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The influence of fault permeability evolution and stress state on injection-induced seismicity

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Understanding the triggering mechanisms of injection-induced seismicity is fundamental to effective seismic hazard assessment and mitigation. Various mechanisms have been proposed. Fluid injections into reservoir formations can sometimes produce earthquakes on faults, by increasing the pore pressure or by perturbating the elastic stresses around the injection. Earthquakes can also be triggered far from the injection by driving forces that involve aseismic deformation on the fault. The relationship between seismic and aseismic fault slip during injection is particularly complex due to the coupling between fluid pressure diffusion, evolving stress and hydromechanical properties.
In this study, we aim to investigate, through 3D hydromechanical modeling, the main fault parameters that govern the aseismic and seismic deformations on a slip-weakening fault that is subjected a local injection of fluid. We simulate a variable injection rate and vary the fault permeability, frictional properties and the initial state of stress. A synthetic seismic catalog is calculated during each simulation to determine the seismic source parameters.
Through our investigations, we observe that a few parameters, including the initial fault permeability and the fault criticality to failure, influence the size of the aseismic zone around the injection point and the seismicity behavior. One interesting finding is that the size of the aseismic zone is affected by the steepness of the gradient between the effective normal stress and the strength in the immediate vicinity of injection. This aseismic behavior is also promoted by a large initial permeability or a small criticality. Conversely, a small initial permeability tends to increase the seismicity close to the injection. Moreover, our models indicate that the maximal distance of seismic events from injection is controlled by the evolving permeability front during pressurization. The similar temporal evolution of the permeability and of the seismicity rate highlights a possible mechanism constraining the relationship between friction and permeability evolution and seismic productivity. These numerical experiments represent a promising attempt to understand the interplay of seismic and aseismic deformations during complex interaction among fault permeability and frictional processes during fluid injection. The subsequent step is to compare with geophysical observations from in-situ experiments and large-scale operational injection sites to better constrain the range of fluid perturbations favoring aseismic slip or seismic rupture.