EGU21-5275
https://doi.org/10.5194/egusphere-egu21-5275
EGU General Assembly 2021

Fluid-induced Seismicity Depends on Injection Rate

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Fluid injection causes fault slip that is partitioned in aseismic and seismic moment release. EGS stimulation campaigns have shown that in addition to total fluid volume injected also the rates of injection and fluid pressure increase affect seismic moment release. We investigate the effect of injection rate on slip characteristics, strain partitioning and energy budget in laboratory fluid injection experiments on reservoir sandstone samples in a triaxial deformation apparatus equipped with a 16-channel acoustic emission (AE) recording system. We injected fluid in sawcut samples containing a critically stressed fault at different pressurization rates. In general, fluid-induced fault deformation is dominantly aseismic. We find slow stick-slip events are induced at high fluid pressurization rate while steady fault creep occurs in response to low fluid pressurization rate. The released total seismic moment is found to be related to total injected volume, independent of fault slip behavior. Seismic moment release rate of AE is related to measured fault slip velocity. Total potential energy change and fracture energy release rate are defined by fault stiffness and largely independent of injection rate. Breakdown power density scales with slip rate and is significantly higher for fast injection and pressurization rates. The relation between moment release and injected volume is affected by fault slip behavior, characterized by a linear relation for slip at constant rate and fault creep while a cubic relation is evident for unstable and dynamic slip. Our experimental results allow separating a stable pressure-controlled injection phase with low rate of energy dissipation from a run-away phase, where breakdown power is high and cumulative moment release with injected volume is non-linear.