Laboratory observations of frictional stability and fault zone evolution under heterogeneous friction, rheology, and stress conditions

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Natural faults experience a variety of frictional, rheological, and stress heterogeneities. To investigate the effects of these heterogeneities on seismic stability and the mode of fault slip behavior, laboratory experiments were conducted using a biaxial shearing apparatus with a 0.76 m by 0.076 m simulated fault where 2.5 to 5 mm thick gouge layers were sheared at applied normal stresses of 7 to 12 MPa for 25 mm of cumulative slip. Laboratory faults consisted of uniform layers of gouge, homogeneous mixtures, and/or heterogeneous patches of talc, quartz, and gypsum minerals. Experiments with a uniform layer of velocity weakening fault gouge revealed the development of two asperities at the highly stressed ends of the fault that could fail independently, and creep fronts that facilitated interaction between asperities. This behavior was also reproduced with simple numerical simulations that employ rate- and state-dependent friction. In other experiments, the fault consisted of patches of alternating velocity strengthening and velocity weakening fault gouges. Patch size and location were varied to understand how earthquake ruptures accelerate or decelerate in this heterogeneous environment. These experiments revealed that a velocity weakening fault patch was more likely to remain stable if located next to a velocity strengthening fault patch. However, stability was dependent on the patch sizes and location relative to where the load is applied. In certain cases, some sections of the fault slipped unstably while others slid stably. These experiments, and matching numerical models, highlight the complexity that can arise on natural faults due to frictional, rheological, and stress heterogeneities.