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Deformation and Healing Processes in granitoid Fault Rock in Experiments and Nature.

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The nature of fault gouge has a large influence on the properties of major fault zones in the middle and upper crust. Fracturing leads to a large range of grain sizes. After the main stress release the fault gouge may heal again. Healed fault gouge has a different grain size distribution, a reduced permeability and an altered frictional velocity behaviour compared to unconsolidated fault gouge. In addition to healing the fault gouge, diffusion processes may cause creep in the very small grains formed during fracturing, even at relatively low temperatures. On a large scale, it has been observed that fault zones are reactivated, but the exact mechanisms for this process are still uncertain, despite numerous previous investigations. With this study, we hope to contribute to the understanding of fault rock deformation by comparing the microstructures of fresh, healed and reactivated fault gouge, formed in naturally and experimentally deformed samples of granitoid rock.

Coaxial deformation experiments were carried out on isotropic Verzasca gneiss using a Grigg's deformation apparatus at $300 - 500\,^{\circ}\mathrm{C}$, 500-1000 MPa, strain rates of $10^{-4}s^{-1}$ to $10^{-7}s^{-1}$ and 0.2 %wt H_2O 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 $500\,^{\circ}\mathrm{C}$ (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 originating from the Nojima Fault Zone (Kobe Earthquake, 1995) and from the Alps (deformed in the Tertiary). Digital images with different magnifications were used for the analysis of the microstructures and the grain size distribution.

Comparison of natural and experimentally deformed rock: The analysis of the microstructures of both the natural and experimentally formed fault rock shows that the shape of the grains can be used as a parameter describing the evolution of the fault rock from cracked minerals into fault gouge. 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). These grain size distribution and fractal dimensions are observed as well for fresh fault rock and old healed 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 ($10^{-7}s^{-1}$ 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. These experiments with cycled deformation will be compared to natural rock samples from reactivated fault zones.