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Parameters driving strain localization in the lithosphere are highly scale-dependent

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Modelling lithospheric deformation requires specifying mechanisms that promote strain localization. This can be done in different ways, such as the inclusion of weaker zones in the model setup (to initiate subduction or slab tearing, for instance) or using various sorts of weakening processes depending upon temperature, grain-size, fluid content or metamorphic reactions, among others. In most cases, this choice is ad hoc because the relevant parameters are largely unknown, especially at the scale of geodynamic models.
Two lines of research have been developed, a traditional one which seeks to determine the rheological parameters of natural or synthetic rocks experimentally, and a more recent one, promoted by the development of fast computing, which aims at reproducing a natural tectonic or rheological evolution through time, not only geometries. The latter requires that the parameters allowing this reproduction are significant at the scale of the model, and which may be different from those obtained in the experimental lab, thus questioning the extrapolation through a wide range of scales of experimental parameters. This apparent discrepancy is due to the intrinsic complexity of the lithosphere, and even more so for the continental lithosphere with its highly heterogeneous crust and its long tectonic history, which implies the co-existence of many different parameters active in nature.
In this presentation, we review the main localizing factors and look to the range of scales in which they are significant. Small-scale processes such as grain-size reduction, coexistence of several mineralogical phases with different strength and rheological behaviour, fluid-rock interactions and/or metamorphic reactions, often cannot initiate strain localization in nature but are all efficient to locally reduce the strength of rock material once localization has started. Some exceptions to this rule, however, exist, such as the mixing of ductile and brittle behaviour in the same material that can promote strain localization. Brittle deformation can initiate the formation of ductile shear zones in homogeneous materials if it is paired with fluid-rock interaction and phase changes. Large-scale localizing factors, beside temperature decrease, all pertain (1) to the lithological heterogeneity of the lithosphere (crust and mantle), due to its tectonic, metamorphic or magmatic heritage, and/or (2) to an inhomogeneous stress field due to asymmetric or changing boundary conditions on the side or below (model geometry and its evolution). Using ad hoc mechanical parameters, possibly different from those obtained in the lab, is justified in numerical experiments at large scale by two main facts: (a) localizing mechanisms cannot be all taken into account in numerical models and only those significant at the scale concerned by the model should be used, and (b) the model geometry, i.e. the initial and boundary conditions in general supersede the small-scale parameters that are then active in nature only to focus deformation where it has been first initiated. It thus seems reasonable to use macroscopic numbers integrating all the small-scale processes that cannot be resolved in large-scale numerical models if one is willing to study the long-term tectonic evolution of the lithosphere through time in its 3D natural complexity.