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Slip velocity has major impact on the frictional strength and microstructure of quartz-muscovite gouges under hydrothermal conditions

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Previous friction experiments on rock analogue experiments of mixtures of salt and phyllosilicates, demonstrated the possibility of producing mylonitic fault rocks through the simultaneous operation of pressure solution and frictional sliding. This frictional-viscous flow process produces a strong velocity-dependence of friction, with friction values dropping from 0.8 to ∼0.2-0.3 over just one order of magnitude decrease in sliding velocity. Here, we present the results of rotary shear experiments on simulated fault gouges of 80 wt% quartz and 20 wt% muscovite. Sliding experiments using a four orders of magnitude range of constant velocities (0.03 - 300 μm/s) to a displacement of 30 mm were done at 500 ˚C, 120 MPa effective normal stress and 80 MPa fluid pressure to verify the mechanism at hydrothermal conditions and to link the produced microstructure to the observed strength.

At the lowest sliding velocity tested, final friction reached a value of ∼0.3, which is lower than that of pure muscovite under similar conditions. With increasing sliding velocity, friction increases, reaching a maximum of ∼0.9 at 3 μm/s after which it decreases mildly to ∼0.8 at 300 μm/s.
The bulk microstructure of the sample sheared at 0.03 μm/s shows an anastomosing foliation of muscovite grain intervened by asymmetrical quartz clasts, with an average grain size of about 20 μm, slightly lower than the median starting size (∼49 μm). In contrast, the grains of the sample deformed at 300 micron/s are very small, many of them smaller than distinguishable in the light microscope (i.e. < 1 μm). In addition, the microstructure is characterized by clear bands of strong uniform extinction in P- and B-shear orientations, possibly indicating a Crystallographic Preferred Orientation. These zones of uniform extinction can be found in all samples and their thickness decreases monotonically with decreasing sliding velocity.

The microstructure observed at low velocity, in the frictional-viscous regime, is similar to numerous examples from natural fault rocks (e.g. the Median Tectonic Line and the Zuccale Fault). The slowest sliding velocity employed here corresponds to a shear strain rate of $\sim 3 * 10^{-5}$ s^{-1}, still several orders of magnitude higher than tectonic plate rates ($\sim 10^{-10}$to 10^{-8} for fault thicknesses of 1 to 0.01 m). At natural, lower strain rates, the frictional-viscous flow regime, where friction is low, is predicted to be operative down to temperatures as low as 250 ˚C and possibly even lower for other minerals than quartz.

In contrast to the low velocity regime, microstructures similar to those observed here at high velocity, have not been reported for natural fault rocks, implying that either these do not survive exhumation (possibly due to the very fine grain size), get overprinted by later, slow deformation, or are not formed in the first place. The strain rates here are still well below the values reached during seismic slip and are probably not common values in nature, nor will they be long-lived and thus not impose a large shear strain. Dynamic or static grain growth after a transient, faster slip pulse will most likely obliterate any evidence of slip rates fluctuating between aseismic and seismic. Clearly, more hydrothermal experiments aimed at understanding the link between the fault microstructure and its strength and the variation of these with sliding velocity, are needed.