Geophysical Research Abstracts
Vol. 18, EGU2016-1815, 2016
EGU General Assembly 2016

Relating rheology to geometry in large-scale natural shear zones

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The geometry and width of the ductile roots of plate boundary scale faults are very poorly understood. Some field and geophysical data suggests widths of tens of km in the lower crust, possibly more in the upper mantle. Other observations suggest they are much narrower. Dip slip shear zones may flatten out and merge into zones of subhorizontal lower crustal or asthenospheric flow.

The width of a ductile shear zone is simply related to relative velocity and strain rate. Strain rate is related to stress through the constitutive relationship. Can we constrain the stress, and do we understand the rheology of materials in ductile shear zones? A lot depends on how shear zones are initiated. If they are localized by pre-existing structures, width and/or rheology may be inherited, and we have too many variables. If shear zones are localized primarily by shear heating, initial shear stress has to be very high (> 1 GPa) to overcome conductive heat loss, and very large feedbacks (both positive and negative) make the system highly unstable. Microstructural weakening requires a minimum level of stress to cause deformation and damage in surrounding rock, thereby buffering the stress. Microstructural weakening leads to grain-size sensitive creep, for which we have constitutive laws, but these are complicated by phase mixing in polyphase materials, by viscous anisotropy, by hydration, and by changes in mineral assemblage.

Here are some questions that need to be addressed. (1) If grain-size reduction by dynamic recrystallization results in a switch to grain-size sensitive creep (GSSC) in a stress-buffered shear zone, does dynamic recrystallization stop? Does grain growth set in? If grain-size is still controlled by dislocation processes, then the effective stress exponent for GSSC is 4-5, even though the dominant mechanism may be diffusion and/or grain-boundary sliding (GBS). (2) Is phase mixing in ultramylonites primarily a result of GBS + neighbour switching, creep cavitation and diffusion, or metamorphic reactions? (3) In two-phase / polyphase mixtures, does the strong phase generally form a load-bearing framework, favoring constant strain-rate (Voigt) bound behavior, or does the weak phase form through-going strain pathways, favoring constant stress (Reuss) bound behavior, or do the phases remain well mixed, favoring an intermediate behavior (e.g., Tullis et al model)? (4) How do we deal with the rheological effect of water? Is it simply an unconstrained variable in nature? Is the water fugacity model in flow laws adequate? (5) How can we better relate experimental results (often carried out at constant strain-rate, and not reaching microstructural steady state) to deformation in natural shear zones? Rheological observations on well-constrained natural shear zones are helping us answer some of these questions.