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Localization and partitioning of deformation in experimentally produced granitoid fault rocks

Matěj Peč (1), Holger Stünitz (2), and Renée Heilbronner (1)

(1) University Basel, Geosciences, Switzerland (matej.pec@unibas.ch), (2) Universitetet i Tromsø, Institutt for geologi, Norway

The complex interplay between frictional and viscous deformation processes taking place in the “brittle-ductile transition” is still poorly understood. Fracturing, as one of the most effective grain size reducing mechanisms, occurs under a wide range of conditions and seems to be an important pre-cursor for the onset of viscous deformation in the crust.
The aim of this work is to study localization and partitioning of brittle and viscous deformation in experimentally produced fault gouges and to identify the active deformation mechanism(s) via quantitative microstructural analysis.
We performed a series of simple shear experiments on granitoid fault gouge in a Griggs solid medium deformation rig at 500 MPa confining pressure and 300 or 500°C. Before deformation, the artificially produced gouge consists of 28% Qtz, 25% Kfs, 15% Plg, 3% Bi and 0.5% Msk. The average thickness of the shear zone is ~1 mm and the porosity is ~28%. All three major phases (Qtz, Kfs and Plg) deform by fracturing along grain-to-grain contacts and have a similar aspect ratio (L/S) ~2.13. Two measures for concavity were determined: paris factor ~7.6% and deltaA factor ~6.5%. Finally, a measure for angularity, omega factor, is slightly higher in Qtz (24.8%) than in feldspars (~20%) (Heilbronner & Keulen 2006). Micas deform mainly by kinking. We observe a slight shape preferred orientation of the grains perpendicular to the applied load indicating that the applied pressure during the pumping up of the experiment is not entirely isotropic.
After fast frictional deformation (shear strain rates of 10^-4 sec^-1 and 10^-3 sec^-1) to a gamma value of up to 2.7, the average thickness of the shear zone is reduced to 0.7 mm and the porosity drops below 3%. We observe overall grain size reduction and shear localization through the development of S-C-C´ fabric with C´ shear bands being the dominant feature. The C´ shear bands form at an angle of 18° to sigma 1 resp. 27° to the shear zone boundary and contain the smallest grains (< 10 nm). Locally, where the amount of fine grain fraction is high or where mica is present, the C´ shear bands change their orientation to C shear bands (boundary parallel). Due to the widespread grain-size reduction it is often hard to identify individual grains even at high magnifications. Therefore we analyze individual grains (well identifiable grains) and grain aggregates (delimited by phase to phase contacts) separately. The fractured qtz grains have a slightly higher average aspect ration (2.3) than the feldspar grains (2.0) and seem to be the strongest phase. Average paris, deltaA and omega values for Qtz grains are higher (12.3%, 7.3% and 21%) than for feldspar grains (10.6%, 5.2% and 16%) due to cleavage effects on fracturing. The grain aggregates have higher aspect ratios (Qtz = 2.4, Kfs = 2.8, Plg = 2.3) a monoclinic symmetry and often form “core-and-mantle” structures where the core is formed by a less fractured porphyroclast and the mantle is formed by finely fractured material of the same phase. These aggregates show a strong SPO synthetic with the induced sense of shear.
After one week of stress relaxation or constant load creep we observe the reorientation of the C´ shear bands to an angle of 30° to sigma 1 resp. 15° to shear zone boundary. The smallest grain fraction is no longer present and we see an overall grain-size increase due to cementation of fine grains into bigger ones with lobate grain boundaries.
The observed microstructures, together with the mechanical data, suggest that the fine-grained material along the C´ shear bands is exploited by viscous deformation. The envisaged deformation mechanism is dissolution – precipitation creep.

References: Heilbronner, R. and Keulen N. (2006) Grain size and grain shape analysis of fault rocks. Tectonophysics 427:199-216