Microseismic Geomechanical Investigation of the Impact of Fracturing Fluid Viscosity on Seismic Hazard

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Summary

In this paper, we use a coupled hydraulic-geomechanical-seismic simulation to examine hydraulic fracture activation of a critically stressed fault and associated projected seismicity. Comparing simulations performed with different hydraulic fracture fluid viscosities, we examine the associated relative seismic hazard changes. We find a scenario of pumping a slickwater system, results in long hydraulic fracture lengths and significant fluid invasion into the fault. The area of the pressurized fault and associated fault slip resulted in increased magnitudes. Alternatively, pumping a more viscous fluid consistent with a 70-quality energized foam system, produced shorter hydraulic fracture lengths and less fluid invasion into the fault. The magnitude of the associated seismicity was reduced. The study suggests that switching from a slickwater fracture to either gel or an energized foam could potentially offer a seismic hazard management tool that could be examined using a comprehensive field test.

Introduction

With the increase of hydraulic fracturing induced seismicity in the Montney and Duvernay shales, focus has looked towards potential operational mitigation strategies to reduce seismic hazard if seismic events are experienced. Typical operational changes include reducing injection energy by reducing injection rates or total volumes, skipping stages or pausing fracturing operations either temporarily or in a worse case scenario completely. Empirical observations have been made about the impact of some of these scenarios (e.g. Maxwell et al., 2015), although the variability in seismogenic potential that is experienced even between adjacent fracturing stages makes it challenging to define the effectiveness of these different strategies. Microseismic geomechanical simulation offers an opportunity to investigate such strategies, assess basic mechanisms and quantify the relative seismic hazard (e.g. Grob et al., 2016).

In this study, we use an existing, calibrated geomechanical model of the microseismic response of a hydraulic fracture stage in the Horn River Basin (Maxwell et al., 2016) to investigate the impact of pumping various fluid systems with different fluid viscosities. Compared to a low viscosity fluid system such as slickwater, viscous fracturing fluids will result in less fluid penetration into pre-existing fractures and shorter, wider hydraulic fractures. Fluid viscosity may therefore have an impact on managing fault slip and offer another operational option to mitigate seismic hazard. Here we use the calibrated Horn River microseismic geomechanical model to examine hydraulic fracture network growth and associated fault activation for different common fracture fluid systems.

Horn River Model

A microseismic geomechanical simulation was performed to match observed microseismicity and modeled events for an ‘as pumped’ gel fracture stage (Figure 1). The model was calibrated by quantitatively matching the observed and modeled microseismic moment distribution (Maxwell et al., 2016). Using this calibrated model, we then simulated injecting slickwater at a rate, volume and proppant schedule typically used in the field (9.6 m^3/min for 55 minutes). As expected, the slickwater frac resulted in increased fluid diffusion into the pre-existing fractures (the discrete fracture network or DFN) and created hydraulic fracture half-lengths roughly double (approximately 500 m compared to 250 m) the original gel fracture dimensions. The largest microseismic event was about Mw~0.5.

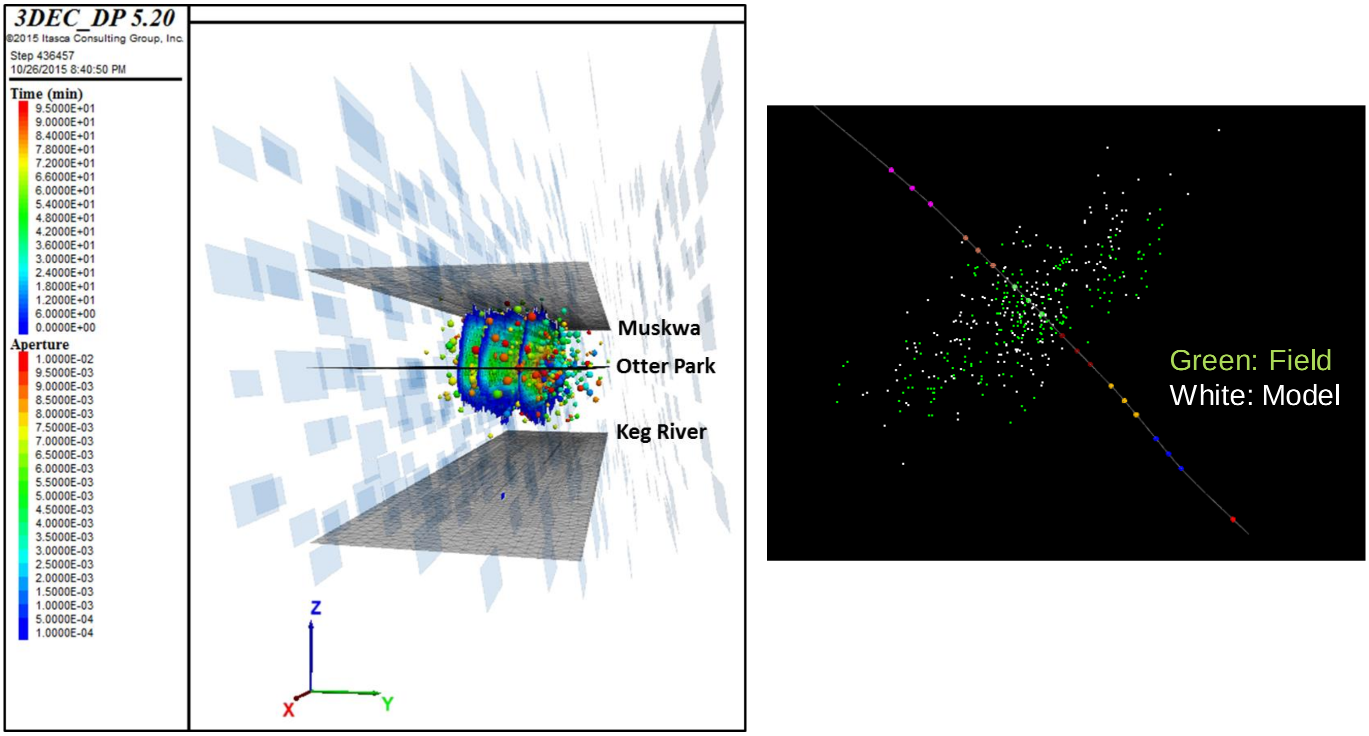

Figure 1. Perspective view of a hydraulic fracture network (left), consisting of three primary hydraulic fractures (contoured by aperture) and associated microseismic events (colored by time). This Horn River Basin model was calibrated to match microseismic recorded during a hydraulic fracture stage (right). From Maxwell et al. 2016.

Fault Model

The slickwater frac model was then repeated including a pre-existing fault approximately 100 m away from the treatement well and at an angle to the well (Figure 2) to study fault activation. The fault was initially hydraulically sealed and close to critically stressed with a friction angle of 30 and 1 MPa cohesion. Once the fault experiences mechanical slip, fluid was allowed to flow along the fault plane where the hydraulic conductivity was controlled by the fault aperture. The slickwater hydraulic fracture resulted in slip on the fault once the hydraulic fracture intersected the fault plane, and the fluid pressure released the normal clamping force. After the hydraulic fracture intersected the fault, fluid invasion and associated slip extended a few hundred meters, resulting in the relatively larger magnitudes as the potential slip area grew. Figure 2 also shows the time evolution of the synthetic microseismicity during the injection. The dynamics of the fault slip were simulated, and modeled microseismic magntiudes were found to increase to Mw ~ 1.5.

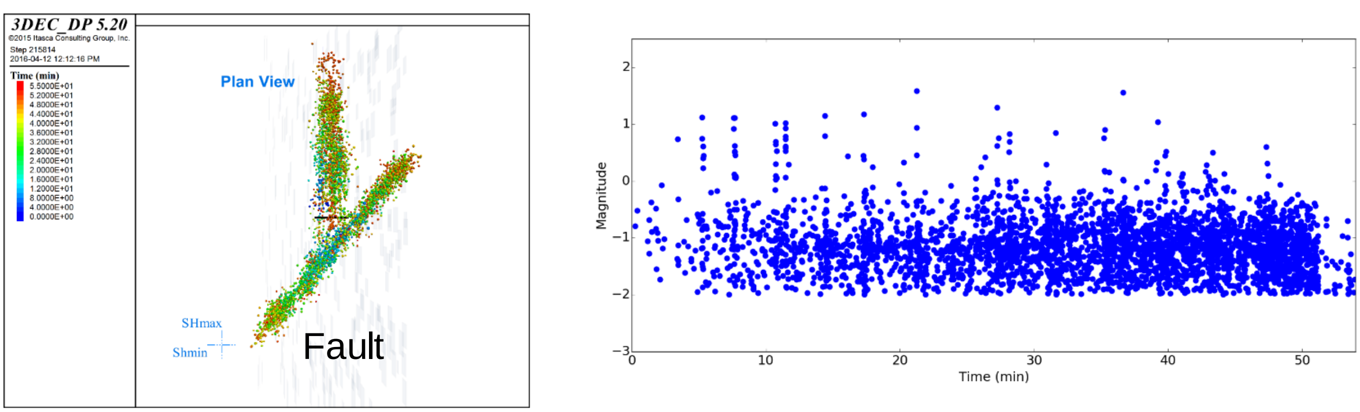

Figure 2. Simulation of a slickwater fracture activating a fault (left) and associated seismicity during the fracturing (right).

In contrast, the models were repeated with a typical energized fluid system, using fluid characteristics (density and viscosity) and an injection schedule (5 m^3/min for 76 mins) typical of that used to pump a 70-quality foam. The geomechanical attributes including the DFN and faults were kept identical. For the scenario with no fault, the hydraulic fracture network had a smaller half-length (roughly 200 m) and less fluid invasion into the DFN. Significantly fewer and smaller magnitude microseismicity (maximum Mw of about -0.5) was forecasted by the model consistent with restricted flow into the DFN and less fracture area to encounter pre-existing fractures. The model with the same fault parameters as the slickwater case also had fewer and smaller magnitude microseismicity as shown in Figure 3. With the energized fluid, the biggest event was approximately Mw ~ 0.5.

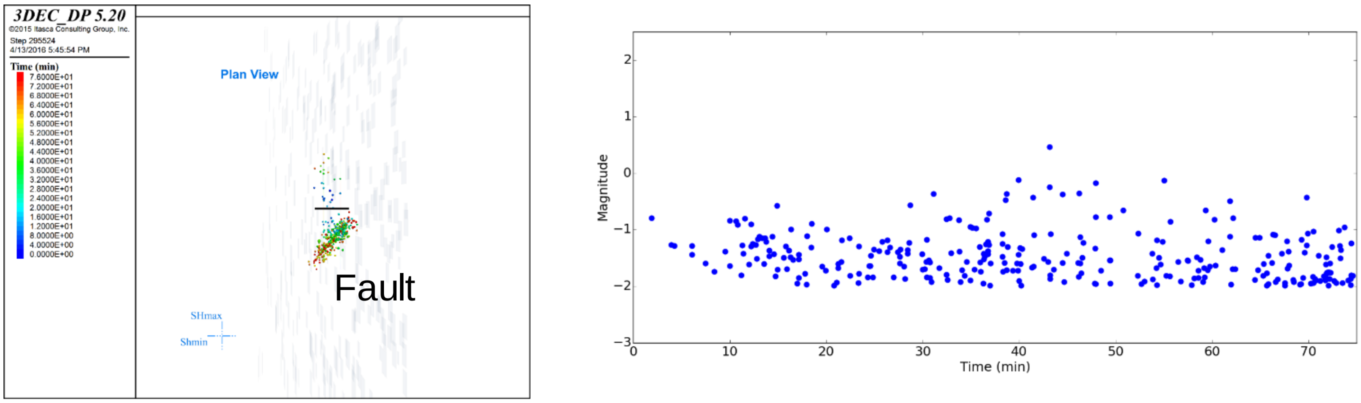

Figure 3. Fault activation with a 70-quality foam hydraulic fracture treatment (left) and associated seismicity (right).

Sensitivity studies were also performed with different injection rates and volumes, along with different fault strengths in each case showing these same relative trends described above.

Discussion and Conclusions

The fault model shows that the forecasted microseismicity is significantly different with different fracturing fluid characteristics. Comparing the portion of the fault that slipped with slickwater compared to the energized fluid (Figure 4) shows that the relatively thin slickwater fluid invades a larger portion of the fault close to 700 m total on strike and hence results in larger magnitude microseismicity. The energized fluid system does not flow as far resulting in less invasion into the fault and hence the seismogenic slip and associated microseismicity is reduced. Therefore, changing the fluid viscosity and in particular avoiding the use of a slickwater system might be a potential seismic hazard management tool.

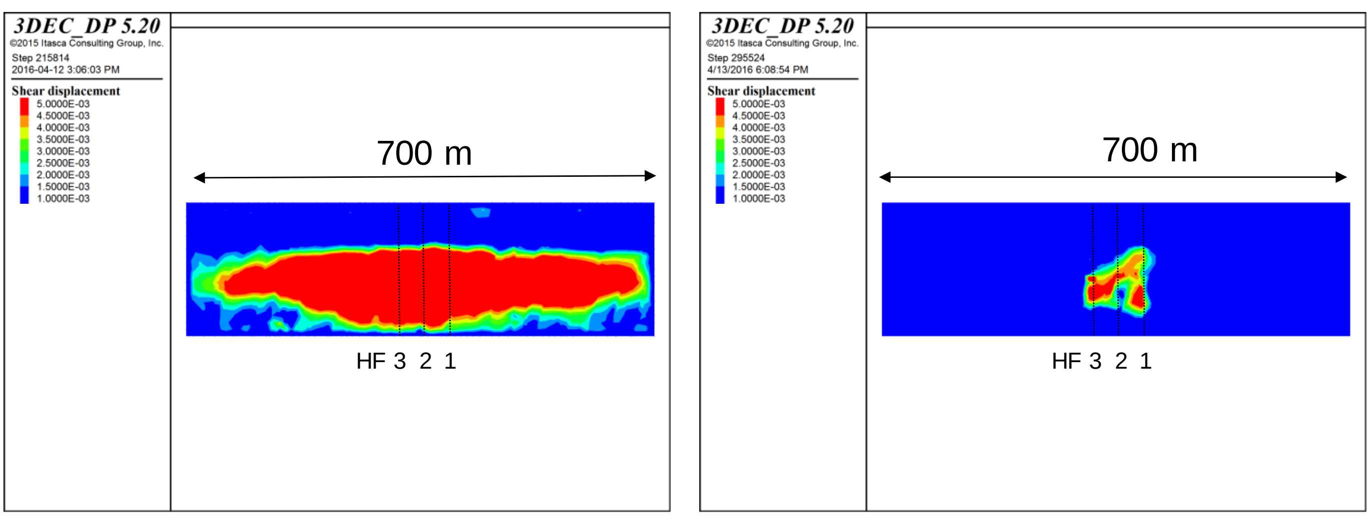

Figure 4. Fault slip contours, for the slickwater case (left) and energized foam (right).

Beyond the fault activations aspects, the proppant transport characteristics will be different with the two types of fracturing fluids which will control the proppant distributions through the fracture network. The modeling results indicated a higher and more uniform proppant concentration within the shorter primary fractures of the energized fluid. Differences in the effectiveness of these hydraulic fracture networks to drain the reservoir can be investigated through a reservoir simulation workflow, although not yet performed in this study. Such an evaluation can potentially be used to optimize the expected drainage and trade-off production against seismic hazard.

A comprehensive field test would be useful as a next step, to examine the effectiveness of such seismic hazard management strategy.

References

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