Geophysical Research Abstracts
Vol. 14, EGU2012-11822, 2012
EGU General Assembly 2012

Strain localization due to linkage of pinches in viscoplastic multilayers

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Two-dimensional finite element simulations are presented for the extension of stiff viscoplastic layers embedded in a weaker viscous matrix. Layers and matrix exhibit power-law flow laws and the layers exhibit additionally a von Mises yield stress. The power-law flow law applies to rock deformation in the diffusion and dislocation creep regime and the von Mises plasticity to the low-temperature plasticity regime (e.g. dislocation glide). No material softening mechanism is applied. In the simulations small initial perturbations either in layer viscosity or geometry cause locally elevated stress and locally plastic yielding. Simulations show that pinch-and-swell structure forms (i.e. necking) for small viscosity ratio (i.e. 10 to 20) and typical power law stress exponents (i.e. 1 to 5). Also, pinches in layers with initial random perturbation form consecutively (i.e. not simultaneous). In multilayers, pinches on both the single-layer- and the multilayer-scale develop. Furthermore, shear zones develop in the multilayers due to the linkage of pinches across the multilayer. These shear zones have a stable position, cause a normal drag geometry and exhibit significant displacement. The basic features of the simulations are observable in deformed rocks. The importance of low-temperature plasticity is supported by microstructural observations and EBSD orientation maps for pinch-and-swell structure in calcite veins. Low-temperature plasticity is a potential mechanism for the formation of pinch-and-swell structure and shear zones, and it has been observed in rock deformation experiments for minerals such as calcite, dolomite, diopside, clinopyroxenite and olivine. The presented model can explain strain localization and the formation of spatially stable shear zones as the result of linkage of pinches across viscoplastic multilayers without the need of any material softening or feedback mechanism (e.g. shear heating). The model can explain observed strain localization on the outcrop scale (examples are presented for calcite veins in marble). Moreover, numerical simulations show that in a simple lithosphere-model made of viscoplastic layers (e.g. brittle-plastic upper crust or viscous lower crust) individual lithospheric-scale shear zones also form due to the linkage of necking zones during lithosphere extension.