Integrating seismic derived rock properties with horizontal well induced fractures in the Duvernay Formation

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Summary

The Duvernay formation is a major zone of interest for unconventional oil production. It is the stratigraphic equivalent of the lower Leduc, and is commonly believed to be the source rock for most of the Devonian age production in Alberta. We propose a method of using prestack seismic attributes is to derive rock properties from the Duvernay Formation. Rock properties such as Poisson's Ratio, Young's Modulus, and brittleness are useful in defining areas suitable for hydraulic fracturing. In this study, prestack seismic attributes are derived from a 2-D seismic line over an area in Alberta where the Duvernay is in the mature oil window. The technique used here is simultaneous inversion, where Vp, Vs, and ρ are calculated from prestack CMP seismic data. Parameters such as Young's modules, shear modulus, brittleness, and Poisson's ratio are in turn calculated from Vp, Vs, and ρ. Ideally, the lithology most suitable has a low Poisson Ratio, and a high Young's Modulus. A common assumption made in horizontal well planning is that the lithology is uniform and homogeneous, which we do not believe is correct. Significant changes in Duvernay rock properties are observed in seismic data over relatively short distances. These changes can have a significant impact on planning horizontal well bores, and subsequent well performance. Wells can be placed in areas that are more suitable for hydraulic fracturing; the rocks that are brittle, and will stay open after proppant and sand is injected are the best candidates for stimulation. Seismic derived attributes can provide valuable information with respect to well placement, and what facies in the Duvernay formation are favorable to hydraulic fracture stimulation. Historically some completions perform well, others fail, and the fracture patterns and induced seismicity vary in a non-uniform manner. This calls into question the homogeneous reservoir assumption commonly used today in well planning. Hydraulic fracture induced seismicity may preferentially follow geological zones of weakness.

Introduction

The Duvernay 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 has become a desired exploration target. The rock type varies in accordance with its position in the basin. Near Leduc reef buildups, there is reef debris, away from the reef, it is an organic carbonate bank. The Duvernay is rich in organic matter and, depending where it is situated in the basin, produces gas, natural gas liquids, or oil. Vertical wells and cores were evaluated for rock properties, total organic hydrocarbon content, and suitability for further development. Common production practice has been to drill a pattern of horizontal wells, and hydraulically fracture these wells in a number of stages. The lithology is often assumed to be uniform, affected only by the overall stress regime and pre-existing fractures.

Recent work by Soltanzadeh (2016), and Cho (2014), indicate that there are significant variances in the Duvernay formation properties. Figure 1. Shows the results of modeling the rock properties on, clay, quartz, limestone and the resulting Poison Ratio, and Young's Modulus. The upper left hand area are rock properties that are believed to be brittle, and can hold a fracture open. Prestack seismic inversion allows us to calculate these same parameters from seismic data

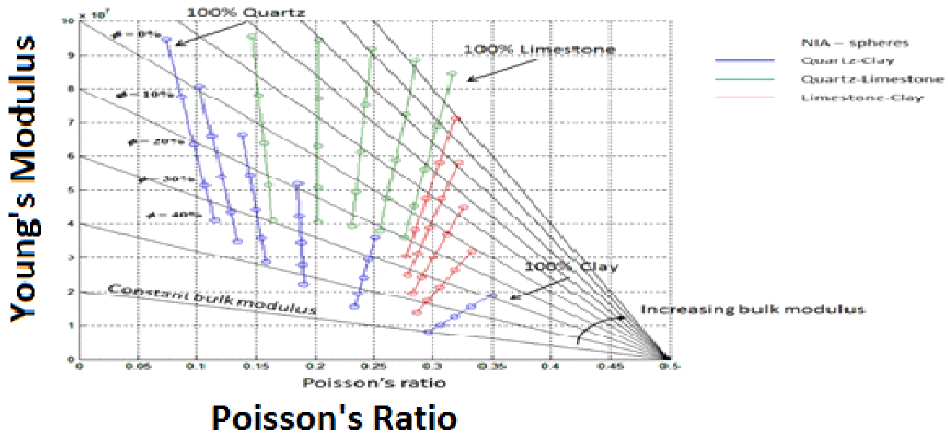

FIG 1 Poisson ratio vs. Young's modulus. The area of this cross plot to the upper left are areas suited to fracture stimulation.

Theory

The PP reflectivity from a boundary of two isotropic layers can be expressed as a function of the incident angle source receiver, or more conveniently as a function of θ, where θ is the incident angle.

$$R_{PP}(\theta) = c_1 R_P + c_2 R_S + c_3 R_D$$

(Aki-Richards Equation)

Where

$$c_1 = 1 + \tan^2\theta$$
$$c_2 = -8\gamma^2 \sin^2\theta$$
$$c_3 = -\frac{1}{2}\tan^2\theta + 2\gamma^2\sin^2\theta$$
$$\gamma = \frac{V_S}{V_P}$$

$$R_P = \frac{1}{2}\left[\frac{\Delta V_P}{V_P} + \frac{\Delta\rho}{\rho}\right]$$
$$R_S = \frac{1}{2}\left[\frac{\Delta V_S}{V_S} + \frac{\Delta\rho}{\rho}\right]$$
$$R_D = \frac{\Delta\rho}{\rho}.$$

Inverting the prestack seismic amplitudes using the above equation gives values for Vp, Vs, and ρ. Once these values are known, the Poisson ratio is calculated using this equation:

$$\text{Possion's Ratio: } PR = \frac{0.5 * \left(\frac{Vp}{Vs}\right)^2 - 1}{\left(\frac{Vp}{Vs}\right)^2 - 1}$$

and Young’s modulus using:

$$\text{Young's Modulus: } E = \frac{2 * Z_s^2 * (1 + PR)}{Density}$$

These are the attributes cross plotted in model data, Figure 1, and derived from seismic data, Figure 2.

Seismic Analysis

The prestack inversion was processed using the Hampsen-Russel software on a single 2-D seismic line in the mature Duvernay oil trend, adjacent to a Leduc Reef. The Poison Ratio vs. Young’s modulus in the Duvernay interval is shown in figure 2. A linear data trend is evident in the Poisson Ratio/Young’s Modulus cross plot. The majority of the points are aligned on a lower right to upper left trend, interpreted to reflect variations in the Duvernay rock brittleness.

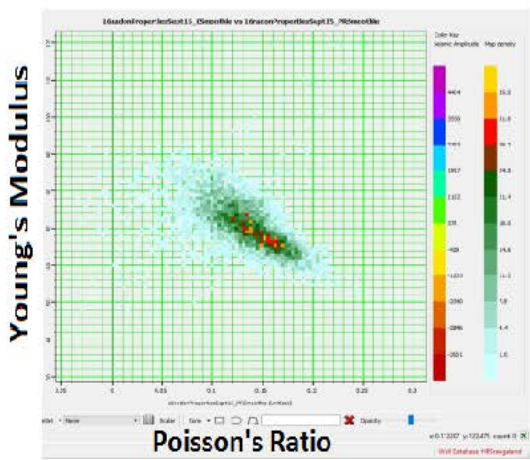

Figure 2. Histogram of Duvernay cross Plot; Poisson`s Ratio vs. Young’s Modulus This is equivalent to the model cross plot displayed in figure 1.

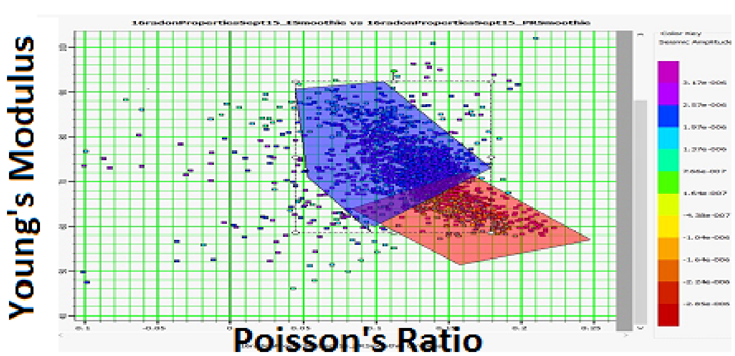

Figure 3. Cross plot of Poisson`s ratio (x) vs Young’s Modulus (y)

Figure 3 is a summation of all the Poisson`s data points inside the seismically defined Duvernay interval. The seismic plot in figure 4 show all points on the seismic line that meet these conditions in the enclosed red and blue polygons. The data points highlighted in red are less brittle, the data points highlighted in blue are more brittle and capable of holding a fracture open. The boundaries between red and blue are user defined. Note the variance from NE to SW in the Duvernay interval. The Blue zone indicates more brittle rock, the red, less. According to this, a hydraulic fracture at the Precambrian well tie (red triangle figure 4) would perform well, induced fractures further to the West, (red color) would perform poorly.

The colors in figure 4 are derived from the E (Young's Modulus) vs. Poison Ration Cross Plot in Figure 3. The zone of interest in the Duvernay is marked with the black arrow. This may explain why there are often unpredictable behaviors in hydraulic fracture patterns in formations that are often assumed to be homogeneous.   The 2-D seismic line in figure 4 shows significant variation in the Duvernay Formation over the eight km. (the displayed) line length.

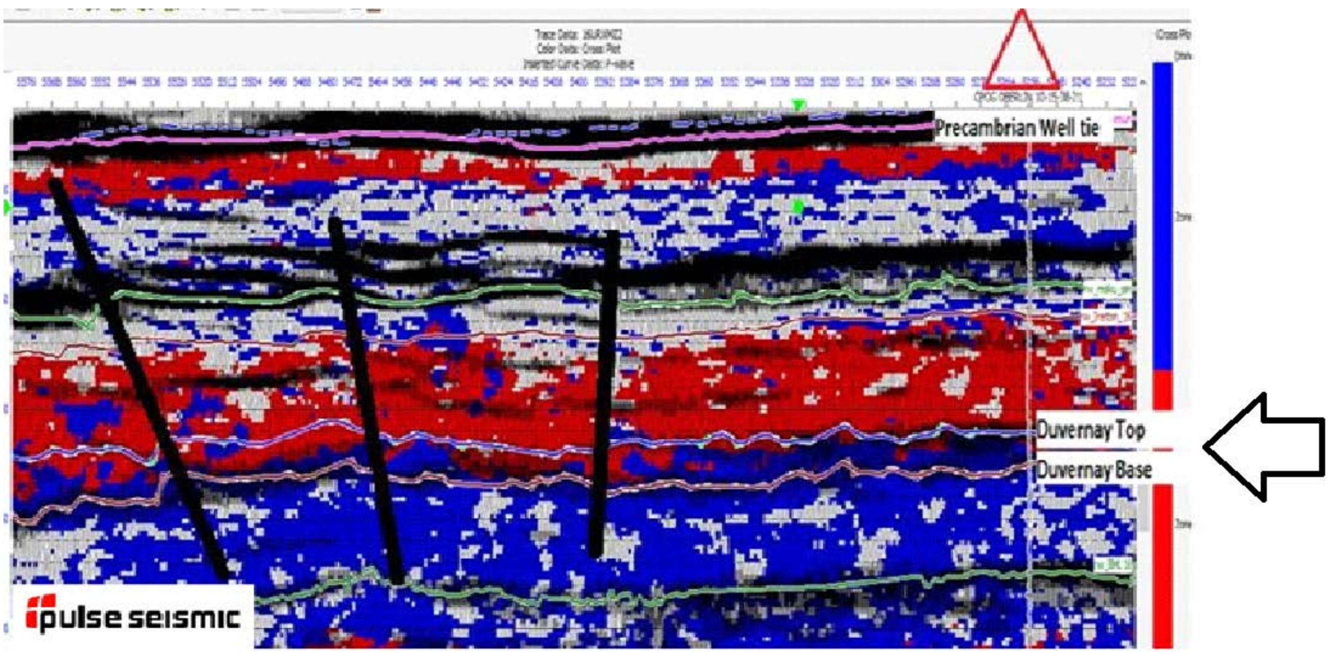

Figure 4. Seismic stack displays overlain with the polygon defined attributes from figure 3.

Conclusions

In order to prove the concept of lithologic controlled fracture patterns, a 3-D seismic survey should be acquired over an existing Duvernay pool in conjunction with a Microseismic survey. Young's modulus and the Poisson`s Ratio (and several other attributes) can be derived from the data and displayed on a 3-D seismic interpretation system. Seismic inversion data can also identify areas with rock properties that likely would hold the fracture open, and not collapse. The seismic inversion suggests that there are significant variations in lithology in the Duvernay in Rangeland. This is consistent with the findings by Fox et al using core analysis in NW Alberta. Prestack inversion can identify these variations. To prove this concept, a 3-D survey would be processed over a known hydraulic fracture program, and Microseismic events observed to follow seismically mapped brittleness trends.

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References

Reference Style (use Arial 9pt normal)

Alberta Energy regulator, 2016 Chapter 12 – Woodbend-Winterburn Strata of the Western Canada Sedimentary Basin http://ags.aer.ca/publications/chapter-12-devonian-woodbend-winterburn-strata

Baig , Allan M, Urbancic, Ted I. Structural Controls on Vertical Growth of Hydraulic Fractures as Revealed Through Seismic Moment Tensor Inversion Analysis. SPE 159795, October 2012.

Bowman, Sheri, 2011 A Decade Monitoring Shale Gas Plays Using Microseismicity: Advances in the Understanding of Hydraulic Fracturing March 2011, esg solutions.

Camp, Wayne, Palovic, Mitch, Eastwood, John O'Brian, John, 2013, Introduction to special section: Interpretation for unconventional resources, November 2013.

Cho, David, Marco Perez, Qeye Labs Canada, 2014, Brittleness revisited GeoConvention 2014 FOCUS

Claudio Virues, Jessica Budge, Eric Von Lune,2016, Value of Integrated Geophysics Microseismic- Derived Ultimate Expected Fracture Half-Length in SRV in a Multi-Staged Pad in the Horn River Basin Nexen Energy ULC, CSEG RECORDER | Apr 2016 | VOL. 41 No. 04

Dunn, L., Schmidt, G., Hammermaster, K., Brown, M., Bernard, R., Wen, E., Befus, R., and Gardiner, S, 2012.The Duvernay Formation (Devonian): Sedimentology and Reservoir Characterization of a Shale Gas/Liquids play in Alberta, Canada GeoConvention 2012: Vision.

Haege, Martin, Zhmodik, Alexey, Boskovic, Drazenko, Ramanathan Venkateshwaran, Hoffat, Tina, and Li, Qiuguo, Perez Oscar Taylor Neil, 2015, Duvernay Fracturing: From Microseismic Monitoring to Unconventional Fracture Model Construction, GeoConvention 2015, Geoscience. New Horizons

Hampson, Dan, Russell, Brian, Hampson-Russell Software Bankhead, Brian, 2005,VeritasDGC.Simultaneous inversion of pre-stack seismic data, 2005 CSEG Convention.

Lines, L., Newrick, Geophysical Monograph Series, 2004, SEG number 13, Fundamentals of Geophysical Interpretation, 2004

Maxwell, S, Urbancic, T., Steinsberger, N. Zinno, R., .2002: Microseismic Imaging of Hydraulic Fracture Complexity in the Barnett Shale, SPE Annual Conference, San Antonio, TX, USA, SPE77440

Mehrdad Soltanzadeh, Amy Fox, Nasir Rahim 2015, Application of an Integrated Approach for the Characterization of Mechanical Rock Properties in the Duvernay Formation, GeoConvention 2015, Canadian Discovery Ltd,

Millar John, and Bancroft, John C, 2004, Multigrid deconvolution of seismic data, CREWES Research Report Volume 16 (2004)

National Energy Board, November 2009 ARCHIVED - A Primer for Understanding Canadian Shale gas - Energy Briefing Note

Russell, Brian, 2014, Seismic Reservoir Characterization and Pre-Stack Inversion in Resource Shale Oct 27, 2014 Search and Discovery Article #41467

Sharma, Ritesh , Chopra Satinder, Arcis seismic solutions, TGS, 2014, Calgary Play Search and Discovery Article #41467(2014) **Posted October 27, 2014.Identification of thin sweetspots in the Duvernay Formation of north central Alberta

Soltanzadeh, Mehrdat, Fox, Amy, 2016, Application of an Integrated Approach for the Characterization of Mechanical Rock Properties in the Duvernay FormatinGeoConvention 2016 New Horizons presentation.

Switzer S.B. et all, 2014, Alberta Geological Survey Chapter 12 - Devonian Woodbend-Winterburn Strata of the Western Canada Sedimentary Basin 2014

Switzer, S.B., Holland, W.G., Christie, D.S.,Graf, G.C.,Hedinger, A.S., McAuley, R.J.,Wierzbicki, R.A.and Packard, J.J. 1994. Devonian Woodbend-Winterburn Strata of the Western Canada Sedimentary Basin. In: Geological Atlas of the Western Canada Sedimentary Basin. G.D.Mossop and I. Shtsen (comps.) Calgary, CSPG and ARC, chapter 12.

Trilogy Energy corporate presentation, Annual Report, 2015 http://www.trilogyenergy.com/properties/duvernay-shale-gas-development

Weir, R, 2016 The Conklin SAGD Project; The Application of Simultaneous inversion to PreStack Gathers CREWES Presentation, March 2016.

Wuestefeld Andreas, Urbancic Ted, Baig Adam, Prince, March, 2012, ESG Solutions. After a Decade of Microseismic Monitoring: Can We Evaluate Stimulation Effectiveness and Design Better Solutions, March 2012, SPE 152665