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The effect of mineral reactions and microstructure on long-term experimental fault zone weakening

Andre R. Niemeijer

Utrecht University, Faculty of Geosciences, HPT Laboratory, Utrecht, Netherlands (a.r.niemeijer@uu.nl)

The frictional properties of fault rocks and, in particular, the velocity dependence of friction and associated rate-and-state parameters, are thought to exert an important control on earthquake nucleation and propagation. Experimental results obtained from natural fault gouges typically show that the velocity dependence of friction is a function of both temperature and sliding velocity, indicating that thermally activated time-dependent processes are fundamentally responsible for causing velocity-weakening behavior in silicate-bearing gouges at earthquake "nucleation velocities" ($\sim$ 1 μm/s) and temperatures around 150-300 °C. In addition, slow experiments at velocities of 10s of nm/s using three different fault gouge types all exhibit major weakening with ongoing displacement at constant velocity. Microstructural and microanalytical analyses demonstrate that the development of a weak through-going foliation as well as the (shear-enhanced) formation of new, weak minerals such as talc or muscovite occurred, which both presumably contributed to the observed weakening. Importantly, the slow deformation rates allow for time-dependent viscous deformation (e.g. pressure solution) to occur at low shear stress within the hard, frictionally strong minerals such as quartz. The results highlight the importance of the chemical effects of fluids and microstructural development on long-term fault weakening under slow loading conditions. The resultant frictionally weak fault gouges allow strain to remain localized, yield a strong permeability anisotropy and provide a barrier for rupture propagation. Along-fault variations in the chemical conditions thus have the potential to produce strong contrasts in frictional properties, which can have a large effect on potential earthquake rupture size and style.