In-situ Stress Estimation around the Kiskatinaw Seismic Monitoring and Mitigation Area

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Summary

In this study, in-situ stresses and pore pressure were estimated for the Montney Formation throughout the KSMMA and surrounding area, which covers townships 78 to 85, ranges 12 to 21 (as shown in Figure 1). By the time of starting this study, there have been 10003 wells drilled and completed in the area. We have reviewed 2166 vertical wells, among which 36 wells have both compressive and shear sonic wave velocity logging data that cover the Montney Formation. Currently, we have estimated full in-situ stresses for six wells in the east and one well in the west of the study area.

It is observed that in the east of the study area, the in-situ stress regime is a normal fault stress regime; the gradients of the minimum horizontal stress, the maximum horizontal stress, and the vertical stress are 17.5 kPa/m, 21.9 kPa/m, and 25.2 kPa/m respectively.

The presence of a normal fault stress regime is unexpected since a strike-slip fault stress regime is typically assumed for the entire region. Yet, analysis of caliper data in two horizontal wells has confirmed its presence. Further analysis shows that the in-situ stress regime likely varies from a normal fault stress regime in the east of the study area back to a strike-slip fault stress regime just west of the KSSMA area, where the gradients of the minimum horizontal stress, the maximum horizontal stress, and the vertical stress are 22.0 kPa/m, 30.3 kPa/m, and 25.6 kPa/m respectively.

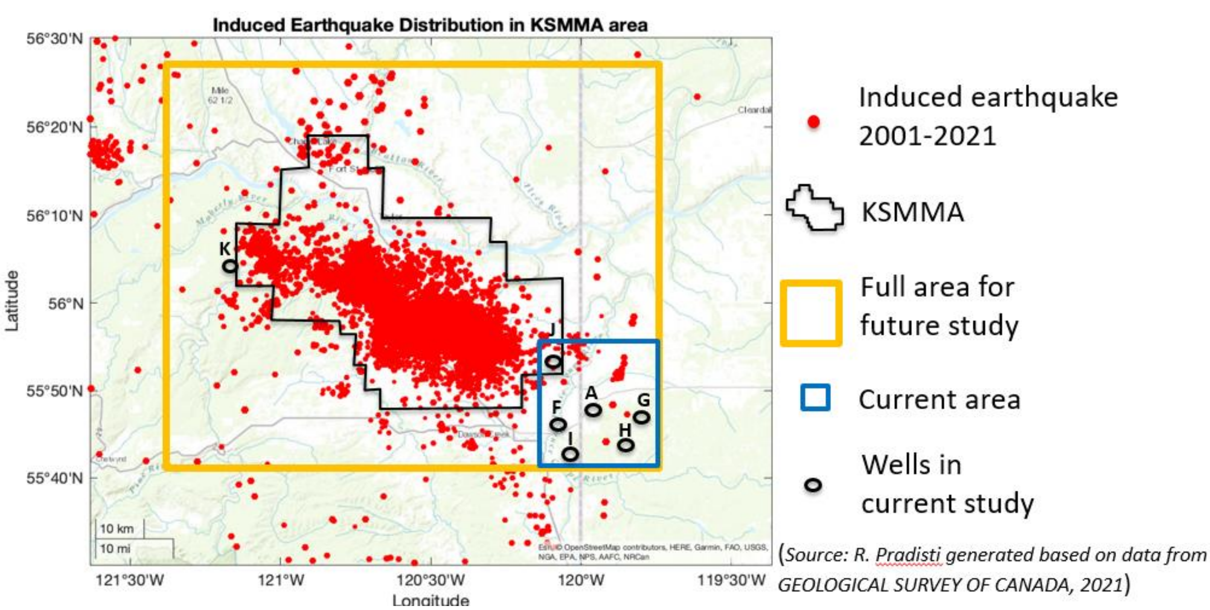

Figure 1 Location of the study area

Workflow

A six-step workflow was applied to the estimation of in-situ stresses: data audit, mechanical properties calculation, pore pressure and closure pressure estimation, maximum horizontal stress direction determination, in-situ stress regime determination, and finally, full in-situ stress magnitudes calculation. The workflow is illustrated in Figure 2.

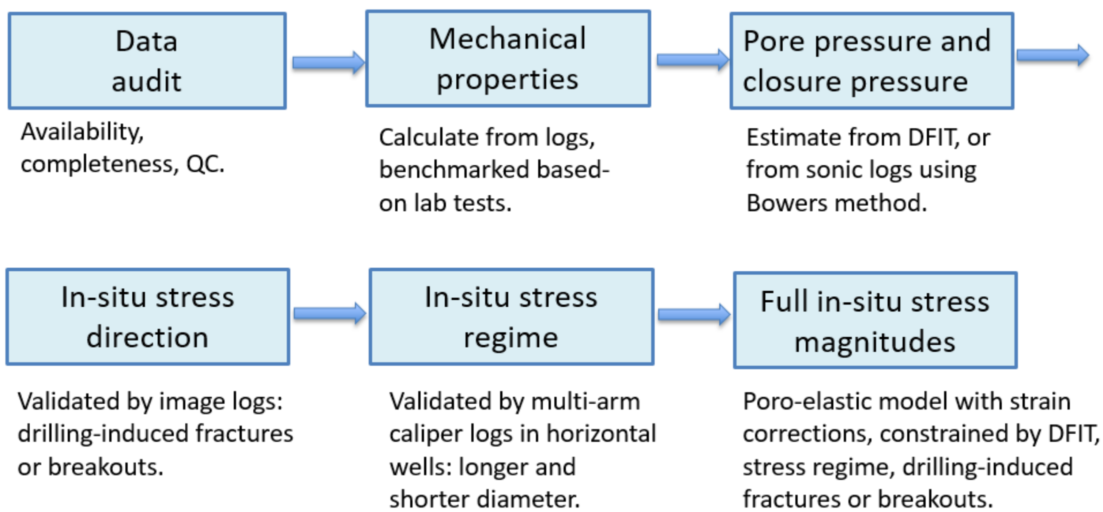

Figure 2 Workflow for in-situ stresses estimation

Results

Seven vertical wells, six wells (wells A, F, G, H, I, and J) in the east and one well (well K) in the west, and four horizontal wells (wells B, C, D, and E, which are on the same pad with well A) were reviewed, quality controlled, and analyzed for the availability and completeness of both compressive sonic wave velocity and shear sonic wave velocity logs, density logs, gamma-ray logs, image logs, caliper logs, core mechanical lab test data, and DFIT data.

Formation pore pressure maps were generated based on pore pressure measurement data from 827 wells. Closure pressure maps were generated based on DFIT closure pressure tests of 537 wells. These maps provide pore pressures and minimum principal stress information for those wells that have neither DFIT nor other pressure measurement data available.

The maximum horizontal stress direction in the area is 30^0-40^0 NE, which is observed from image logs of wells A, J, and K.

The analysis of caliper logging data of two horizontal wells (C and D), drilled along the minimum horizontal stress direction, indicated that the in-situ stress regime in the east of the study area is a normal fault stress regime because the vertical diameters of the horizontal borehole were smaller than the horizontal diameters. The same conclusion was reached when taking a range of anisotropic rock properties into account based on laboratory and well-log measurements for the area.

Full in-situ stresses were calculated for six wells in the east (wells A, F, G, H, I, J) and one well in the west (well K). The results are summarized in Table 1.

Table 1 Summary of calculated in-situ stress gradients

Well name	∇p_0 kPa/m	$\nabla \sigma_h$ kPa/m	$\nabla \sigma_H$ kPa/m	$\nabla \sigma_V$ kPa/m
A	12.2	18.0	22.6	25.4
F	13.0	17.9	22.1	25.5
G	11.9	17.3	21.7	25.2
H	10.5	16.6	21.1	24.5
I	12.5	17.6	22.0	25.2
J	12.5	17.8	21.9	25.1
K	16.4	22.0	30.3	25.6

Discussions

The calculated magnitudes of the pore pressure, the minimum horizontal stress, and the vertical stress are in reasonable agreement with an independent geomechanics study in the area by Fox and Watson (2021), adding confidence to the results.

Our results indicate the in-situ stress regime varies from a strike-slip fault stress regime west of the KSSMA area to a normal fault stress regime in the east of the study area. The observed normal fault stress regime in the east part of the study area is unexpected since a strike-slip or thrust fault stress regime is regionally assumed to be present (Bell et al., 1990; Fox & Watson, 2021; Shen et al., 2018). However, analysis of caliper logs in horizontal wells in the east of the study area reveals a normal fault stress regime. The implication is that the in-situ stress estimations from previous log-based studies may display biases. Specifically, the in situ stress regime has a considerable influence on likelihood predictions for fault reactivation due to fluid injection (Yaghoubi et al., 2022). Inspection of additional caliper data in horizontal wells, combined with further in situ stress analyses of more wells in the area is needed to verify and delineate the transition location of a strike-slip fault to a normal fault stress regime in the KSSMA region.

Uncertainties exist in the estimation of the maximum horizontal in-situ stress because the magnitude of the maximum horizontal stress cannot be measured accurately or precisely (Schmitt et al., 2012, Roche & van der Baan, 2017). For this reason, we estimated a probable range. The maximum horizontal stress gradient around well locations A and K is estimated to be between 21.5 kPa/m to 23.6 kPa/m (well A) and 28.6 kPa/m to 32.0 kPa/m (well K), respectively.

It is also observed that the pore pressure gradient in the Montney Formation in well K, which is 16.4 kPa/m, is much higher than the pore pressure gradient in well A, which is only 12.2 kPa/m. Pore pressure mapping based on 827 wells in the area also indicates that the pore pressure in the Montney Formation is high in the southwest of the study area and decreases toward the east and north. A similar trend was observed in pore pressure maps reported by Fox and Watson

(2021). This pore pressure trend is proportional to the vitrinite reflectance, and thus maturity, of the source rocks in the area (Euzen et al., 2021; Ferri et al., 2013). In other words, the pore pressure is higher in the southwest of the KSSMA where the maturity of source rocks is also higher; whereas in the east and north part of the study area, pore pressure decreases, and rocks are less mature.

Conclusions

In-situ stress magnitudes were estimated for typical wells in the KSMMA and surrounding area. The in-situ stress regime varies from a strike-slip fault stress regime in the west to a normal fault stress regime in the east of the KSMMA and surrounding area. The pore pressure trend is proportional to the richness and maturity of the Montney source rocks in the area.

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