Viscoelasticity of the lower mantle from forward modeling of normal modes and solid Earth tides

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Grain scale diffusive processes are involved in the rheology at convective timescales, but also at the transient timescales of seismic wave propagation, solid Earth tides and post-glacial rebound. Seismic and geodetic data can therefore potentially provide constraints on lower mantle properties such as grain size that are unconstrained otherwise. Current models of the transient viscosity of the lower mantle infer an absorption band of finite width in frequency. Seismic models predict a low frequency end to the absorption band at timescales corresponding to the longest normal modes of about an hour. By contrast, geodetic models infer the onset of an absorption band at these frequencies to cover anelastic deformation at timescales up to 18.6 years. A difficulty in extracting frequency dependence from mode and tide data is its convolution with depth dependence.

To circumvent this problem we select a distinct set of seismic normal modes and solid Earth body tides that have similar depth sensitivity in the lower mantle. These processes collectively span a period range from 7 minutes to 18.6 years. This allows the examination of frequency dependent energy dissipation over the lower mantle across 6 orders of magnitude. To forward model the transient creep response of the lower mantle we use a laboratory-based model of intrinsic dissipation that we adapt to the lower mantle mineralogy. This extended Burgers model represents an empirical fit to data principally from olivine, but also MgO and other compounds. The underlying microphysical model envisions a sequence of processes that begin with a broad plateau in dissipation at the highest frequencies after the onset of anelastic behavior, followed by a broad absorption band spanning many decades in frequency. The absorption band transitions seamlessly into viscous behavior. Since dissipation both for the absorption band and for (Newtonian) viscous behavior is due to diffusion along grain boundaries there can be no gap between the end of the absorption band and onset of viscous behavior.

Modeling of the planetary response to small strain excitation necessitates consideration of inertia and self gravitation. The phase lag due to solid Earth body tides therefore does not correspond directly to the intrinsic dissipation measured in the laboratory as material property. We have developed a self consistent theory that combines the planetary response with time-dependent anelastic deformation of rocks. Results from a broad range of forward models show that at lower
mantle pressures periods of modes fall onto the broad plateau in dissipation at the onset of
anelastic behavior. This explains the apparent frequency independence or even negative
frequency dependence observed for some normal modes. At longer timescales, solid Earth tides
fall on the frequency-dependent absorption band. This reconciles seemingly contradictory results
published by seismic and tidal studies. Observations at even longer timescales are needed to
constrain the transition from absorption band to viscous behavior.