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Control of temperature, pressure gradient and flow law on the formation of crustal-scale shear zones: results from 1D thermo-mechanical modeling

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Localization of deformation plays a major role during tectonic processes at all scale from the formation of deformation bands within single grains up to crustal and lithospheric scale shear zones. Deformation in continental collision belts is typically driven by such localizations resulting in the formation of fold nappes and thrust sheets. There are considerable speculations as to which process dominates the localization behavior. We present a self-consistent pressure-driven thermo-mechanical 1D numerical model to study the formation of shear zones in the upper crust. The numerical model is based on the finite element method and solves the equations for the fluid dynamic force balance and for transient heat conduction. Our model consists of a sediment layer and its underlying basement which is considered rigid. For the sediment layer we apply several calcite flow laws for diffusion creep and dislocation creep. For dislocation creep we use power-law flow laws as well as a flow law based on Peierls mechanism. We study under what thermal and pressure conditions the shear zones form at the base of the sediment layer. We also investigate the impact of thermal coupling through shear heating and of grain size reduction coupled to the Peierls-type flow law on shear zone formation. We apply our model to the Morcles fold nappe in the western Swiss Alps by considering previously published estimates for strain rates, stresses, flow laws and temperatures. Detailed EBSD (electron backscattered diffraction) analyses have been made on the rocks at the contact between the Morcles nappe sediments and the autochthonous cover of the Aiguille rouge massif in order to investigate the deformation mechanisms. We identify the thermal and pressure conditions as well as the different flow laws for calcite for which the model results fit best the field observations and estimates for stress and strain rate.

An advantage of the applied 1D thermo-mechanical shear zone model is that neither the strain rate nor the stress is prescribed at any point in depth but is controlled by the applied overall pressure gradient and the temperature profile. Furthermore, the computationally cheap 1D simulations allow a systematic analysis of the control of temperature, pressure gradient and flow law on the formation of shear zones. The results of our 1D model will be used to set up a more elaborated 2D model for the formation of crustal scale shear zones and fold nappes.