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Stresses, deformation, and seismic events on scaled experimental faults with heterogeneous fault segments and comparison to numerical modeling

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Faults in the upper crust cross-cut many different lithologies, which cause the composition of the fault rocks to vary. Each different fault rock segment may have specific mechanical properties, e.g. there may be stronger and weaker segments, and segments prone to unstable slip or creeping. This leads to heterogeneous deformation and stresses along such faults, and a heterogeneous distribution of seismic events. We address the influence of fault variability on stress, deformation, and seismicity using a combination of scaled laboratory fault and numerical modeling. A vertical fault was created along the diagonal of a 30 x 20 x 5 cm block of PMMA, along which a 2 mm thick gouge layer was deposited. Gouge materials of different characteristics were used to create various segments along the fault; quartz (average strength, stable sliding), kaolinite (weak, stable sliding), and gypsum (average strength, unstable sliding). The sample assembly was placed in a horizontal biaxial deformation apparatus, and shear displacement was enforced along the vertical fault. Multiple observations were made: 1) Acoustic emissions were continuously recorded at 3 MHz to observe the occurrence of stick-slips (micro-seismicity), 2) Photo-elastic effects (indicative of the differential stress) were recorded in the transparent set of PMMA wall-rocks using a high-speed camera, and 3) particle tracking was conducted on a speckle painted set of PMMA wall-rocks to study the deformation in the wall-rocks flanking the fault. All three observation methods show how the heterogeneous fault gouge exerts a strong control on the fault behavior. For example, a strong, unstable segment of gypsum flanked by two weaker kaolinite segments show strong stress concentrations develop near the edges of the strong segment, with at the same time most of acoustic emissions being located at the edge of this strong segment. The measurements of differential stress, strain and acoustic emissions provide a strong means to compare the scaled experiment to modeling results. In a finite-element model we reproduce the laboratory experiments, and compare the modeled stresses and strains to the observations and we compare the nucleation of seismic instability to the location of acoustic emissions. The model aids in understanding how the stresses and strains may vary as a result of fault heterogeneity, but also as a result of the boundary conditions inherent to a laboratory setup. The scaled experimental setup and modeling results also provide a means explain and compare with observations made at a larger scale, for example geodetic and seismological measurements along crustal scale faults.