Geophysical Research Abstracts
Vol. 18, EGU2016-8667, 2016
EGU General Assembly 2016

Slickenline development during fault slip depends on temperature under hydrothermal conditions

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Polished silica discs embedded in synthetic gouge were deformed under hydrothermal conditions to examine i) if there is any relationship between slickenline morphology and P, T, or shear strain, ii) what processes and deformation mechanisms control slickenline development, and iii) the implications of slickenline development for fault rheology. Experiments were performed using the hydrothermal rotary shear apparatus at the HPT laboratory, Utrecht University at 100 or 450˚C, σ_{neff} = 100 MPa, P_f = 100 MPa to shear strains in the range $2.02< \gamma <8.25$. The mechanical records show slip hardening and slip weakening at low and high temperatures, respectively.

Examination of recovered samples on the scanning electron microscope reveals that the disc surfaces are decorated by fine gouge, sometimes arranged in trails, pits, and scratch marks. In the discs deformed at 100˚C the orientation of these slip vector-parallel features varies across a single disc surface. Additionally, only the discs deformed at 450˚C and best developed on higher strain samples, have smooth grooves that extend in one direction over the whole disc surface. White light interferometry confirms a cross sectional wavelength $<7\mu$m and amplitude $<0.5\mu$m. These grooves are slickenlines developed parallel to the direction of relative shear of the gouge and the disc surfaces. In some places, the parts of the grooves below the original disc surface have surfaces decorated by scattered rounded beads of silica $\sim$100nm diameter (composition confirmed by EDS). Conversely, close examination of pits in the 100˚C experiments reveals they contain angular particles ranging $<2\mu$m diameter.

A TEM foil cut perpendicular to the disc surface and inferred slip direction cross-sectioned the undulating surface and the rounded particles. There are no significant systematic dislocation arrays in the adjacent disc quartz, but microfractures are sporadically present. Additionally, amorphous silica fills the space between the rounded quartz beads. We infer that dislocation processes were not important in deformation of the sample surface. Instead, we propose that at both temperatures brittle failure generated microfractures and micro-comminution occurred where gouge particles impacted the disc surfaces. Furthermore, at the higher temperatures, amorphous silica formed on the disc surface. We calculate that 200 nm diameter crystalline quartz particle could precipitate at 450^OC in only 250 second, well within the timeframe of the experiments but that at 100˚C, precipitation takes 8 years.

We therefore suggest formation of silica beads by growth (precipitation) from amorphous silica facilitates slip weakening, smoothing of the fault surface parallel to the slip vector, development of undulations perpendicular to the slip vector, and maintenance of a constant slip direction. This mechanism is likely to be effective on a seismic timescale only at elevated (greenschist or greater) facies conditions.