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Spontaneous initiation of subduction in mantle convection: new insights from viscoelastic models with a free surface

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Understanding the mechanisms that lead to initiation of subduction is a key to explaining dynamic evolution of the Earth and its fundamental difference to all other rocky planets. Several processes have been proposed to result in the formation of lithosphere-scale shear zones which are necessary to trigger subduction. Both small-scale convection in the sub-lithospheric mantle (Solomatov 2004) and global-scale convection (Lu et al. 2015; Crameri and Tackley 2016) have been tested as possible candidates for such process, since the stresses that develop in the lithosphere due to pull of downwellings and push of plumes may be sufficiently large to activate deep zones of plastic yielding. Crameri and Tackley, 2016, argued that to correctly capture the critical value of yield stress one must perform numerical models with a free surface instead of the traditional free-slip boundary condition. It is because much larger stresses form in the lithosphere when its bending is allowed, and bending cannot occur in models with vertically fixed surface. However, Thielmann et al. 2015 and Patočka et al. 2017 demonstrated that the amplitudes of stresses are exaggerated in numerical models with a free surface, as long as elastic properties of the lithosphere are not considered. The bending stresses of highly viscous lids are generally governed by the value of their shear modulus, and not the viscosity, which results in a significant stress reduction in viscoelastic models when compared to viscous models. In the present work we use the code StagYY (Tackley 2008) to investigate formation of lithosphere-scale shear zones in mantle convection models with visco-elasto-plastic rheology and a free surface. By performing several sets of simulations with a different value of yield stress we distinguish between plausible and improbable scenarios.

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