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Thermal Softening Induced Strain Localization, a Possible Mechanism of Lithospheric Scale Shear Zone Formation and Subduction Initiation

Dániel Kiss (1), Lorenzo G. Candioti (1), Thibault Duretz (1,2), Yury Podladchikov (1), and Stefan M. Schmalholz (1)

(1) University of Lausanne, Institute of Earth Sciences, Géopolis, Lausanne, Switzerland (daniel.kiss@unil.ch), (2) Univ. Rennes, CNRS, Géosciences Rennes - UMR 6118, F-35000 Rennes, France

Active plate tectonics, characterized by excessive areas of no or little deformation divided by localized areas of intense deformation, is a distinctive feature of our planet. Despite its importance, the physics of lithospheric scale shear zone formation and subduction initiation is still incompletely understood. We focus on two major challenges, that are: (1) To find a mechanism of spontaneous shear localization without prescribing the shear zone. (2) Based on experimentally derived flow-laws of olivine, the upper and hence colder part of the mantle must be very strong. In fact, the stresses required to deform a yet intact and cold mantle are difficult to reach and maintain without a softening mechanism.

In this study we discuss the possible role of thermal softening in subduction initiation. 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). Also, it has been shown that thermal softening induced shear localization can result in significant stress drops of a few hundred MPa.

We present a one-dimensional (1D), simple shear model that helps both qualitative and quantitative understanding of the first order characteristics of shear zone evolution. We compare the results of the simple shear zone models with results of high resolution numerical simulations of Alpine lithospheric deformation. In these simulations, we first model the formation of hyper-extended passive margins and mantle exhumation by extending a continental lithosphere. After a period of thermal relaxation, we start to compress the extended configuration. This leads to subduction initiation by thermal softening, if certain conditions are satisfied. The occurance of subduction initiation is in agreement with the predictions based on the simple 1D shear zone model.