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Experimental investigations on the brittleness and slowness of shear rupture propagation in porous saturated rocks

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Pore fluid pressure and shear rupture are long known to be interwoven: an increase in pore fluid pressure can unclamp a fault by reducing the effective normal stress and thus cause the fault to slip at lower shear stress. This mechanism is well illustrated by induced seismicity near fluid injection. More recently, several lines of evidence suggest that pore fluid pressure play a significant role in slow slip phenomena, which include non-volcanic tremors, low to very low frequency earthquakes, episodic tremor and slip. However, the differences in seismic signals between the induced but regular seismicity and the slow slips indicate different rupture processes which question our understanding of the source processes.

In this study, we designed loading configurations and 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. Using the existing theoretical framework (bifurcation model, slip weakening model), we provide quantitative measure of the differences between slow and regular slip behaviors. In the brittle faulting regime, generally considered to allow the dynamic propagation of a shear fracture which produces regular earthquakes, excess pore pressure does not induce any change in slip behavior but enhanced seismic slip by lowering the shear strength which can explain the increased seismicity associated with elevated pore pressure near reservoirs. In the transitional regime where aseismic creep takes place instead, failure process should lead to a diffused, velocity strengthening aseismic fault. However, in these conditions, excess pore pressure enables slip to occur with quantifiable differences from that in brittle regime, showing a slower slip rate and smaller stress drop. A decrease of normal stress only produces similar rupture characteristics than observed in the brittle faulting regime. Microstructural observations highlight that increasing pore pressure allows overcoming the dilatancy strengthening. Moreover, our data show that if a rock already ruptures in a slow manner in the brittle regime, increasing pore pressure allows sustaining a more brittle slip behavior. Further observations even suggest that there may exist a continuous spectrum of slip rate and energy budget between ordinary earthquake (rapid slip) and slow slip phenomena.