EGU22-4758
https://doi.org/10.5194/egusphere-egu22-4758
EGU General Assembly 2022

Asymmetric growth of planetary stagnant lids

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Both the Moon[1] and Mars[2] are known to have significant degree-1 variations in their crustal thicknesses, with the Moon's far side and Mars's southern hemisphere having far thicker crusts than their respective opposing hemispheres. A number of potential mechanisms have been proposed to explain these dichotomies, including large impacts in both cases[3,4], radiant heat from the Earth[5] (in the case of the Moon), and large-scale volcanism[6] (in the case of Mars). However, the effectiveness of these mechanisms are limited by the difficulty of sustaining a large hemispheric difference during the tens to hundreds of Ma of crustal formation. Both planets' lithospheres are examples of a fluid-dynamical boundary layer known as a stagnant lid, caused by temperature-dependent viscosity in a convecting system. We consider the effect of pressure on the viscosity of magma oceans and mantles, finding that under certain circumstances a spherically-symmetric stagnant lid is linearly unstable to asymmetric perturbations. The fastest-growing wavenumbers of this instability is degree 1, meaning that a small initial asymmetry may grow into a full-scale hemispherical dichotomy. We then numerically examine the stability of these asymmetric states, finding that they may last for hundreds of Ma. We also compare to the case of Mercury, a similarly-sized planet with no such crustal dichotomy, to determine if our analysis matches observations.

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