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Predictive models of the temperature structure of shear zones caused by thermal softening and their potential occurrences in the lithosphere

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Using strain rates and stresses averaged on a lithospheric or global scale results in an average value of dissipative heat production that is negligible compared to radioactive heat production. This could misleadingly suggest that dissipative heat production can be neglected in the description of the thermal structure of the lithosphere.

Localized zones of strain are common geological observations in various geodynamic settings. Localization of strain plays a major role during geodynamic processes, such as mountain building, and in particular during the formation of shear zones on all geological scales. Strain localization in a homogenous material requires a softening mechanism and we consider here thermal softening. Thermal softening is a result of the conversion of mechanical work into heat (i.e. shear heating) and of the temperature dependence of rock viscosities. Previous studies have shown that thermal softening can cause strain localization and the formation of large-offset shear zones in ductile materials whose deformation behavior is described with creep flow laws (e.g. dislocation creep). Conversely localizing strain in these shear zones can be accompanied by significant local temperature anomalies compared to a model lithosphere.

Systematic analysis of data resulting from one-dimensional (1D) numerical simulations of simple shear provides scaling laws involving dimensionless parameters that can be used to predict the temperature evolution (the maximum and the width of the temperature curve) of shear zones. The applied 1D simple shear model is made of a homogenous medium and the bulk shear deformation is controlled by a constant far-field shear velocity. The initial configuration exhibits a small thermal perturbation to nucleate the localization.

To show the general applicability of the scaling laws which have been derived from 1D simple shear models we compare predictions of these scaling laws with results of 2D and 3D models of shear zone development under far-field pure shear. The results of the 1D model are practically identical with the results of the more sophisticated 2D and 3D pure shear models. The presented scaling laws are, hence, applicable to a wide range of shear zones caused by thermal softening. We discuss the applications of the scaling laws to a variety of natural shear zones and for laboratory-derived dislocation creep flow laws for quartzite (representing upper crust), plagioclase (representing lower crust) and olivine (representing mantle lithosphere).

Finally, we discuss the probability of the occurrence of such shear zones in a deforming lithosphere. We present the typical stress evolutions of these shear zones and the typical situations in a model lithosphere where we expect shear zones formed by thermal softening.