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On the possible deep origin of long-wavelength gravity anomalies on the Moon and Mercury

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Like on the Earth and Mars, but notably different from Venus, the non-equilibrium equipotential shape of the Moon is dominated by very long wavelengths, in particular spherical harmonic degree two. Preliminary results from the Messenger mission indicate that the same is also the case for Mercury. We extend here a method that we previously applied to the Earth, Venus and Mars to study which part of the gravity anomalies have likely a sublithospheric mantle origin. The method is based on the assumption that density anomalies in both the convecting mantle and the lithosphere of planets and the Moon have the same spectral characteristic as inferred on the Earth from seismic tomography. We then apply a presumed pressure and temperature dependence of viscosity, that is based on mineral physics and consistent with other constraints on viscosity structure for the Earth's mantle to construct radial viscosity profiles. We compute geoid kernels for the planetary bodies, assuming a viscous mantle and an elastic lithosphere. Combining geoid kernels and density spectra, we can predict gravity spectra arising from density anomalies both in the convecting mantle and the lithosphere. By comparison, we infer which part of the observed spectra is likely derived from the convecting mantle. Our previous results had indicated that this is probably the case up to about spherical harmonic degree l=30 for Earth, 40 for Venus and 5 for Mars. Here we conclude that a sublithospheric mantle origin is likely up to l=5 for the Moon, and perhaps l=4 for Mercury. For these degrees, radially averaged mantle density anomalies can be inferred. Similar to the Earth and Mars, the Moon and possibly Mercury can be interpreted to have a dominant degree-two convection pattern. Given large uncertainties, results for Mercury remain tentative. The degree-two non-hydrostatic shape interpreted here as a consequence of mantle convection also includes excess flattening, such that it is not necessary to invoke a “fossil” bulge. For the Earth and Mars, interpretations are further corroborated, and long-term stability of the convection pattern is suggested by the distribution of volcanism in space and time: On Mars, recorded volcanism through its entire history tends to occur primarily in regions above inferred present-day low mantle density. On the Earth, the reconstructed eruption locations of Large Igneous Provinces of the last 300 Myr mostly fall above the margins of “Large Low Shear Velocity Provinces”, interpreted as piles of hot but chemically heavier material in the lowermost mantle, stable for hundreds of Myr and underlying presumed upwellings of the large-scale degree-two convection pattern. However, for the Moon and Mercury, no such obvious correlation is found, and further testing is needed.