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The onset of plate tectonics on super-Earth's using a damage rheology

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Numerical simulations of mantle convection with a damage — grainsize feedback are used to develop scaling laws to predict conditions at which super-Earths would have plate tectonics. In particular, we introduce a new criterion for the onset of plate tectonics on terrestrial planets: that the viscosity of the lithosphere must be reduced to some critical value, which we assume to be the mantle viscosity. We formulate this criterion using the viscosity ratio between the pristine lithosphere and underlying mantle (μ_0/μ_1). These conditions are mapped out in regime diagrams of μ_0/μ_1 versus the damage fraction (f_a). The regime diagrams show that the transition from stagnant lid to mobile surface occurs for higher μ_0/μ_1 as f_a increases, with a power law relationship between those two variables; moreover, decreasing the healing constant (k_a) at the surface shifts the transition boundary to higher μ_0/μ_1. A scaling law is developed assuming that the transition between regimes occurs when damage, driven by convective stresses, reduces the viscosity in the lithosphere to a viscosity comparable to the mantle viscosity. This scaling law explains the numerical results well and can be applied to terrestrial planets. For the Earth, damage is efficient in the lithosphere, and viscosity can be reduced by 10 orders of magnitude with grains being reduced to a size on the order of a micron. When applied to super-Earth's, we find that larger planets are capable of larger viscosity reductions, but the viscosity ratio increases with planetary size at roughly the same rate. Therefore, contrary to previous results [e. g. O'Neill, Lenardic, 2007; Valencia et al., 2007], we find that the size of the planet has little effect on the convective regime that planet lies in. Factors such as surface temperature and thermal evolution may be more important in explaining the convective style of terrestrial planets.

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