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From flash heating to frictional melting: capturing the incipient microstructural development of experimental fault interfaces

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The propagation of seismic slip is often attributed to the activation of weakening mechanisms at high slip velocities, resulting from complex thermo-mechanical changes to asperities at the slip interface. Despite considerable experimental effort being directed towards understanding high-velocity fault behaviour, the mechanisms that drive the onset of instability and formative stages of weakening remain an area of considerable uncertainty. Here we present new evidence for the very rapid onset of microstructural changes on experimental faults surfaces that have been sheared over a range of slip velocities and under stress conditions comparable to upper- to mid-crustal conditions (σn = 92-320MPa). Experiments have been undertaken using pre-ground fault surfaces of Fontainebleau sandstone in a classic triaxial configuration. The traditional high-precision mechanical data of the gas-medium apparatus has been supplemented by the installation of a custom built interferometric sensor that provides microsecond resolution of displacement during stick-slip events. Deformed samples have been analysed using multiple techniques, including FE-SEM and FIB-TEM, that provide insights into physical and structural changes to asperity contacts over a range of scales.

Significant findings include recognition of textures that capture the transition from mechanical amorphisation, to flash heating and the early stages of frictional melting. Our results include the formation of a partially amorphous nano-gouge layer during aseismic sliding, the development of amorphous zones at asperity tips and the generation of frictional melt during stick-slip. While the average fault temperature is estimated to remain well below the quartz solidus ($\sim$1700ºC), we show that extreme localised heating occurs during all stick-slip events, with a clear correlation between slip velocity and the morphology of the amorphous material produced. These microstructural changes occur over slip distances that are several orders of magnitude less than have been previously identified during high-velocity experiments, occurring within 50μm of the commencement of slip. The rapid onset of micromechanical and microstructural changes has implications for understanding the dynamics of fault rupture including weakening distances and co-seismic fault strength. It also suggests that in natural fault zones, pseudotachylytes may, in fact, be far more common than field observations suggest.