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A simple analytical solution for slab detachment

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An analytical solution is presented for the nonlinear dynamics of high amplitude necking in a free layer of power-law fluid extended in layer-parallel direction due to buoyancy stress. The solution is one-dimensional (1-D) and contains three dimensionless parameters: the thinning factor (i.e. ratio of current to initial layer thickness), the power-law stress exponent, n, and the ratio of time to the characteristic deformation time of a viscous layer under buoyancy stress, t/tc. tc is the ratio of the layer's effective viscosity to the applied buoyancy stress. The value of tc/n specifies the time for detachment, i.e. the time it takes until the layer thickness has thinned to zero. The first-order accuracy of the 1-D solution is confirmed with 2-D finite element simulations of buoyancy-driven necking in a layer of power-law fluid embedded in a linear or power-law viscous medium. The analytical solution is accurate within a factor about 2 if the effective viscosity ratio between layer and medium is larger than about 100 and if the medium is a power-law fluid. The analytical solution is applied to slab detachment using dislocation creep laws for dry and wet olivine. Results show that one of the most important parameters controlling the dynamics of slab detachment is the strength of the slab which strongly depends on temperature and rheological parameters. The fundamental conclusions concerning slab detachment resulting from both the analytical solution and from earlier published thermo-mechanical numerical simulations agree well, indicating the usefulness of the highly simplified analytical solution for better understanding slab detachment. Slab detachment resulting from viscous necking is a combination of inhomogeneous thinning due to varying buoyancy stress within the slab and a necking instability due to the power-law viscous rheology (n>1). Application of the analytical solution to the Hindu Kush slab provides no "order-of-magnitude argument" against slab detachment and, therefore, supports existing studies suggesting a currently ongoing slab detachment in the Hindu Kush slab.