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Healing of Cataclastic Rocks in Nature and Experiment

HOLGER STUNITZ[1], NYNKE KEULEN[1], RENEE HEILBRONNER[1]
[1] *Dept. of Geosciences, Basel University*

The formation of gouge in fault zones and the resulting grain size distribution are a matter of interest because the surface area generated during rupture is related to the energy release during an earthquake. The healing of fault gouge after rupturing is important for (a) understanding the way in which fault rocks are preserved, and (b) understanding potential relationships between movement and quiescence periods of fault zones. If a distinction between seismic and aseismic gouges can be made, there may be a large inventory of former seismic natural fault zones to be studied. If healing helps to re-estalish the strength of fault zones, the healing rate may be related – among other factors - to the recurrence time of earthquakes. Coaxial deformation experiments were carried out on isotropic Verzasca gneiss using a Grigg's deformation apparatus at 300-500°C, 500-1000 MPa, strain rates of 10-4 to 10-7 s-1 and 0.2 %wt H2O added. Experiments were performed in four ways.1) Samples were quenched immediately after fracturing (deformed-only).2) After fracturing the samples were kept at hydrostatic conditions for 4 to 14 days at 300 or 500°C (healing).3) A cycle of fracturing – healing - fracturing was preformed to study the strength evolution of the fault gouge.4) Samples were deformed at variable strain rates to study the interaction between deformation and healing for 4 to 14 days. The experimentally deformed granitoids were compared to natural fault rock samples. Digital images with different magnifications were used for the analysis of microstructures and grain size distribution. In the experimental samples two types of microstructures are distinguished: (1) cracked grains, where the geometric relationship of the fragments with respect to each other is maintained, and (2) gouge, where the fragments are moved with respect to each other due to the fault displacement. The grain size distribution of quartz and feldspar shows the same characteristics for all samples, regardless of H2O content, confining pressure, temperature and strain rate in gouge and cracked grains: (1) The grain size distribution shows a change in D-value for all samples at grain sizes around 2 to 4 microns. The D-values below 2 to 4 microns range between 0.7 and 1.1, those above 2 to 4 microns between 1.4 and 2.3. (2) For every sample, gouge invariably shows a higher D-value (1.9 to 2.3) than cracked grains (1.4 to 1.7) in the coarser grain size range (>2-4 micron). (3) The largest grain size range analysed (10 - 150 micron) is present in the cracked grains but not in the gouge, while the gouge contains grains <0.08 micron not present in the cracked grains. (4) An increase in axial strain from 25 to 38% (corrsponding to a gamma in the fault zone of about 1 to 5) does not increase the D-values of the gouge. (5) Feldspar shows smaller D-values (1.8-2.1) in gouge than quartz (1.9-2.3) in the larger grain size range (>2-4 microns) indicating more efficient grain size reduction in quartz. The results demonstrate that the rupture event in fault rocks produces very fine grain sizes by initial cracking of grains

as concluded by Wilson et al. (2005). However, displacement in the fault zone produces a post-rupture-processing of the gouge decreasing the grain size further as documented by higher D-values and smaller grain sizes of the gouge compared to the cracked grains. The post-cracking grain size refinement takes place during initial displacement of the fault because a strain increase beyond a gamma of about 1-5 does not change the D-value. Thus, when analysing grain size distributions in fault zones for deriving values of energy release, the further grain size comminution in the gouge during post-rupture processing causes higher values for the surface area of gouge than created during rupture alone and thus will lead to an overestimation the energy released. On the other hand, the grain size comminution takes place during the initial small amounts of shear displacement so that the D-values of the grain size distribution cannot be related to magnitudes of fault displacement as proposed by Sammis et al. (1987). Comparison of natural and experimentally deformed rock: The grain size distribution and its fractal dimension (D) describe the evolution from fresh fault gouge (D > 2.0) to healed fault gouge (D = 1.6). The same grain size distribution and fractal dimensions are observed for fresh fault rock and old natural fault zones, respectively. Healing experiments: The healing of the fault gouge is enhanced by increasing healing time, temperature, and stress. Samples healed during stress release or under low strain rates (10-7s-1 or slower) appear more efficiently healed than samples under hydrostatic conditions. A process similar to pressure solution is probably dominant during slow deformation and in post-seismic creep after the main stress release in earthquake zones. Healing and continued deformation occur simultaneously. Samples that were loaded again after the healing (cycle) show that not all the fault zones of the earlier deformation are reactivated in later deformation. New fault zones are formed adjacent to earlier fault zones. Grains healed after the earlier deformation can still be observed. The same amount of load as for deformation of the unfractured sample is needed to deform the sample with consolidated gouge again. Wilson et al. (2005): Nature 434, p.749-752Sammis et al. (1987): Pageoph 125, p. 777-812