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Fault zone roughness controls slip stability

Christopher Harbord, Stefan Nielsen, and Nicola De Paola
Rock Mechanics Laboratory, Department of Earth Sciences, Durham University, United Kingdom
(c.w.a.harbord@durham.ac.uk)

Fault roughness is an important control factor in the mechanical behaviour of fault zones, in particular the frictional slip stability and subsequent earthquake nucleation. Despite this, there is little experimental quantification as to the effects of varying roughness upon rate- and state-dependant friction (RSF). Utilising a triaxial deformation apparatus and a novel adaptation of the direct shear methodology to simulate initially bare faults in Westerly Granite, we performed a series of velocity step frictional sliding experiments. Initial root mean square roughnesses (Sq) was varied in the range 6x$10^{-7} - 2.4$x10^{-5} m. We also investigated the effects upon slip stability of normal stress variation in the range $\sigma_n = 30 - 200$ MPa, and slip velocity between $0.1 - 10$ μm s^{-1}. A transition from stable sliding to unstable slip (manifested by stick-slip and slow slip events) was observed, depending on the parameter combination, thus covering the full spectrum of fault slip behaviours. At low normal stress ($\sigma_n = 30$MPa) smooth faults (Sq$<$ 1x10^{-6} m) are conditional unstable (stress drops on slow slip events upon velocity increase), with strongly velocity weakening friction. When normal stress is increased to intermediate values ($\sigma_n = 100 - 150$ MPa), smooth faults (Sq$<$ 1x10^{-6} m) are fully unstable and generate seismic stick-slip behaviour. However at higher normal stress ($\sigma_n = 200$ MPa) a transition from unstable to stable sliding is observed for smooth faults, which is not expected using RSF stability criteria. At all conditions sliding is stable for rough faults (Sq$>$ 1x10^{-6} m). We find that instability can develop when the ratio of fault to critical stiffness $\frac{k_f}{k_c} > 10$, or, alternatively, even when $a - b > 0$ at $\sigma_n = 150$MPa, suggesting that bare surfaces may not strictly obey the R+S stability condition. Additionally we present white light interferometry and SEM analysis of experimentally deformed samples which provide information about the distribution and physical nature of frictional contact. Significantly we suggest that bare fault surfaces may require a different stability criterion (based on roughness, normal stress and velocity) to those with gouge, where RSF is already very successful.