Geophysical Research Abstracts
Vol. 13, EGU2011-1499, 2011
EGU General Assembly 2011

Is there strain softening in the Earth's crust?

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In this session dealing with localization of deformation in the lithosphere, we would like to draw attention to the process of "kinematic strain localization", a purely geometric effect that results in strain localization without the need for strain weakening/softening.

We base our argument on the simple hypothesis that deformation within a steady-state compressional orogen, i.e. where tectonic accretion is, on geological time scales, balanced by surface erosion, can be described by a stationary velocity field. In this framework, instantaneous deformation results from spatial gradients in the velocity field, whereas total accumulated strain results from the integration of this instantaneous deformation along rock paths, i.e. following the flow lines defined by the velocity field.

Under these basic assumptions, we have computed strain distributions for rocks that "travel" through an orogenic system to end up at its surface using a variety of simple, linear velocity fields corresponding to (a) simple shear within a dipping shear zone and (b) pure vertical shear. In both cases, we predict surface strain patterns that do not reflect the geometry of the assumed velocity field: large gradients in accumulated strain are predicted where little or no velocity gradient exists. We then note that similar patterns of deformation have commonly been associated with more complex velocity fields resulting from nonlinear, localizing crustal rheologies.

Our simple geometrical argument demonstrates that caution should be exercised in interpreting observed strain patterns because a substantial proportion of the observed strain localization may in fact be due to purely kinematic (or geometrical) effects. We advise those studying and measuring strain localization that such kinematic effects should be quantified and subtracted from observed strain distributions before they can be used to constrain the rheological behavior of rocks. We also suggest that in a simple shear (thrust) setting, kinematic strain localization may in fact nucleate strain softening on the side of the deforming region that is stable or fixed with respect to the Earth's surface and thus be responsible for the asymmetry that characterizes the large majority of thrust systems.