Healing mechanisms and healing period of granitoid fault gouge at hypocentre depth *pT*-conditions.

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The period required to heal a fault gouge to a consolidated impermeable rock plays an important role for the recurrence time of earthquakes and the development of fluid flow paths through the earth's crust. The healing processes in fault gouge are not well understood in terms of microstructural processes. Earlier studies propose that under hydrostatic conditions healing is achieved by neck-growth (sealing of the grain to grain contacts), or by cementation (the filling of pore space by material from a super-saturated advecting fluid). Under non-hydrostatic stress healing is driven by a pressure solution process. With this study, we hope to contribute to the further understanding of the fault gouge healing process, by studying the microstructures of experimentally and naturally deformed granitoid samples with different microscopy techniques. To determine the healing period of fault rock we developed a new approach based on the microstructures of laboratory experiments and natural fault systems, especially the change in grain size distribution with temperature and time.

Coaxial deformation and healing experiments were carried out on isotropic Verzasca gneiss using a Grigg's deformation apparatus at T = 300 to 500 °C, P_c = 500 MPa, strain rates of 10^{-4} s^{-1} and 0.2 %wt H_2O added. Samples were fractured to create fault gouge; after fracturing the samples were kept at hydrostatic or non-hydrostatic conditions for 4 hours to 14 days at 200 - 500°C (healing). Thin sections of the samples were prepared and analyzed with a light microscope (LM) connected to a cathodoluminescence camera (CL) and with a scanning electron microscope under back-scattered electron contrast (BSE). Digital images with different magnifications were used for the analysis of the grain shape, grain size, and changes in luminescence. The experimentally deformed granitoids were compared to natural fault rock samples originating from the Alps (deformation in Tertiary) and the Black Forest (Tertiary).

The evolution of fresh experimental fault gouge to healed gouge is different for hydrostatically and non-hydrostatically healed grains: after a few days small bridges connecting grains are observed in hydrostatically healed samples. In non-hydrostatically healed samples small grains coalesce into a solid healed zone. Non-hydrostatic healing is very efficient at 500 °C: low magnification CL reveals fault zones, where the gouge is surrounded by newly precipitated material. On the corresponding BSE micrographs the evidence for the earlier deformation is lost. A BSE micrograph of a sample healed under hydrostatic conditions at 500°C still displays individual grains.

Naturally deformed samples from the Black Forest show two different fracturing events under different temperature conditions with CL, whereas LM and BSE only showed the last event. In CL healing microstructures that were established after the first fracturing event resemble those of the hydrostatically healed samples. Healing after the last fracturing event occurred by cementation, strongly affecting the grain size and grain shape distribution of the fault gouge. Microstructural details of healing of fault gouge, obtained by CL in comparison with LM and BSE, are demonstrated.

We measured the grain size distribution of fault gouge to calculate the healing period for fault gouge. The grain size distribution of fresh fault gouge, described by its D-value (defined as the slope of the log frequency – log grain size histogram), is > 2.0 in both natural and experimental fault zones (Stünitz et al., this conference). For healed granitoid fault gouge D is reduced, typically to 1.58 < D < 1.60 for older natural fault and in our healed samples. Whether or not healing occurs depends on temperature, time and degree of mixing of the gouge. In natural granitoid gouge both polymineralic (well mixed) and monomineralic gouge fractions occur. Polymineralic gouge shows nearly unchanged D-values, even after ~54 Myrs. From our experiments the healing rate of monomineralic quartz and feldspar gouge, described as the change in D-value, is derived. Extrapolation of the laboratory data to natural fault gouges located at 8 - 12 km depth shows that healing of the monomineralic fraction of the gouge occurs within two years.