Geophysical Research Abstracts,
Vol. 11, EGU2009-9048-2, 2009
EGU General Assembly 2009

A new mechanism for fluid migration in midcrustal shear zones based on viscous grain boundary sliding and creep cavitation

F. Fusseis (1), K. Regenauer-Lieb (2), and J. Liu (2)

(1) Multiscale Earth System Dynamics, The University of Western Australia, School of Earth & Environment, Perth, Australia (fusseis@cyllene.uwa.edu.au), (2) CSIRO Exploration & Mining, Perth, Australia

The common perception of fluid migration pathways in midcrustal shear zones relies mostly on hydraulic fractures forming by tensile failure where pore fluid pressure equalizes the combined lithostatic pressure and the tensile strength of the rock. Where the associated pervasive fracturing on multiple scales does not occur but the presence of a fluid phase is indicated, different models are needed to explain fluid transfer. Here we present the 'granular fluid pump', a model that is capable of explaining fluid migration in fine-grained ultramylonites typical for midcrustal shear zones.

We investigated the porosity evolution across the margin of a shear zone in central Australia that formed in granitic gneiss at upper-greenschist facies conditions (Fliervoet et al., 1997). The strain gradient in the sample, which is macroscopically expressed by the reorientation of a preexisting foliation and a substantial grain size reduction, is interpreted as a proxy for time. Our investigation showed that the microstructural evolution of the sample is characterized by two major processes: a) The progressive reduction in abundance and size of potassium feldspar and plagioclase clasts, which decay, with increasing strain, in hydration reactions to form a fine-grained (<25 microns) ultramylonitic matrix composed of secondary potassium-feldspar, quartz, muscovite, biotite and epidote. b) The nucleation of secondary phases (mostly potassium-feldspar) at triple junctions in monomineralic quartz ribbon bands, which characterize the low-strain fabric in the rock. Both processes involve an aqueous fluid phase. Fliervoet et al. (1997) identified the feldspar reaction as the dominant strain softening process. Where the multiphase matrix forms an interconnected framework a transition in the dominant deformation mechanism occurs, from dislocation creep to a combination of viscous grain boundary sliding and pressure solution/precipitation.

Our Synchrotron radiation microtomographic study showed that along the strain gradient, towards the shear zone center, the total porosity doubled from $\sim$2.5% to >4% and that the relative frequency of the smallest detectable pores (1.3-3.9 microns) increases from <25% to more than 35%. At the same time it revealed a change in the character and distribution of pores: In low-strain segments of the shear zone margin large pores (> tens of microns) tend to cluster in plagioclase grains, a form of porosity that is associated with feldspar decay and a removal of chemical components. Towards the shear zone center, pores are smaller (micron-sized and below) and generally occur along grain boundaries. Most pores occur in 'pore sheets' that characterize the multiphase ultramylonitic layers. These grain boundary pores often occur at triple junctions. Lobes extending into neighboring grains and pockmarked surfaces evidence dissolution; little crystallites in grain boundary pores indicate precipitation and mineral growth. Both observations indicate the presence of a fluid.

Our observations show that the transition in the dominant viscous deformation mechanism coincides with a change in the amount, character and distribution of porosity. We interpret the porosity in the shear zone center to result from a combination of creep cavitation (Fusseis et al., in review) and dissolution. Based in this, we develop a model for fluid migration in the shear zone center: The relative motion of grains during viscous grain boundary sliding is responsible for the simultaneous opening and closure of fluid-filled grain boundary pores by creep cavitation. Assuming at least partially open grain boundaries in the stressed aggregates, grain boundary sliding thereby gives rise to minute grain-scale pressure differences between neighboring pores. These pressure differences initiate a granular fluid pump. The fluid pressure in the individual cavities is the sum of the mechanical pumping term and a 'virtual' pressure caused by the solution reactions and associated volume changes. Deformation, pore formation and growth dissipate a total power that is the time rate of the pressure work done by the granular fluid pump minus the time rate of the energy stored in the pore surface. If the rate of dissipation is maximized and constant, pore growth is stable.

Note that this granular fluid pump relies on the opening and closing of pores and consequently describes a dynamic permeability. It should occur wherever viscous grain boundary sliding is active in shear zones with a free fluid phase. This is the case in many midcrustal shear zones that are either characterized by episodic cataclastic/mylonitic deformation (during the earthquake cycle) or by reaction softening associated with retrogression. The granular fluid pump provides comparatively steady, non-episodic fluid transfer and does not require pervasive fracturing.

References: Fliervoet et al., 1997, JSG 19/12, 1495-1520, Fusseis et al., in review, Nature.