Geophysical Research Abstracts
Vol. 18, EGU2016-16043, 2016
EGU General Assembly 2016

Synthetic modeling of a fluid injection-induced fault rupture with slip-rate dependent friction coefficient

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Poro-elastic stress and effective stress reduction associated with deep underground fluid injection can potentially trigger shear rupture along pre-existing faults. We modeled an idealized CO_2 injection scenario, to assess the effects on faults of the first phase of a generic CO_2 aquifer storage operation. We used coupled multiphase fluid flow and geomechanical numerical modeling to evaluate the stress and pressure perturbations induced by fluid injection and the response of a nearby normal fault. Slip-rate dependent friction and inertial effects have been aken into account during rupture. Contact elements have been used to take into account the frictional behavior of the rupture plane.

We investigated different scenarios of injection rate to induce rupture on the fault, employing various fault rheologies. Published laboratory data on CO_2-saturated intact and crushed rock samples, representative of a potential target aquifer, sealing formation and fault gouge, have been used to define a scenario where different fault rheologies apply at different depths.

Nucleation of fault rupture takes place at the bottom of the reservoir, in agreement with analytical poro-elastic stress calculations, considering injection-induced reservoir inflation and the tectonic scenario. For the stress state here considered, the first triggered rupture always produces the largest rupture length and slip magnitude, correlated with the fault rheology. Velocity weakening produces larger ruptures and generates larger magnitude seismic events. Heterogeneous faults have been considered including velocity-weakening or velocity strengthening sections inside and below the aquifer, while upper sections being velocity-neutral. Nucleation of rupture in a velocity strengthening section results in a limited rupture extension, both in terms of maximum slip and rupture length. For a heterogeneous fault with nucleation in a velocity-weakening section, the rupture may propagate into the overlying velocity-neutral section, in cases when the velocity weakening and associated friction drop is large enough.