Dilatancy hardening, rupture stabilization and instability in hydraulically isolated faults

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Delayed failure or slip stabilization are expected outcomes of transient dilatancy and associated loss of pore pressure in isolated faults during rupture nucleation. Segall and Rice (1995), for example, developed relationships for pore pressure transients in the rate and state (r-s) friction formalism. They considered pore volume changes that were log(velocity) dependent and, depending on the hydraulic diffusivity and fault/fluid compressibility, could significantly change fault stability and rupture nucleation properties. Despite the theoretical importance of transient pore pressure effects, few laboratory experiments exist that show the effect of variable pore pressure in hydraulically isolated faults. This is due in large part to the difficulties involved in measuring pore pressure directly in isolated faults. We report on triaxial deformation of model sawcut faults in Westerly granite at normal stresses to 197 MPa. Samples were 76.2 mm-diameter cylinders with a fault inclined 30° to the sample axis. Tests were performed on bare surface granite and on faults containing 1 mm quartz gouge. Fault pore pressure was measured directly with a miniature pressure transducer with fast frequency response. Velocity-stepping experiments showed log(velocity) pressure drops as large as 4 MPa that are consistent with Segall and Rice (1995) and often larger than intrinsic r-s dependent strength changes. However, for large velocity steps the initial pressure response was a rapid increase that led to either slow slip or dynamic failure. We attribute this sudden pore pressure increase to rapid compaction as the open pore structure in the gouge became unstable and collapsed. Since this effect is only observed during rapid velocity increase, it is most likely to occur as a rupture front propagates along the fault. In this case, the pore collapse and associated weakening could contribute to an overall stress drop and is likely to slow rupture propagation. For example, a 4 MPa pore pressure rise on a fault with 40 MPa effective normal stress could result in a 2 to 3 MPa loss of shear strength, a strength loss much larger than would be predicted from typical r-s parameters.