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The role of fluid pressure on slip instability

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Faults were first thought to relieve stress either through continuous aseismic sliding, or as earthquakes resulting from sudden rupture of locked faults. Recent data from geodetic and global seismic networks revealed a remarkable array of new slip instabilities. This discovery creates new challenges to our understanding of the mechanics of earthquakes and faulting. Slow slip phenomena, including non-volcanic tremor, low to very low frequency earthquakes, episodic tremor and slip, share a common underlying mechanism: shear slip (e.g., Ide et al., 2007). Seismic tomographic imaging of elastic properties (e.g., Audet et al. 2010) suggests that high fluid pore pressure may be responsible for these events. The working hypothesis is that high pore pressure reduces the effective normal stress and thus enhances slip instability. However, to date, experimental evidence on how different slip instabilities results from high pore pressure is still missing. In this study, we conducted triaxial deformation experiments to investigate how the reduction of effective normal stress affects slip instability and fracture propagation. Water saturated porous sedimentary rocks were deformed at constant strain rates and under fully drained conditions. We designed loading configurations so that brittle failure and frictional instability in samples deformed under decreasing effective stress ('high pore pressure' tests) can be compared to those under increasing effective stress (conventional tests).

Under the conventional loading, failure modes in deformed samples change from brittle faulting to cataclastic flow with increasing confinements. At the transitional regime, slip along the fault becomes more stable. Our data show that high pore pressure facilitates fault slip thus enhances slip instability. At a low confinement, unstable faulting is observed in samples deformed under either the conventional or 'high pore pressure' loading configuration. Interestingly, the fracture energy release at 'high pore pressure' conditions is associated with a more gradual fault slip than that under the conventional loading. At confinements high enough to inhibit instability under the conventional loading (i.e. in the transitional regime), samples under 'high pore pressure' (at otherwise identical stress conditions) show enhanced slip instability. Compared to the brittle faulting process at low confinements, fault slip at "high pore pressure" is accompanied by smaller stress drop and the fracture energy release rate is slower. Microstructural observations on deformed samples show that at 'high pore pressure' conditions, the microcracks form a well-connected network, which may explain the slip enhancement. The mechanical and microstructural data provide laboratory constraints on mechanisms responsible for slow slip events.