Investigating Fault Sealing Effects on Induced Seismicity and Pore Pressure Distribution in NEBC

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Summary

The Montney play contains overpressured terranes, which preserve the signature of elevated formation pressures that formed during hydrocarbon migration near the time of maximum burial. The spatially varying pattern of overpressure signatures is thought to reflect loss of pressure along permeable fairways, such as faults, during uplift and exhumation. Other studies, however, show that distinct pressure terranes within the Montney play are likely fault-bounded, implying that some faults continue to serve as seals that inhibit pressure migration. These two concepts can be reconciled within the framework of the fault-valve model, wherein a fault experiences a transient co-seismic increase in permeability during an earthquake. According to this model, the fault seal rebuilds gradually over time during the ensuing interseismic period, such that complete release of overpressure within a fault-bounded compartment may require multiple fault activation cycles. This paper reviews the available data from Northeast British Columbia, with the objective of reappraising pressure terrane boundaries, and evaluating the relationship between fault structures, pressure terranes and induced seismicity.

Observations

The Montney tight gas play extends from central Alberta to northeast British Columbia (BC). The Septimus field is part of this unconventional play and is located centrally within the Kiskatinaw Seismic Monitoring and Mitigation Area (KSMMA), BC. On November 30, 2018, an earthquake sequence initiated during hydraulic fracturing operations in the Lower Middle Montney Formation in the Septimus region. The M_L 4.5 mainshock was followed by two significant aftershocks within an hour, measuring M_L 4.3 and M_L 3.6. This moderate earthquake, and the aftershock sequence, were localized near the southern bounding fault of the Fort St. John Graben (FSJG).

Enlighten Geoscience Company performed a comprehensive study on pressure and stress mapping, and fault slip potential analysis in KSMMA area in 2020. They used More than 2000 Montney pressure data points in their study including DFIT data, Drill Stem Tests (DSTs) and all forms of Reservoir Pressure Survey tests. Of this 2000 data, 1700 is related to the upper Montney layer. In the Enlighten reports, the hydrodynamic discontinuities are interpreted as faults that provide a significant seal due to low permeability of the fault core. Distinct variations in pressure gradient therefore could provide a proxy for identifying faults that may otherwise be difficult to discern. Public domain and inferred faults were incorporated into the gridding process to identify fault-bounded distinct pressure terranes within the Montney.

In order to better understand the pore pressure behaviour, we re-generated the pore pressure maps, independent of faults. In our study, sub-hydrostatic gradients (<10 kPa/m) have been removed and Natural Neighbor Interpolation algorithm was used to generate pore pressure gradient maps.

Figure 1 shows the pore pressure gradient map of the Upper Montney, as well as the KSMMA area, the location of the Fort St. John Graben (FSJG) southern bounding fault and Nov. 2018 suspended well.

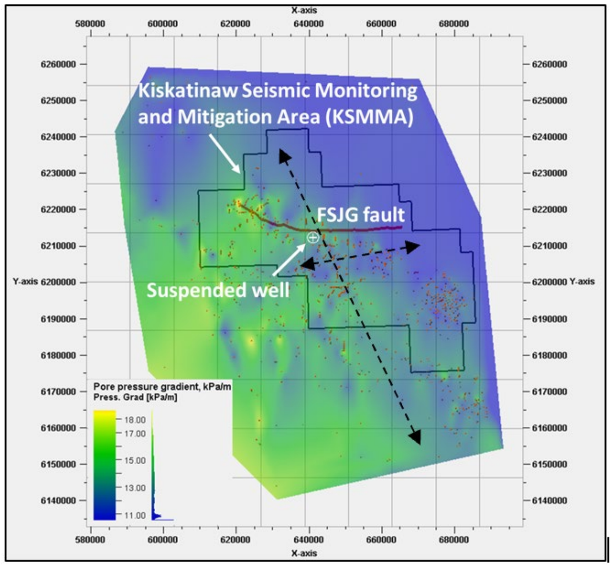

__Figure 1__ Pore pressure gradient map of the Upper Montney. Dashed arrows show the major pressure trends.

As obvious on the map, a major pressure gradient is observed from West to East as a result of hydrocarbon migration during uplift and exhumation. Certain faults have increased the system permeability and allowed pressure leakage while other faults have not increased the system permeability and, thereby, preserved higher relative pressure. In addition, Pressure trends exhibit a fabric parallel to the Cordilleran deformation front, with a strong gradient normal to the front. There is also a significant pressure discontinuity in proximity to the Fort St. John Graben (FSJG) structure.
Figure 2 shows the pore pressure gradient map of the Lower Middle Montney. Pressure data is sparser in other zones of the Montney. However, similar pressure trends to the upper Montney are observed on the map.

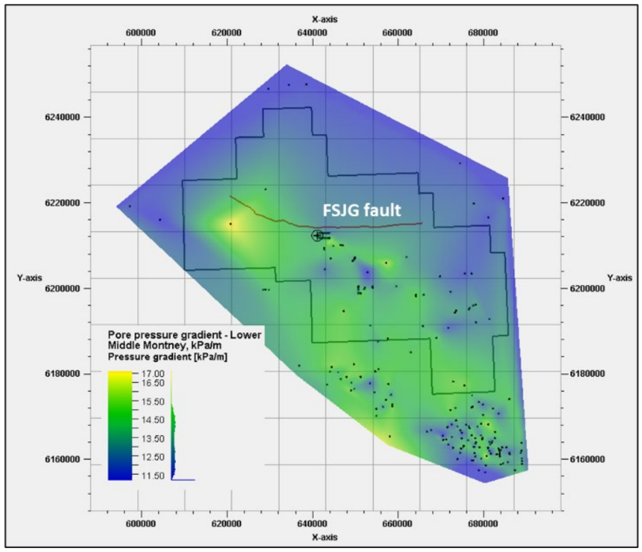

Figure 2 *Pore pressure gradient map of the Lower Middle Montney. Similar pressure trends to the upper Montney are observed on the map.*

Figure 3 shows the comparison between the pore pressure gradient of the Upper Montney with known and inferred faults in the study area. There is a good relationship between lateral pore pressure contrast and faults, however as expected, not all fault segments are acting as pressure barriers. Fault seal preservation depends on several factors including the depth, original pressure distribution in the reservoir and fault properties.

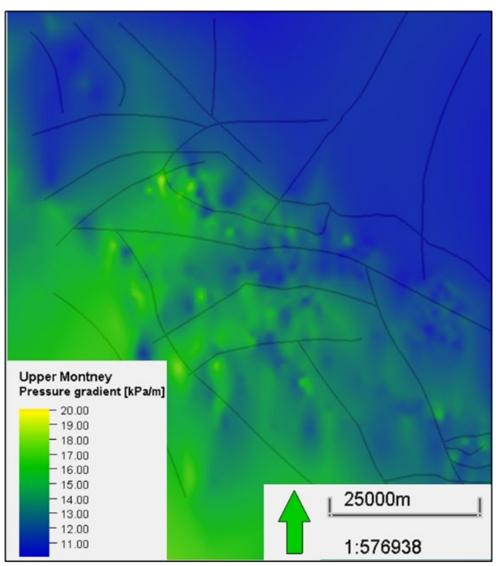

Figure 3 *Comparison between pore pressure gradient of the Upper Montney with known and inferred faults. Faults act partially as pressure barriers.*

Eaton and Schultz (2018) showed that High in situ overpressure of shale formations may represent a controlling factor for inducing earthquakes. According to their study, earthquake locations are characterized by a multimodal distribution of formation-pressure gradient with a mean of 15.1 kPa/m. In Figure 4, the pore pressure gradient data along the cross-section AA' which passes through the Nov. 2018 suspended wellbore and earthquake sequence, is plotted. the maximum observed pressure gradient of 16 kPa/m is expected to encounter the epicenter of the Nov. 2018 M_L 4.5 mainshock. We have also found that 86.75 % of M_L > 3 earthquakes in entire BC are located near pressure gradients and about 50 % are associated with lateral ΔP > 10 MPa. These observations raise the hypothesis that not only overpressure behaviour, but also sharp lateral pore pressure contrast across the fault can be a risk factor for moderate and large earthquakes. Importantly, the Nov. 2018 sequence, was also localized near the mapped boundary between two pressure terranes, the overpressured Septimus high and the normally pressured Tower Low. This hypothesis is being further investigated through numerical modelling studies.

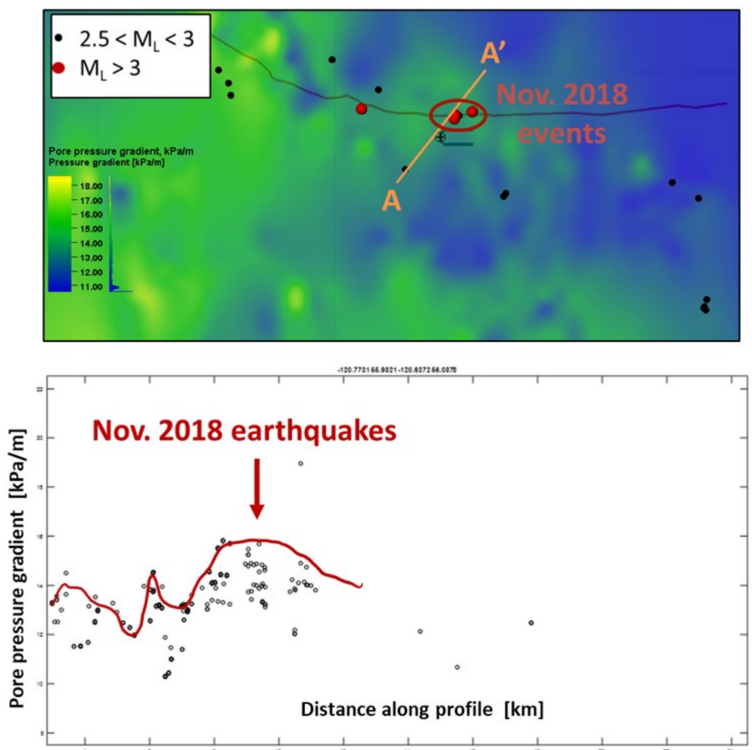

Figure 4 *Pore pressure gradient data along the cross-section AA'. Sharp lateral pore pressure contrast across the fault can be a risk factor for moderate and large earthquakes.*

Conclusion

Strong ΔP across a fault could be a risk factor for induced seismicity. Fault sealing behaviour depends on the depth and original pressure distribution, as well as fault properties. No systematic change in gas production was observed in wellbores close to the major faults after Nov. 2018 earthquake. Modelling results show it is harder to frac the high-pressure zone; however, production is modelled as higher on the high-pressure side, supported by higher reservoir pore pressure. Induced seismicity related to Montney HF is concentrated along the Septimus High structural corridor. Two pressure trends are recognized on Montney pore-pressure gradient map parallel to the Cordilleran deformation front and controlled by the FSJG structure.

Acknowledgements

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