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Aseismic and seismic slip induced by fluid injection from poroelastic and rate-state friction modeling with application to the Fox Creek, Alberta, 2013-2015 earthquake sequence

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Stress change and pore pressure evolution caused by fluid injection has been postulated as a key factor for inducing both moderate-size earthquakes and aseismic slip on pre-existing faults. In this study, we have developed a numerical model that simulates aseismic and seismic slip in a rate-and-state friction framework with stress perturbations provided by a poroelastic model for multistage hydraulic fracturing scenarios. The coupling of external stress changes and their spatiotemporal variation to fault frictional strength in a single computational procedure provides a quantitative understanding of the source processes (i.e. slip rate, triggering threshold) of the spectrum of induced slip modes.

We apply the physics-based fault slip model to the induced earthquake sequences near Fox Creek, Alberta, in the western Canada sedimentary basin, where two earthquakes of ML4.4 (2015/01/23) and Mw4.6 (2015/06/13) were potentially induced by nearby hydraulic fracturing activity. In particular, we use the relocated December 2013 seismicity sequence to approximate the fault orientation, and find the seismicity migration spatiotemporally correlate with the positive Coulomb stress changes calculated by the poroelastic model. When the poroelastic stress changes are introduced to the rate-state friction model as external perturbations, we find that the fault, previously undergoing aseismic slip, can be perturbed into seismic rupturing even after hydraulic fracturing has stopped but stress perturbations continues to evolve in the medium (Scenario 1). In an end-member case (Scenario 2) where stress perturbations are instantaneously returned to zero at shut-in, we observe aseismic slip; all other conditions unchanged from Scenario 1. Seismic slip is also more readily induced by larger stress perturbations. Our preliminary results thus suggest the design of flow-back strategy, either passively evolving in the medium or actively dropping to pre-perturbation level, is essential to inducing seismic versus aseismic slip on pre-existing faults.