). However, at greater depth, seismic data do not provide sufficient resolution on the velocity profile, leaving the near-centre Moon structure uncertain. Other studies based upon geophysical constraints (Khan et al. [2004], Harada et al. [2014, 2016], Matsumoto et al. [2015]) and the re-analysis of the Apollo seismic data suggested the existence of an attenuated region called low viscosity zone (LVZ) originated from a melting layer at the core-mantle boundary (Khan and Mosegaard [2001], Weber et al. [2011], Harada et al. [2014], Rambaux et al. [2014]).

Based on geodetic observations and seismic studies, we perform Monte Carlo simulations for combinations of thicknesses, densities and viscosities for two classes of Moon's models, one including an undifferentiated core and one including an inner and outer core, with both classes assuming an LVZ at the core-mantle boundary. By comparing predicted and observed tidal deformation parameters we find that the existence of an inner core cannot be ruled out. Furthermore, by deducing temperature profiles for the LVZ and the mantle following Earth assumptions, we obtain stringent constraints on the radius, viscosity, and density of the LVZ. We also infer the first estimation for the outer core viscosity, for our two possible scenarios.