Insights into Induced Seismicity in the Duvernay East Shale Basin from 3D Seismic

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Summary

3D reflection seismic data are interpreted to study Hydraulic Fracturing-Induced Seismicity (HFIS) in the Duvernay East Shale Basin (ESB), revealing distinct geological scenarios that influenced seismicity. Though 3D seismic data fails to provide clear direct evidence for seismogenic faults, their presence is suggested by compelling indirect evidence in one case: a highly structured zone of subvertical faults associated with laterally limited reflectivity anomalies at multiple carbonate horizons upward through the Paleozoic succession, which we interpret to be fault-controlled diagenetic zones. Identifying distinct seismogenic scenarios within a local area demonstrates that careful examination of the subsurface, including intervals above and below the target reservoir, is required to understand the geological susceptibility to seismicity before commencing hydraulic fracturing operations at a new location.

Method

This study focuses on HFIS within the Westerdale Embayment of the ESB (Figure 1), including the notable 4.18 M_L event felt in the Red Deer region on March 4th, 2019 (Figure 2). We consider Paleozoic sedimentary strata within the ESB (Figure 1): mixed siliciclastics of the Cambrian as well as the carbonate buildups and time-equivalent shaley strata of the Devonian.

Our regional understanding of the geology is complemented by observations from well logs and insights from 3D seismic interpretation. The 3D seismic reveals deep-seated structural lineaments whose influence propagates upwards through the reservoir in some cases. In one

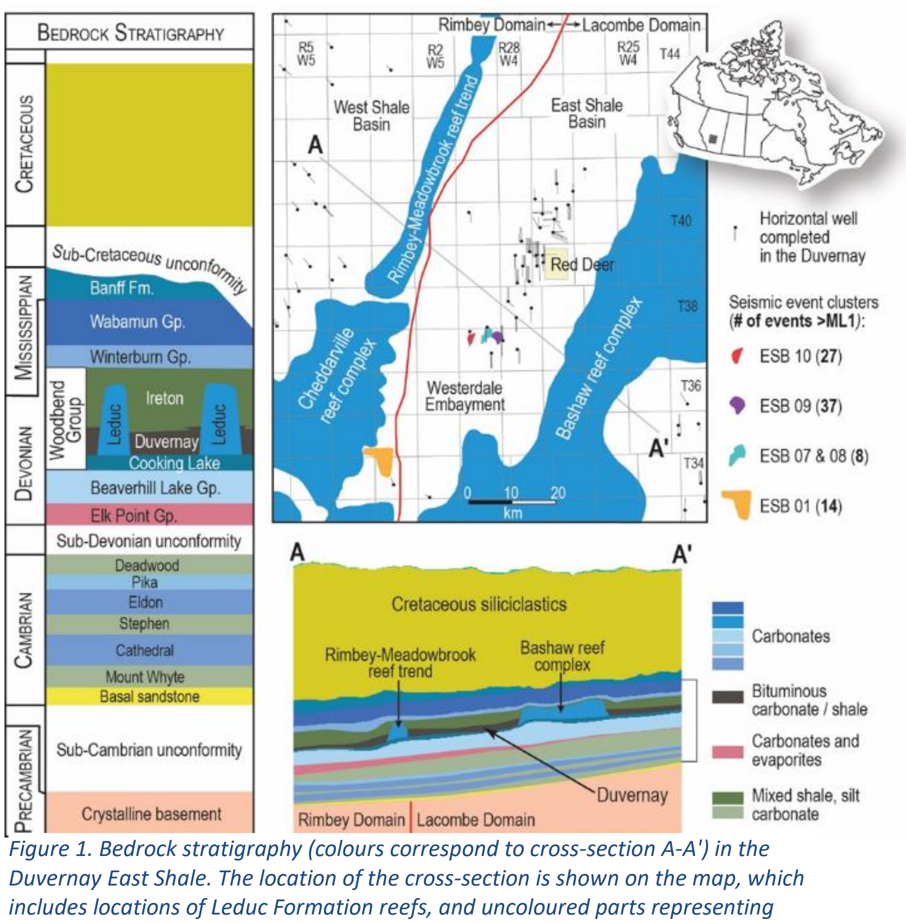

Figure 1. Bedrock stratigraphy (colours correspond to cross-section A-A') in the Duvernay East Shale. The location of the cross-section is shown on the map, which includes locations of Leduc Formation reefs, and uncoloured parts representing basinal deposition of the Duvernay Formation (target reservoir). Horizontal wells completed in the Duvernay are shown, with associated hydraulic-fracturing induced seismic events.

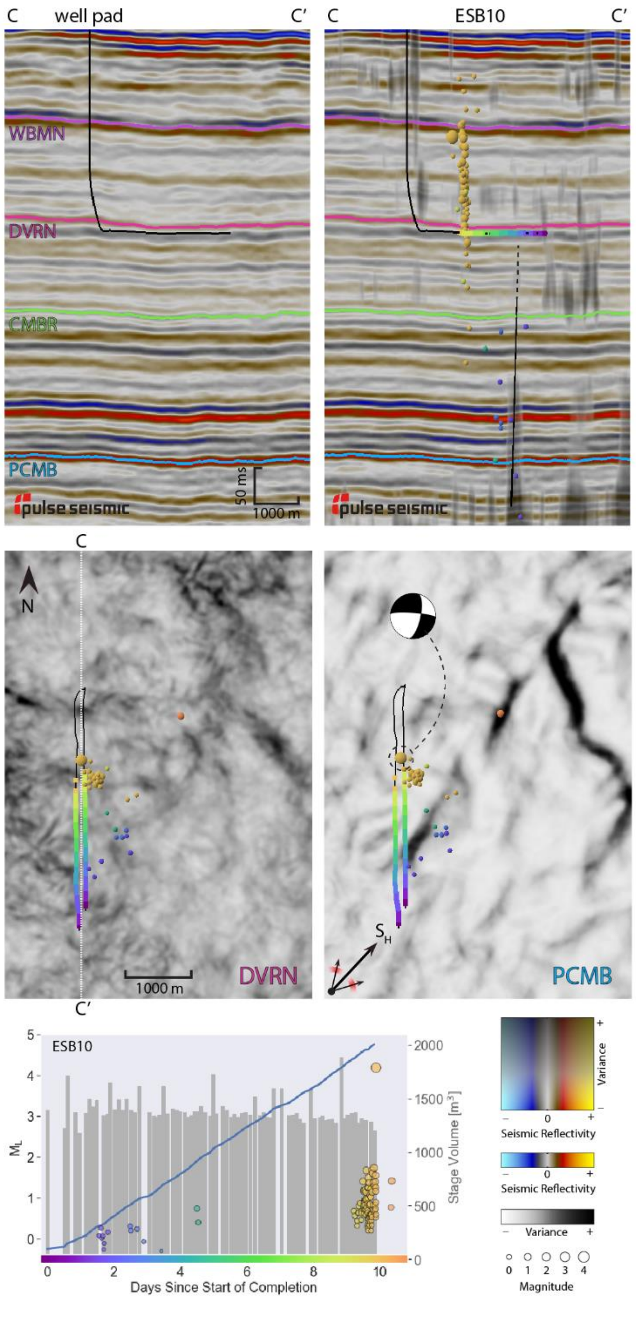

Figure 2. Seismic Seismic cross-section C-C′ is shown with (top right) and without (top left) interpretation, ESB10 hypocenters (circles colored according to time, size according to magnitude), and seismic variance overlay. A sub-vertical fault extending from the Precambrian through the Cambrian is interpreted below the well pad, with presumed extension into the Duvernay Formation. Discontinuity attribute anomalies along the Precambrian basement near cluster ESB10 are shown (middle right). A seismic discontinuity attribute map 25 ms above the Duvernay Formation top (middle left) shows weak correlation with deeper discontinuity anomalies. The temporal evolution of HFIS (bottom) shows a distinct change in character in the hours before the 4.18 ML event. The moment tensor for the largest event in ESB10 is shown.

area, the lineaments are associated with localized seismic amplitude anomalies along Paleozoic carbonate reflectors.

The observations from 3D seismic are considered alongside the regional orientation of the maximum horizontal stress as well as the evolution, location, and motion of seismicity during HF. The scenarios that emerge demonstrate that even well pads within a single township can produce distinct responses to HF.

Conclusions

The recognition that distinct geological scenarios can influence HFIS on a local scale demonstrates the detail required to understand susceptibility to HFIS. We observed that factors enhancing susceptibility can be laterally limited, explaining why the character of HFIS varies from pad to pad (or even stage to stage) in this area, and underscoring the utility of 3D reflection seismic data. Evidence of geological susceptibility to HFIS were found hundreds of meters above and below the target reservoir, indicating that an understanding of a broad geological interval is important.

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