

EGU22-5127

<https://doi.org/10.5194/egusphere-egu22-5127>

EGU General Assembly 2022

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Experimental strain localization in granitoid ultramylonites: Pre-fracturing vs. viscous strain localization

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Rheological models of Earth's granitoid mid- to upper crust are commonly based on the physico-chemical properties of the most abundant rock forming minerals quartz and feldspar. However, there is increasing field evidence that deformation in these rocks localizes in ultrafine-grained polymineralic shear zones, which are weaker than any of the end member minerals. Especially at the brittle to viscous transition, the localization and deformation mechanisms, i.e. the role of incipient brittle deformation vs. continuous viscous strain localization, is not yet fully understood.

To fill this gap in knowledge, ultramylonite samples with granitic composition from the Central Aar Granite (Aar Massif, Central Switzerland) were deformed using a Griggs type apparatus. The foliation of the ultramylonitic starting material was oriented 45° to the compression direction, to investigate the influence of grain size and composition on strain localization in the different mylonite bands. Two types of coaxial experiments were conducted at 650°C, and 1.2 GPa confining pressure: A) Discrete fractures were created before the shear deformation starts; B) No fractures were induced during an early stage of the experiment.

All experiments have in common that strain is accommodated in 20-100 µm wide viscous shear zones with elongated grains and minor grain size reduction. In these shear zones, most strain is further localized in 10-20 µm wide zones, showing dramatic grain size reduction down to few tens of nanometres. In the experimentally generated shear zones, both, brittle and viscous processes are active. In terms of overall rock strength, all newly formed ultrafine-grained shear zones are up to three times weaker than comparable experiments on pure quartz or coarser grained granites – which agrees well with field observations. Furthermore, pre-fractured type A) is up to two times weaker than the non-fractured type B), and the orientation and number of shear zones is also fundamentally different between the two experiment types.

This study confirms two weakening factors promoting different types of strain localization at the brittle to viscous transition: 1) The existence of fractures and their interconnectivity – facilitating highly-localized grain size reduction; 2) Initial sample heterogeneity by polymineralic composition and ultrafine grain size – generating grain size reduction along strain gradients by activating viscous processes. Further quantitative microstructural analyses will reveal the role of chemistry and the deformation mechanisms on the localization behaviour.

