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The role of intergranular creep fracturing and cavitation in viscous deformation

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We present evidence strongly supporting the hypothesis that intergranular creep fracturing controls permeability and mineral phase distribution in fine-grained greenschist-facies mylonites. Fine-grained (<25 microns) mylonites often deform by diffusion-accommodated viscous grain boundary sliding (VGBS), a highly efficient deformation mechanism in mid-crustal shear zones - especially when a fluid supports diffusive mass transfer. VGBS requires the maintenance of small, often below-equilibrium grain sizes, which are stabilized by an anti-clustered mixing of the individual mineral species in polymineralic mylonites (i.e. a minimum number of boundaries between the same minerals, Kruse & Stuenitz, 1998). Despite its control on the important transition from dominant dislocation to grain-size sensitive creep, the formation of such mineral phase mixtures is still poorly understood.

We present data from a sequence of increasingly deformed granitic gneiss samples from the Redbank Shear Zone, Australia. The samples were analysed using high-resolution FE-SEM imaging of coated and uncoated thin sections and split samples, NanoSIMS microchemical analysis and Synchrotron tomography. The strain gradient in the sample sequence is interpreted as a proxy for an evolution in time. The progressive microstructural evolution of this rock is characterized by a decrease in number and size of plagioclase and K-feldspar clasts, corresponding to an increase in the proportion of ultramylonitic matrix and a decrease in matrix grain size to <25 microns. The ultramylonitic matrix is a mixture of quartz, K-feldspar and biotite. Earlier work on the Red Bank mylonites already concluded that VGBS dominates deformation in

this matrix (Fliervoet et al. 1997).

Our FE-SEM data support earlier interpretations of anti-clustered mineral phase mixtures as to result from the heterogeneous nucleation of dissimilar minerals, in our case quartz and K-feldspar, next to each other. Our observations show that the crystal nuclei formed in cavities that were frequently found along both, grain and phase boundaries. All samples exhibit ample evidence for dissolution, emphasizing the contribution of diffusive mass transfer by a fluid. We currently analyse the composition of the newly-grown nuclei; first results indicate that it was mostly K-feldspar which nucleated in cavities that opened along grain boundaries in relatively pure quartz layers. The three-dimensional tomographic data will provide further information on how the distribution of the individual mineral phases was related to the formation of cavities as the rock was deformed.

Our preliminary results complement previous models of deformation and fluid flow in mid-crustal shear zones by emphasizing the importance of cavitation. The high density of cavities along grain and phase boundaries suggests that diffusion-controlled intergranular creep fracturing, which is responsible for their formation, controls the formation of anti-clustered phase distributions in fine-grained mylonites. Cavities that open and close dynamically during deformation may efficiently distribute small amounts of fluids through low-permeability (in a static sense) mylonites. In combination with the evidence for fluid-assisted dissolution and precipitation given by our data this justifies a critical discussion of the deformation rate-controlling processes in fine-grained greenschist-facies shear zones.

We show first preliminary numerical results that explore the fundamental effect of creep fracturing on large-scale deformation and dynamic fluid transfer.

References: Fliervoet et al (1997), J. Struct. Geol. 12, 1495-1520, Kruse & Stuenitz (1999), Tectonophysics 303, 223-249.