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Fabric evolution of quartz-gouge from stable sliding to stick-slip and implications for fault slip mode

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Numerous laboratory studies have documented the mechanisms that control the earthquake nucleation phase, when fault slip velocity is slow (<0.001 cm/s), or the earthquake dynamic phase when fault slips at high velocities (>1 cm/s). Although these studies are fundamental to characterize specific phases of the seismic cycle, they are not able of capturing the entire evolution of fabric and mechanical data from stable sliding to stick-slip. Here we report on laboratory experiments that illuminate the mechanisms controlling the transition from stable sliding (v= 0.001 cm/s) to dynamic stick-slip (v > 1 cm/s), by altering the elastic stiffness of the loading system (k) to match the critical rheologic stiffness of the fault gouge (kc). In particular we observe that the stiffness ratio, K = kc/k, controls the transition from slow-and-silent (K = 0.9, slip velocity 0.01 cm/s, stress drop 0.5 MPa, slip duration 0.5 s) to fast-and-audible (K = 0.5, slip velocity 3 cm/s, stress drop 2.4 MPa, slip duration 0.003 s) slip events. Microstructural observations show that with accumulated strain, deformation localizes along sharp shear planes consisting of nano-metric grains, which favour the development of frictional instabilities. Once this fabric is established, for the tested boundary conditions (normal stress 13-35 MPa), fault fabric does not change significantly with slip velocity, and fault slip behaviour is mainly controlled by the interplay between fault rheological properties and the stiffness of the loading system. As applied to tectonic faults, our results suggest that a single fault segment can experience a spectrum of fault slip behaviour depending on the evolution of fault rock frictional properties and elastic conditions of the loading system.