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

Ronald Weir, D. Eaton, L. Lines, D. Lawton
Introduction

• Overview of Duvernay Geology
  • Regional Framework
  • Modern Analogue
  • Core work
  • Theoretical Rock properties

• Current development practices
  • Horizontal drilling, microseismic results

• Seismic inversion analysis
  • Simultaneous inversion
  • Derivation of rock properties

• Uses and applications
  • Implications of reservoir characteristics
  • Future work
Duvernay Formation Depositional Environment

- Both North Duvernay (Wild River) and South Duvernay (West Shale Basin) were centered in areas adjacent to reef development.
- Reefs created restricted basin conditions, where organic productivity was high resulting in thick, high TOC shale deposits.
Great Barrier Reef, modern analogue to the Leduc / Duvernay

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Kaybob area, core analysis of rock properties.

Figure 1. Mechanical properties calculated based on sonic logs for 26 wells for the Duvernay and Ireton formations: (a) dynamic Poisson’s ratio, (b) dynamic Young’s Modulus, (c) Rickman’s brittleness Index, and (d) plane-strain Young’s modulus.

Amy D. Fox, Mehrdad Soltanzadeh Canadian Discovery Ltd.
Theoretical calculation of rock properties

Cho Et al, GeoConvention 2014 FOCUS
Duvernay Horizontal plan, Kaybob/Bigstone

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Variations in microseismic activity in the Montney Shale

Shawn C. Maxwell
Schlumberger, Calgary, Alberta, Canada
Oct 2011 | VOL. 36 No. 08 |
Study area, East – Central Alberta
Large scale synthetic tie, highlighting the zone of interest
We start with Fatti’s version of the Aki-Richards’ equation. This models reflection amplitude as a function of incident angle:

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

where:

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

\[ R_p = \frac{1}{2} \left[ \frac{\Delta V_P}{V_P} + \frac{\Delta \rho}{\rho} \right] \]
\[ R_s = \frac{1}{2} \left[ \frac{\Delta V_S}{V_S} + \frac{\Delta \rho}{\rho} \right] \]
\[ R_D = \frac{\Delta \rho}{\rho} \]
From the Fatti’s version of the Aki-Richards’ equation:

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

Where,

\[ c_1 = 1 + \tan^2 \theta, \quad c_2 = -8\gamma^2 \sin^2 \theta, \quad c_3 = -\frac{1}{2}\tan^2 \theta + 2\gamma^2 \sin^2 \theta \]

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

These equations form the basis to estimate the PP and PS reflect derived from sonic, shear and density logs.
P, S, and density inversion workflow

1. Optimally process the seismic data

\[ S_{EI}(\theta) = W(\theta) * R_{EI}(\theta) \]

2. Build model from picks and impedances

\[ M = EI(\theta) = V_p^a V_s^b \rho^c \]

3. Iteratively update model until output synthetic matches original seismic data.

\[ EI(\theta) = V_p^a V_s^b \rho^c \]

In elastic impedance inversion the seismic, model and output are as shown here.
Prestack Inversion, PP reflectivity
Youngs Modulus and Poisson Ratio Calculation from inversion

Related equations are defined as follows:

Poisson’s Ratio: \( PR = \frac{0.5 \left( \frac{V_p}{V_s} \right)^2 - 1}{\left( \frac{V_p}{V_s} \right) - 1} \); Closure Stress Ratio: \( CSR = \frac{PR}{1 - PR} \)

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

Britleness: \( BRI = 100 * \left( w * \frac{(PR_{max} - PR)}{PR_{max} - PR_{min}} + (1 - w) * \frac{(E - E_{min})}{E_{max} - E_{min}} \right) \)

Brinell Hardness Number: \( BHN = 75.156 * E + 18.21 \)

The default impedance unit used in the equation is (m/s)*(kg/m3);
Default velocity unit is (m/s); Default density unit is (kg/m3).
Input values in other units will be converted automatically.
Young’s Modulus derived from inversion
Poisson’s Ratio derived from prestack inversion
Cross Plot of Poisson Ratio Vs Young’s Modulus, Duvernay interval
Cross Plot, Poisson Ratio Vs. Young’s Modulus, Cambrian

Young's Modulus

Poisson's Ratio

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Department of Geoscience
Derived and theoretical rock properties, Duvernay Formation.
Blue areas are high brittleness, Red areas are low brittleness.
Estimated response to fracture stimulation based on brittleness
Geologically defined prediction for induced fractures
Conclusions

• Reservoir attributes can readily be extracted from prestack data
• Wells can be better positioned based on rock parameters
• Reservoir characterization may be able to explain the variable fracture patterns and productivity of horizontal wells
Future work

• A 3-D data set has become available in Bigstone, with well control and ongoing microseismic monitoring.

• This data set will be analyzed using the same methodology outlined in this presentation, with the incorporation of microseismic data.

• I expect to have results late 2017, or early 2018.
• TECHNICAL SOFTWARE USED

• Geoview (HRS), pre and poststack inversion
• Geoscout, Well grid and culture data base, LAS files, production and perforation information
• Seisware, Conventional seismic interpretation
• Vista, prestack data preparation.
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