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Numerical Analysis of the Induced Seismicity Triggered by Hydraulic Fracturing in the Duvernay Formation in Alberta, CA

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In the past decades, induced seismicity has become a major concern due to its correlation with oil and gas production and wastewater disposal. Unlike the induced seismicity observed in the United States that is associated with massive saltwater disposal, the induced seismicity observed in the Duvernay formation, a shale target in Alberta, Western Canada, is associated with hydraulic fracturing operations. In this work, we explore the possible mechanisms and the hydro-geological factors responsible for the seismic events that occurred between 2014 and 2015 in the Duvernay formation. By a two-dimensional finite element poroelastic model, using COMSOL Multiphysics, we couple fluid flow and solid deformation to estimate the change in the Coulomb Failure Stress (CFS) along two critically stressed faults existing near the hydraulic fracturing operations. One fault (Fault 1) is 1.01 km away from the location of hydraulic fractures while the second fault (Fault 2) is 0.425 km below the location of hydraulic fractures. The variations of the CFS along the two pre-existing faults are analyzed and compared to the seismic events obtained from the observational data in the Duvernay formation from December 2014 to March 2015 (Bao & Eaton, 2016). Our results show that most of the seismic events correlate spatially and temporally with positive CFS values that imply a risk of failure. During the early stages of hydraulic fracturing, the triggering failure mechanism of “Fault 1” is the increase in the shear stress on portions of the fault that are under extension and that of “Fault 2” is the pore pressure diffusion. Moreover, the distance between the centers of the two faults must range between 1.5 km and 2 km for the CFS results to agree with the observed seismic events. Under this condition, the shallower sections of “Fault 1” are under compression and show a stabilizing behavior (i.e., negative CFS) that is confirmed by the lack of seismic events from observational data, and the deeper sections of “Fault 1” are under extension and show a destabilizing behavior (i.e., positive CFS), which correlates with the measured seismic events. If the distance between “Fault 1” and “Fault 2” is less than 1.5 km, the shallower section of “Fault 1” would be destabilized by the effect of pore pressure, which does not agree with the observed seismic data. Moreover, if the distance between “Fault 1” and “Fault 2” is greater than 2 km, “Fault 1” would be entirely stabilized. Hence, the position of the faults with respect to the location of the hydraulic fracturing operations played an important role in the induced earthquakes triggering mechanisms and in the spatiotemporal distribution of the seismic events.