The application of seismic derived rock properties in predicting Duvernay Induced Fractures

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Summary

The Duvernay shale, equivalent to the Devonian age Muskwa member of the Horn River Group, is a major resource play in the Western Canadian Sedimentary Basin. The Duvernay shale is rich in organic matter and, depending upon situation within the basin, produces gas, natural gas liquids, or oil. It is commonly believed to be the source rock for the Leduc reef, Nisku, and Wabamun carbonate plays. With the development of horizontal drilling, and multi-stage hydraulic fracturing, the Duvernay is a desirable exploration target, especially within the condensate window. The rock type varies in accordance with its position in the depositional basin; near Leduc reef buildups, there is reef debris, whereas away from the reef it is deposited in a carbonate bank environment. Vertical wells and cores are evaluated for rock properties, total organic hydrocarbon content, and suitability for further development.

Microseismic surveys are routinely carried out for Duvernay well completions to monitor the induced fractures and seismicity. There is often a discrepancy between the homogeneous reservoir assumption, and the observed microseismic events.

Prestack seismic inversions can provide valuable information about reservoir characterization and fractures. Prestack seismic attributes such as Poisson's Ratio, Young's Modulus, brittleness, P and S impedances can be extracted from inverted seismic data. AVO inversion may provide information about density and orientation of natural fracture network.

A common assumption made in horizontal drilling programs is that the lithology is homogeneous, and that fracture orientations are determined by the direction of maximum horizontal stress. This is not always the case, as observed in microseismic observations following a completion program. Lithology and preexisting fractures play a significant role in determining the size and patterns of the newly induced fractures.

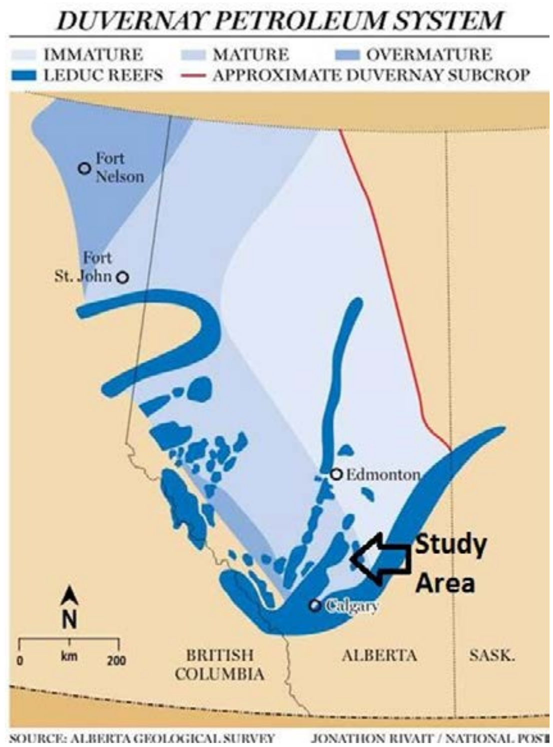
Seismic attributes can be combined with geological mapping, and a combined reservoir characterization map can be produced. Meaningful facies relationships can be established between seismic attributes, reservoir quality, and lithofacies. Seismic reservoir characterization can give relationships between rock properties, hydraulic fracture performance, and hydrocarbon production.

The seismically mapped brittleness variations may explain why observed micro seismicity departs from the homogeneous lithology assumption

Introduction

In the planning stages of a horizontal drilling program, well logs, cores and seismic data can provide valuable information for horizontal well placement and fracture positioning. Seismic data can provide lithologic parameters of the Duvernay such as Young's Modulus, Poisson`s ratio, brittleness, and others. If the more brittle rocks are more susceptible to fracturing, it follows that the seismic data could provide valuable a priori information for designing drilling and completion programs.

Figure 1: Duvernay Petroleum system, Western Canada. The mature oil facies is medium blue. (Source: Alberta Geological survey



Background Geology

. Figure 1 shows the extent of the Duvernay Formation, and the extent of the mature oil window in Alberta and NE

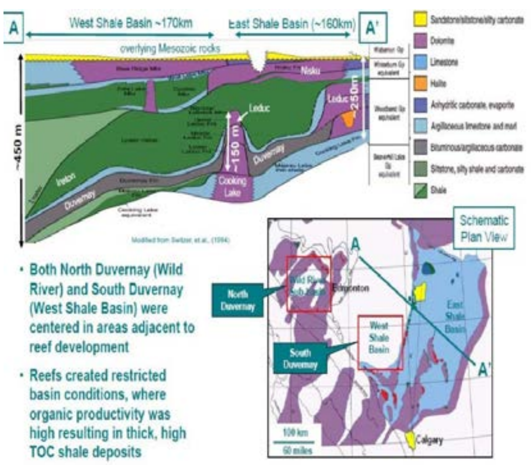


Figure 2. Schematic cross section Leduc-Duvernay (Switzer et al, 1999)

BC. The area is comparable in size to the Great Barrier Reef in Australia

The Duvernay shale is the stratigraphic equivalent of the Leduc formation (Figure 3). The Leduc and Duvernay formations have received considerable attention from an exploration and development point of view. According to Switzer, the Alberta Geological Survey describes the deposition of the Duvernay as a period of great accumulation of organic carbon.

The Duvernay is believed to be the source rock for most of the Leduc, Nisku, and Wabamun oil pools in Alberta. Adjacent to Leduc reef complexes, the Duvernay contains a large portion of reef detritus. Further out from the reef, the formation gradually thins, whist remaining rich in organic

Figure 3. Great Barrier Reef, Australia

matter. There is depositional mixing of the Ireton and Duvernay in the lower energy, distal portions of the reef. Low energy deposition can also occur near the reef in protected low energy areas. This results in silica clay mixing with the Duvernay. The high silica clay content and the high total organic content increase the brittleness of the formation (Scoltanzadeh and Fox, 2014).

Figure 3 shows a map of the Great Barrier Reef, which is a modern analogue to the Leduc reef complexes (Lines, Newrick, 2005). The large reef masses are several tens of kilometers across, with several outlying smaller pinnacle reefs. Organic rich

material is deposited between the reefs. The depositional environment varies enormously from the near reef detritus, to the distal carbonates, all rich in organic matter.

Rock Properties

Figure 4. shows derived rock properties at the Duvernay level in the Kaybob area. These data were acquired from

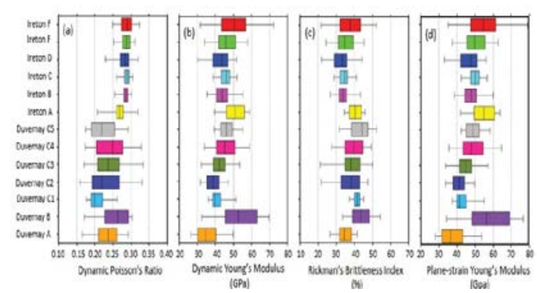


Figure 4. Variance in Duvernay rock properties, Kaybob area (Soltanzadeh and Fox 2015)

over 25 well locations using cores and well logs. (Soltanzadeh and Fox 2015). This analysis shows there is variation both laterally and vertically in the Duvernay Formation over the study area.

According to Cho et al. (2014), the optimal conditions for a formation is the ability to fracture easily, and the ability to hold a fracture, open with proppant. (Figure 9, center plot) A lower Poisson`s ratio translates to more favorable conditions for fracture development; a low Young’s modulus will be favorable for failure (and subsequent fracture collapse), a higher Young’s modulus in a rock represents its ability to maintain its fracture, and not collapse back on itself. Higher porosity and quartz content

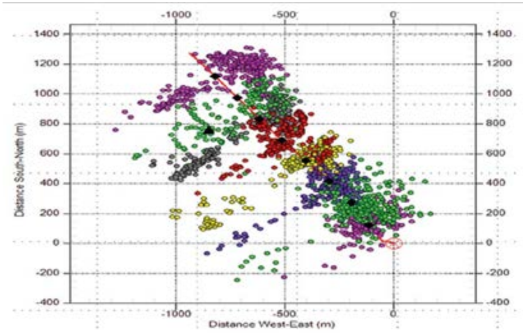


Figure 5. Shawn C. Maxwell Schlumberger, Calgary, Alberta, Canada Nov 2011 Vol 36 No. 09 GeoConvention

are significant when predicting suitable places to induce fracturing.

The desired rock properties on figure 8 are in the upper left corner of the cross plot. The combination of low Poisson ratio and high Young's modulus equates to a reservoir suitable for hydraulic fracturing.

The example of micro seismicity in Figure 5 comes from the Montney Formation of Alberta. Like the Duvernay, it was assumed to be homogeneous lithology. If the homogeneous reservoir assumption were true in this case, the microseismic events would be much more uniform and fracture patterns would be uniform around the perforations. The microseismic survey shows very different patterns NE and SW of the wellbore.

Methodology

A 2-D seismic line was acquired by Pulse Seismic in Eastern Alberta between two Devonian Oil Fields, the Wabamun pool to the West, and Leduc to the East. Figure 7 shows the location of the seismic line, the deep well tie,

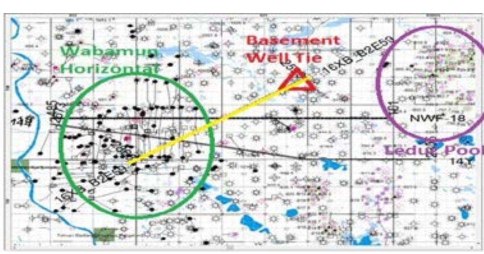
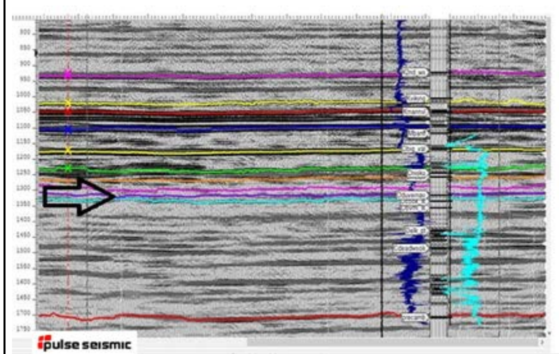
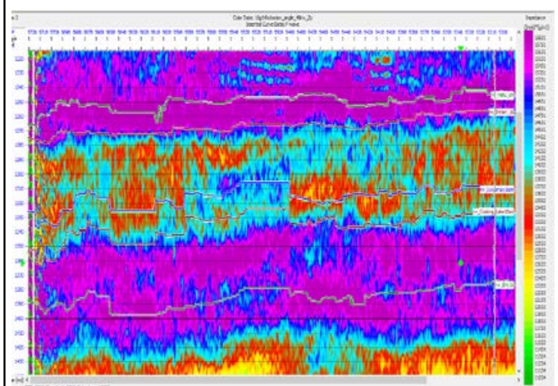


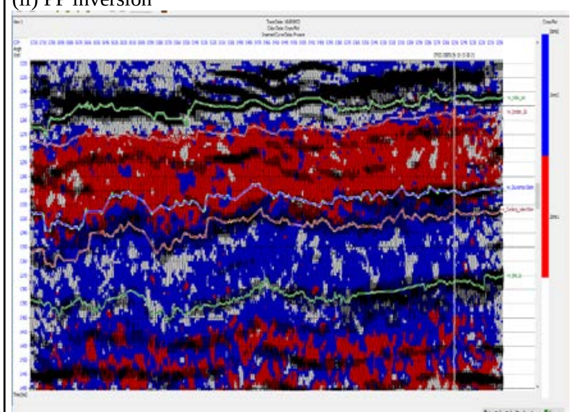
Figure 6, Base map The Wabamun pool is circled in green, the Leduc pool in purple. The Triangle is the deep well tie.



(i) Stack data correlatio



(ii) PP inversion



(iii) Poisson's Ratio/Youngs Moduls conditions (from figure 9)

Figure 7. Work flow progression: Synthetic tie, middle PP prestack inversion, bottom, Posson's ratio and Youngs modulus hodogram.

and the nearby oil pools The data were reprocessed to preserve AVO effects, stacks and gathers were output. The

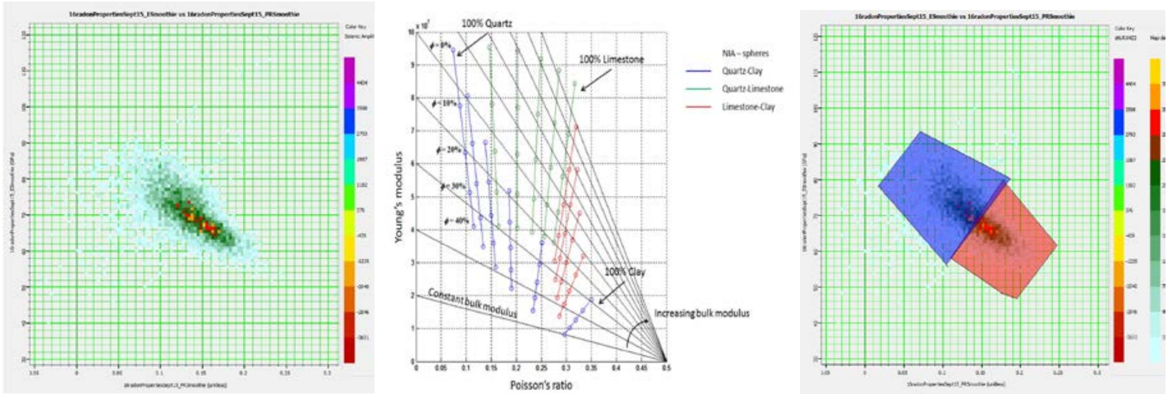


Figure 8. Calculated Poisson ration Vs, Youngs modulus compared to theoreticdal values. The center display is the theoretical calculation (Cho et.al. 2014.

stacked data was tied to 10-15-038-21 W4. Using the Precambrian well tie, a time/depth velocity relationship was established. The top and base of the Duvernay were identified, correlated on the sonic log, and converted to time. A prestack inversion was processed followed by calculations for Young's modulus and Poison's' ratio (Figure 9). The inversion determined values for Vp, Vs,

Poisson's ratio

$$PR = \frac{V_P^2 - 2V_S^2}{2(V_P^2 - V_S^2)}$$

Young's modulus

$$E = \frac{\rho V_S^2 (3V_P^2 - 4V_S^2)}{V_P^2 - V_S^2}$$

Figure 9. Calculation of Poison's ratio and Young's modulus from Vp, Vs, and density.

and density; from these values Young's Modulus (E) and the Poisson ratio (PR) were calculated. These data are plotted in Figure 8 within the Duvernay interval.

These data are plotted over the Duvernay interval and show a linear trend, from the lower right to upper left.

Analysis and results

The results of the inversion, and subsequent calculations of the PR and E across the seismic lines show significant variations over 3 km. This is the expected result, as the Duvernay formation is deposited in the intra reef areas of the Leduc and shows varying lithologic properties. The location at the synthetic seismogram (10-15-038-21 W4) would likely be favorable for a Duvernay completion (blue on the cross plot). Conversely the area to the west of the well in the Duvernay interval (red on the cross plot) would react poorly to fracture stimulation. The inversion results indicate the lithology is not homogenous, and shows significant variation in brittleness across the 2-D seismic line.

Given the variations in lithology are a major factor in hydraulic fracture performance, we propose the following scenarios (Figure 10) to explain the way induced fractures differ from the homogenous reservoir assumption. Figure 11 illustrates how lithology combined with regional stress may influence induced microseismic events.

Future work

The University of Calgary has acquired a 3-D, 3-C data set in NW Alberta. These data sit over a Duvernay pool under active development. The wells are to be drilled horizontally with a multi stage hydraulic fracture completion program. There is a permanent buried microseismic array in place to monitor seismicity. We will use the same methodology over the 3-D, 3-C data set and compare the results to micro seismic.

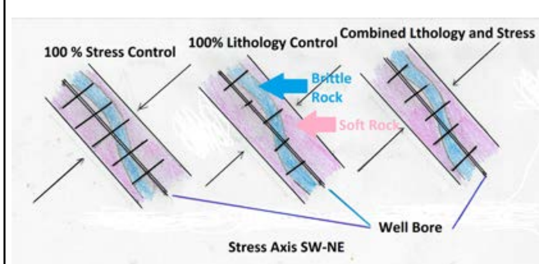


Figure 10. Proposed variations in fracture control.

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