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A new interpretation for the nature and significance of mirror surfaces in experimental carbonate seismic faults

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Highly reflective, continuous smooth surfaces, known as "mirror surfaces" (MSs) develop in natural and experimental carbonate faults when sheared at seismic velocities (> 0.1 ms-1); therefore MSs possibly offer a unique evidence of past seismicity. MSs are typically interpreted to be principal slip surfaces where weakening mechanisms are activated by shear heating of contact asperities.
We re-examined these interpretations by performing friction experiments in a rotary shear apparatus on calcite gouge at seismic velocities up to v = 1.4 ms-1 and normal stress σn = 25 MPa to analyse the evolution of microstructures as displacement and temperature increases. During dynamic weakening (e.g., friction coefficient $\mu < 0.2$), sheared gouges consistently develop a well-defined principal slip zone (PSZ) of constant finite thickness (few tens of μm), which shows ultramylonitic texture. It is composed by nano-sized material, which displays polygonal grain shapes, triple junctions and shape preferred orientation, suggesting the operation of grain-size dependent creep mechanisms. MSs occur at both boundaries of the PSZ, where they mark a sharp contrast in grainsize with the sintered, coarser material outside the PSZ. Our observations suggest that, with the onset of dynamic weakening, MSs partition the deformation, forming rheological boundaries of no finite strain that separate strong, little deforming wall rocks from a central weak, actively deforming viscous PSZ.
Furthermore, the monitoring of acoustic emissions (AEs) during the experiments shows the transition between different deformation regimes and supports a multistage weakening history. The AEs dramatically diminish to a silent stage during the transient evolution of friction from peak to low steady state values. We interpret this to be consistent with the transition from cataclasis to viscous flow deformation mechanisms observed within the PSZ. AEs reappear during the decelerating latest stages of deformation, when the sudden decrease in temperature causes embrittlement of the material and thermal cracking, overprinting the viscous microstructures.
Hence, we propose that the MSs may not correspond to frictional slip surfaces in the classical sense, but mark the sharp rheological contrast between the sintered peripheral material and the weaker PSZ, where fault lubrication is sustained by thermal and grain-size-dependent creep mechanisms.