Coupling poroelastic stress change and rate-state fault slip models to simulate fluid injection induced seismic and aseismic slip

Yajing Liu¹, Alessandro Verdecchia¹, Kai Deng², and Rebecca Harrington³
¹McGill University, Earth and Planetary Sciences, Westmount, Canada (yajing.liu@mcgill.ca)
²College of Geophysics, Chengdu University of Technology, China
³Institute for Geology, Mineralogy and Geophysics, Ruhr-Universität Bochum, Germany

Fluid injection in unconventional hydrocarbon resource exploration can introduce poroelastic stress and pore pressure changes, which in some cases may lead to aseismic slip on pre-existing fractures or faults. All three processes have been proposed as candidates for inducing earthquakes up to 10s of kilometers from injection wells. In this study, we examine their relative roles in triggering fault slip under both wastewater disposal and hydraulic fracturing scenarios. We first present modeling results of poroelastic stress changes on a previously unmapped fault near Cushing, Oklahoma, due to injection at multiple wastewater disposal wells within ~ 10 km of distance, where over 100 small to moderate earthquakes were reported between 2015/09 to 2016/11 including a Mw5.0 event at the end of the sequence. Despite the much larger amplitude of pore pressure change, we find that earthquake hypocenters are well correlated with positive shear stress change, which dominates the regimes of positive Coulomb stress change encouraging failure. Depending on the relative location of the disposal well to the recipient fault and its sense of motion, fluid injection can introduce either positive or negative Coulomb stress changes, therefore promoting or inhibiting seismicity. Our results suggest that interaction between multiple injection wells needs to be considered in induced seismicity hazard assessment, particularly for areas of dense well distributions. Next, we plan to apply the model to simulate poroelastic stress changes due to multi-stage hydraulic fracturing wells near Dawson Creek, British Columbia, where a dense local broadband seismic array has been in operation since 2016. We will investigate the relative amplitudes, time scales, and spatial ranges of pore pressure versus solid matrix stress changes in influencing local seismicity.

Finally, we have developed a rate-state friction framework for calculating slip on a pre-existing fault under stress perturbations for both the disposal and hydraulic fracturing cases. Preliminary fault slip simulation results suggest that fault response (aseismic versus seismic) highly depends on 1) the relative timing in the intrinsic earthquake cycle (under tectonic loading) when the stress perturbation is introduced, 2) the amplitude of the perturbation relative to the background fault stress state, and 3) the duration of the perturbation relative to the “memory” timescale governed by the rate-state properties of the fault. Our modeling results suggest the design of injection parameters could be critical for preventing the onset of seismic slip.