Geophysical Research Abstracts
Vol. 19, EGU2017-18680, 2017
EGU General Assembly 2017

The role of creep cavitation and ductile failure in mid-crustal deformation – a critical one in the formation of shear instabilities and the nucleation of deep slow slip events?

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Mid-crustal shear zones host deep slow slip events and play a critical role in transferring stress from viscously deforming lower-crustal domains to the frictional, seismogenic upper crust. At the same time, these shear zones act as conduits for trans-crustal fluid transfer. Deformation in shear zones at the frictional-viscous transition is accommodated by a complex combination of deformation mechanisms that is dominated by grain-size sensitive creep in fine-grained ultramylonites. Over the past years, the significance of synkinematic creep cavitation in the deformation of these ultramylonites has been established, and Fusseis et al. (2009) have formulated the dynamic granular fluid pump model to consider this form of porosity in models of fluid transfer through the middle crust.

In this presentation we analyse amphibolite-facies ultramylonitic samples from the Redbank Shear Zone (Australia) that have been exhumed from the frictional-viscous transition without any significant retrograde overprint. The ultramylonites, which were derived from a granitic protolith, appear compositionally layered, with alternating layers of extremely fine-grained ($\sim$1-2 um) polymineralic mixtures of feldspar, quartz, mica, epidote and ilmenite and mono-mineralic quartz layers. The latter exhibit abundant creep cavities, which are the focus of this contribution. A hierarchy of creep cavities are found to exists in the quartz domains. This porosity can be considered to have formed synkinematically by two distinct mechanisms: Zener-Stroh cracking and superplastic void growth. The porosity is shown to have evolved with the disaggregation of the dynamically recrystallising quartz ribbons during ultramylonitisation. In initially thick and coherent quartz ribbons, pores generated by Zener-Stroh cracking emerge on grain-boundaries aligned with the YZ plane of finite strain. With decreasing quartz domain thickness and increasing quartz dispersion into the fine-grained ($\sim$1-2 μm) polyphase domains, viscous grain boundary sliding (VGBS) becomes active and cavities form as superplastic voids. Quartz creep cavities are suggested to evolve in tandem with creep cavities present in the fine-grained polyphase domains (as described in Fusseis et al., 2009). The polymineralic domains in the samples show grain boundary alignments extending parallel to the shear plane for several grain diameters. These phenomena are hard to explain by conventional models for grain boundary sliding, and we interpret them as the remnants of former ductile failure events that emerged where a critical creep cavity density was reached, but stalled.

Our study is among the first to identify specific mechanisms behind the formation of synkinematic creep cavities and anchors cavitation firmly in the microstructural evolution of the rock. We demonstrate that, during the deformation of the ultramylonite, fluid could not move freely through the rock, but was channelized into sheet-like conduits parallel to the shear plane provided by creep cavitation. Synkinematic fluid movements were likely driven by the granular fluid pump, following hydraulic potentials that arose dynamically on the grain scale. Our study provides an observational database for testing the hypothesis that creep cavitation could have led to ductile failure in these rocks, a process we consider relevant for the emergence of shear instabilities and the nucleation of slow slip events at the frictional-viscous transition.