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Coseismic ultramylonites: An investigation of sub-solidus viscous flow and fault weakening during earthquakes.

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Faults are weak during seismic slip due to the onset of thermally-activated mechanisms, which are dependent on the rock type. Recent experimental work suggests that carbonate-hosted faults are lubricated by viscous flow in nano-granular aggregates displaying ultramylonitic textures. However, their frail nature has often hindered the characterization of the textures and the deformation mechanisms that operate at extreme strain rates (> 10ˇ3), which remain so far poorly investigated and understood.

We explore the formation, evolution and deformation mechanisms of coseismic ultramylonites in carbonate-hosted faults generated during high velocity (1.4 m/s), displacement-controlled shear experiments in a rotary apparatus. Microstructures were analysed using integrated SEM and TEM imaging while detailed crystallographic fabrics were investigated using the electron back-scattered diffraction (EBSD) technique.

Mechanical data show that the strength of the experimental fault decays dynamically with slip, according to a four stage weakening history; each stage is associated with characteristic textures. Microstructural observations show that when the fault is strong (friction coefficients > 0.6) brittle deformation processes are dominant. Cataclasis aided by twinning and crystal plasticity operate and form an extremely comminuted shear band (mean grain size $\sim$ 200 nm). As the fault starts weakening, shear localizes within a well-defined principal slip zone. Here, thermally-activated grain size sensitive (GSS) and insensitive (GSI) creep mechanisms compete with brittle processes in controlling fault strength. GSI mechanisms produce strong monoclinic crystallographic preferred orientations in the slip zone, while textures and crystallographic orientations in adjacent locations do not evolve from the previous deformation stage. By the end of the transient weakening stage, the slip zone has reached a steady state thickness (30 μm) and shows a ultramylonitic texture and sub-micron grain sizes. The intensity of the crystallographic preferred orientation in the coseismic ultramylonite is reduced compared to the previous stage, due to grainsize sensitive creep mechanisms becoming gradually more dominant. As the experimental fault re-strengthens, upon deceleration to arrest, the ultramylonite may be partially reworked by brittle deformation.

Our findings show that the crystallographic orientations of transient microstructures are preserved in the slip zone of coseismic ultramylonites and in narrow, adjacent deactivated layers, where mirror-like surfaces are located. This shows that EBSD techniques can usefully be employed to investigate the deformation mechanisms of coseismic ultramylonites and their evolution during earthquake slip in both experimental and, potentially, natural faults.