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Pore Pressure Anomalies in the Horn River Basin, Northeastern BC

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Summary

The Horn River Basin, along with Cordova and Liard shale basins, are located in northeastern British Columbia, Canada (Figure 1), all three being host to significant accumulations of gas. Nexen's production efforts are currently focused in the Horn River Basin. The Horn River Basin is bounded by the Bovie Fault and the Presqu'ile Barrier (Keg River and Slave Point carbonates). Nexen has a significant land base and develops gas from the Devonian aged Muskwa, Otter Park and Evie formations.

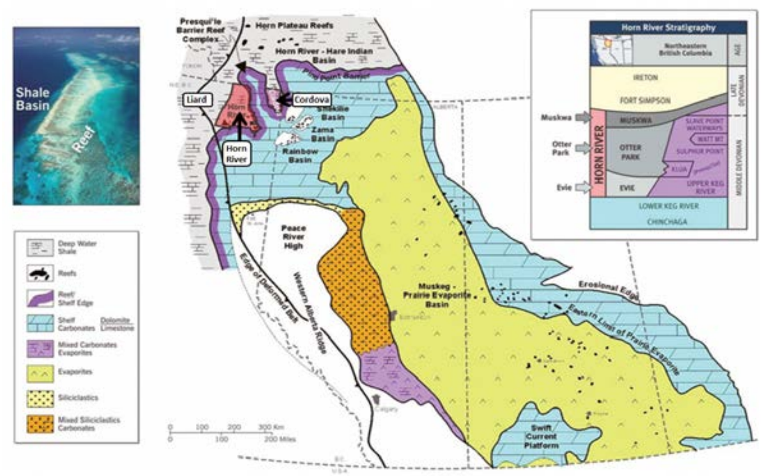

Figure 1 – Location map showing the position of the Horn River, Liard and Cordova basins in northeastern British Columbia showing it's setting in relation to the WCSB (modified from Goodway et al., 2012)

Pressure is an important consideration when developing low perm, gas-charged "unconventional" reservoirs. Unexpected variations in pore pressure can impact initial production (IP) and estimated ultimate recovery (EUR) by nearly 50%. Throughout NEBC, the range in pressure data is significant: from underpressured in Cordova, the shallowest, to overpressured in Horn River, to significanty overpressured in Liard, the deepest. An investigation into undestanding the anomalies and range of pressures was undertaken. In-situ measured pressures correlate to deep seated basement faults oriented obliquely to maximum horizontal stress. These faults reactivated during Laramide events and slice through the entire stratigraphic section and potentially provide a fluid migration pathway for the hydrocarbons from high pressured shale reservoir, downwards to the underpressured carbonate aquifer below.

Theory / Method

In order to determine the most accurate estimate of reservoir pressure, Diagnostic Fracture Injection Tests (DFITs) have been conducted prior to hydraulic fracturing. Nexen's DFIT's sample the three different reservoir targets (Figure 2), in total there are 37 measurements. After evaluation of the DFIT's, a signifincant range in pressure gradients and absolute pressures was seen on Nexen land, over a range of only six kilometers. Collection of public pressure data basin-wide was undertaken as part of the initative to understand why this range in pressure exists. A total of 90 pressure measurements have been used in this evaluation.

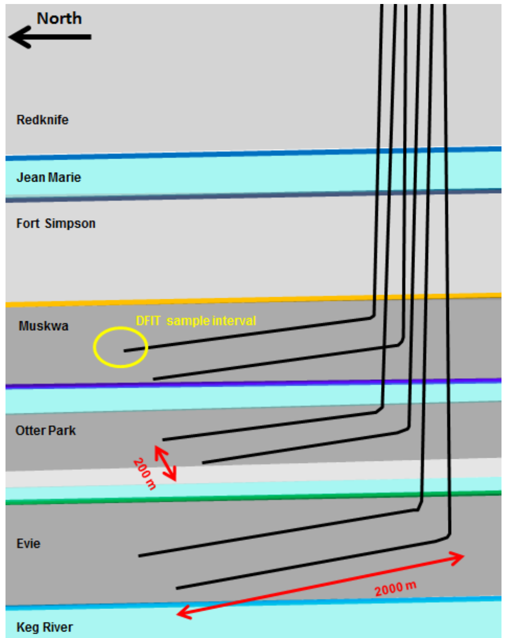

Figure 2 – Simplified layout of well pad in HRB showing reservoir (Muskwa, Otter Park and Evie) and location of DFIT's at the toe of the horizontal. VE 15x.

Discussion

Conventionally, we expect pressure to trend 1:1 with depth meaning the sediments are normally compacted and pressures do not deviate from the hydrostatic (normally pressured) gradient. Across NEBC, there is significant excess pressure, or deviation away from the normally pressured gradient (Figure 3).

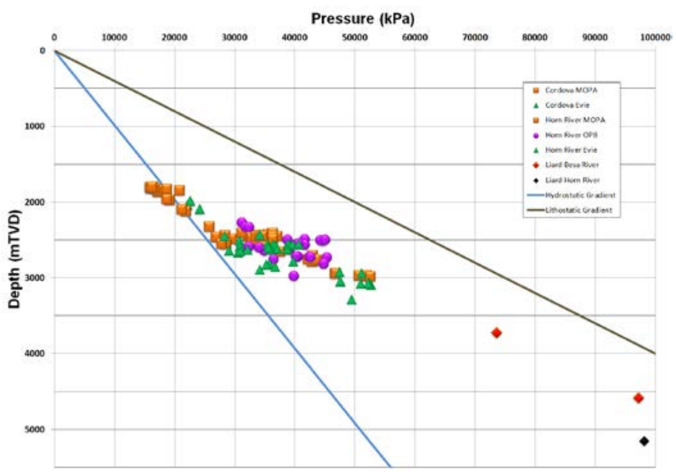

Figure 3 – Pressure vs depth across NEBC.

The pressures range from underpressured in Cordova (<10 kPa/m), to overpressured in Horn River (>10 kPa/m), to significantly overpressured in Liard, (>19 kPa/m). In the Horn River Basin alone, pressure gradients range from 11-18 kPa/m and absolute pressures range from 25000 to 50000 kPa. Integration of seismic and geological data has provided a means to correlate these pressure anomalies with faults rooted in the basement that penetrate the entire stratigraphic section (Figure 4). These faults are laterally extensive in the N-S direction and are oriented obliquely to present day maximum horizontal stress, meaning shear stress is higher and implying that leakage or slippage is possible.

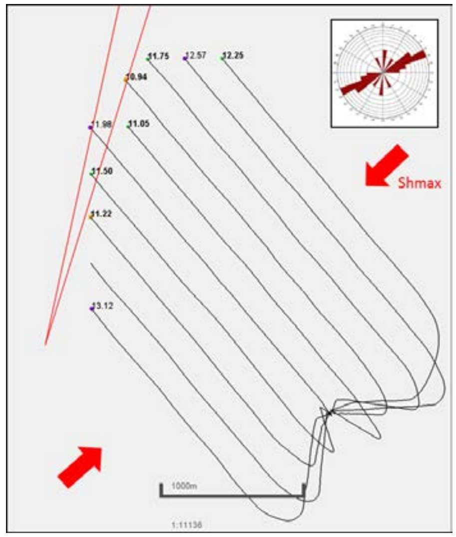

Figure 4 – Example of low pressure gradient values correlate to an interpreted fault (red polygon) that is oriented oblique to Shmax.

Given the nature of the reservoir – low permeability, gas-charged, uplifted – the pressure anomalies are a function of depletion. The shales in the basin most likely would have been all overpressured initially, but throughout geological time the fluids have escaped via large faults as shown above. The faults cut through the reservoir as well as the thick section of Keg River carbonates below. It is plausible that the fluid has migrated downards via the faults to the underpressured (hydrostatic) carbonates. The fluid would flow eastwards in the aquifer and updip where it meets up with the Presqui'le Barrier (reef and shelf carbonates of the Keg River and Slave Point). On a regional scale, as seen in figure 5, basin fluids flow SW to NE and discharges at the Great Slave Lake where the carbonates outcrop in the Northwest Territories (Bachu, 1997) is enhanced in the carbonates by processes such as karsting, dolomitiziation and fracturing.

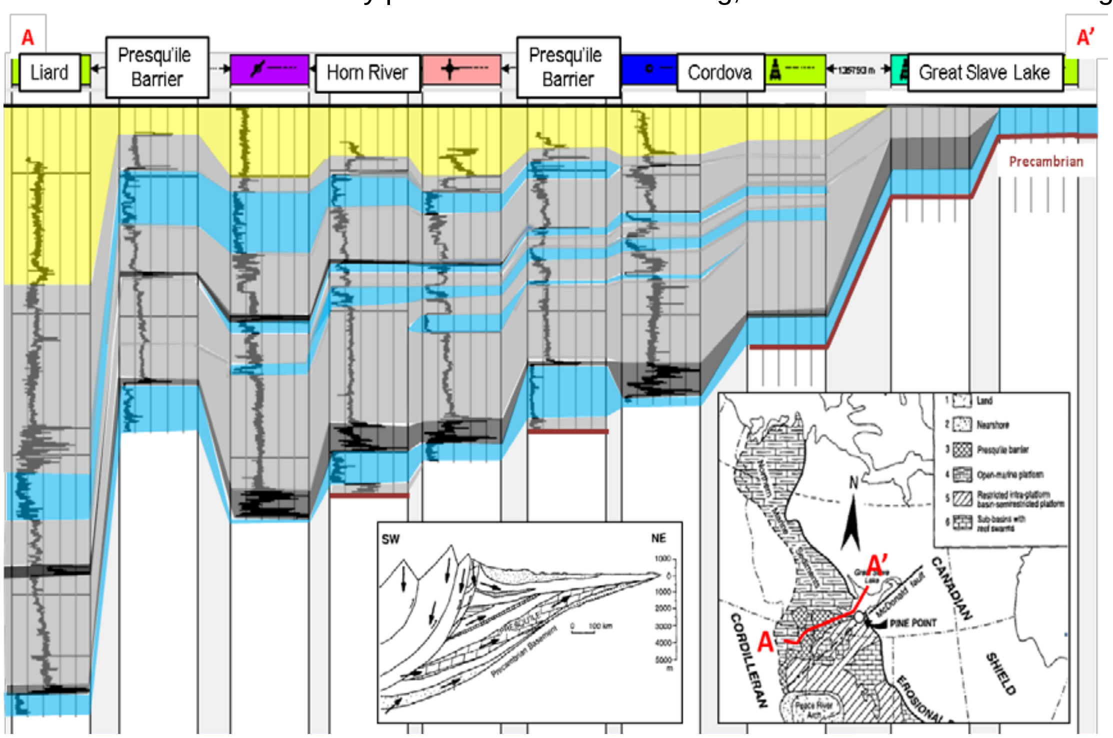

Figure 5 – Regional cross section SW to NE illustrating how the carbonates outcrop at the Great Slave Lake and its plausible that flow updip eastwardly. Inset photos modified from Qing and Mountjoy, 1992.

Combining the enhanced undestanding and interpretations of pore pressure distribution, it is believed that the faults have a negative impact to the production of the reservoir. Since the faults are connected to the thick succession of underpressured carbonates below the shale gas reservoir, they are assigned a value of 10-11 kPa/m which is equal to the hydrostatic gradient. Figure 6 shows the pressure gradient map for the reservoir that reflects the interpretations of the major structural elements that are responsible for anomalies.

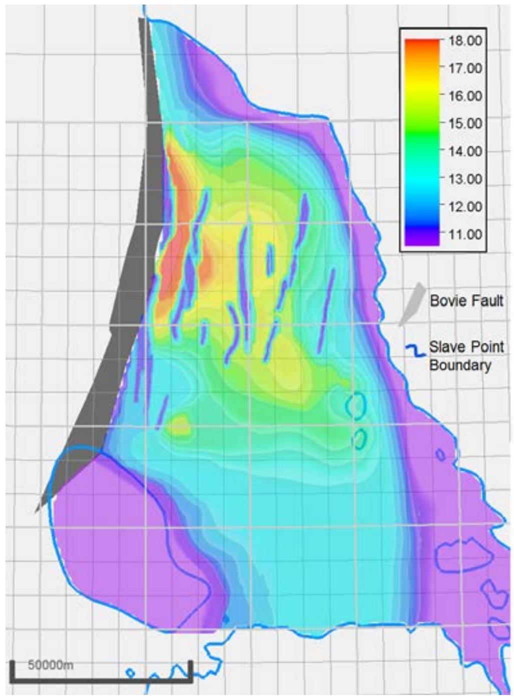

Figure 6 – Proposed pressure gradient (kPa/m) map for the reservoir interval.

Conclusions

Understanding the mechanisms and controls on the distribution of pore pressure is critical for shale gas reservoir production and development. In the Horn River Basin of northeastern British Columbia, pore pressure gradients deviate from “normal” and range from 11 to 18 kPa/m, while aboslute pressures range from 25000 to 50000 kPa. Pore pressure anomalies are explained by large faults seated in the basement that are oriented to present day SHmax and slice through the entire stratigraphic section. The faulting occurred long after gas generation, and provided conduits for the the fluid to escape the reservoir downwards into an underpressured aquifer, the Keg River, which transports fluids via the Presqui’le Barrier to discharge in the northeast at the Great Slave Lake.

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