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How dilatancy-induced pore pressure changes control rupture and slip during failure experiments in crystalline rock.

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Failure and fault slip in crystalline rocks is associated with dilation. When pore fluids are present and drainage is insufficient, dilation leads to pore pressure drops, which in turn lead to strengthening of the material. We conducted laboratory rock fracture experiments with direct in-situ fluid pressure measurements which demonstrate that dynamic rupture propagation and fault slip can be stabilised (i.e., become quasi-static) by such a dilatancy strengthening effect. We also observe that, for the same effective pressures but lower pore fluid pressures, the stabilisation process may be arrested when the pore fluid pressure approaches zero and vaporises, resulting in dynamic shear failure.

We use acoustic emission locations and our fluid pressure sensors to further detail dilatancy-induced stable failure by tracking the progression of the rupture front (i.e., creation of the fault) and the active slip patches of the newly formed fault. In doing so, we are able to link local pore pressure records to the position of the rupture front where dilation is strongest. We see minimal slip in the wake of the rupture front. Once the fault is completed, we observe that the entire fault slips for up to a few minutes, driven by pore pressure recharge of the fault zone. Hence, we directly observe decoupling of rupture and "after"-slip that would otherwise – in a dynamic failure – occur simultaneously.

All our observations are quantitatively explained by a spring-slider model combining slip-weakening behaviour, slip-induced dilation, and pore fluid diffusion. Using our data in an inverse problem, we estimate the key parameters controlling rupture stabilization: fault dilation rate and fault zone storage. These estimates are used to make predictions for the pore pressure drop associated with faulting, and where in the crust we may expect dilatancy stabilisation or vaporisation during earthquakes. For intact rock and well consolidated faults, we expect strong dilatancy strengthening between 4 and 6 km depth regardless of ambient pore pressure, and at greater depths when the ambient pore pressure approaches lithostatic pressure. In the uppermost part of the crust (<4 km), we predict vaporisation of pore fluids that limits dilatancy strengthening.