A parameterized rheology for creating lithospheric-scale shear zones.

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Shear localization is a process of primary importance for the onset of subduction and the evolution of plate tectonics on Earth. Here we focus on a model in which shear localization is initiated through shear heating. The rheology employed is linear Maxwell viscoelastic with von Mises plasticity and an exponential dependence of viscosity on temperature. Dimensional analysis reveals that four non-dimensional parameters control the initiation of shear zones. The onset of shear localization is systematically studied with 0-D, 1-D and 2-D numerical models, both under constant stress and under constant velocity boundary conditions. Mechanical phase diagrams demonstrate that six deformation modes exist under constant velocity boundary conditions. A constant stress boundary condition, on the other hand, exhibits only two deformation modes (localization or no-localization). Scaling laws for the growth rate of temperature are computed for all deformation modes. Numerical and analytical solutions demonstrate that diffusion of heat may inhibit localization. Initial heterogeneities are required to initiate localization. The derived scaling laws are applied to Earth-like parameters. For a given heterogeneity size, stable (non-seismic) localization only occurs for a certain range of effective viscosities. Localization is inhibited if viscosity is smaller then a minimum threshold, which is a function of the heterogeneity size. The simplified rheological model is compared with a more realistic, and more complex model of olivine that takes diffusion-, power law and Peierls creep into account. Good agreement exists between the models. The simplified model proposed in this study thus reproduces the main physics of ductile faulting. Two-dimensional late-stage simulations of lithospheric-scale shear localization are presented that confirm the findings of the initial stage analysis.