Journey to the Centre of the Unconventional Play: The Pathway from Regional Analysis through Quantitative Interpretation to Well Planning

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Laurie Bellman
Welcome!

INTRODUCTION

Well Planning

Geomechanics

Quantitative Seismic Interpretation

Stress Analysis

Reservoir Characterization

Source Rock Evaluation

Hydrodynamics
Agenda

• **CHERYL WRIGHT**
  - Introduction

• **NEIL WATSON**
  - Montney Regional Setting and Production Summary

• **AMY FOX**
  - Geomechanics

• **LAURIE BELLMAN**
  - Quantitative Interpretation

• **KAUSH RAKHIT**
  - Concluding Remarks
  - Acknowledgements
  - Next Talk – Cap Rock Integrity issues
MONTNEY REGIONAL SETTING AND PRODUCTION SUMMARY
Montney, the #3 N.A. Resource Play

Shale Gas Resources by Play

EIA, 2011
- Detailed understanding of facies through high resolution stratigraphy and core work
Montney IP Vertical vs. Horizontal

Average IP (boe/d)

- Montney - Distal Shelf Resource (110):
  - Horizontal: 616
  - Vertical: 79

- Montney Distal Shelf (820):
  - Horizontal: 368
  - Vertical: 231

- Montney - South Subcrop (1134):
  - Horizontal: 123
  - Vertical: 141

- Montney - Ring - Border (381):
  - Horizontal: 139
  - Vertical: 109

Legend:
- Orange: Horizontal
- Brown: Vertical
Montney Multi-Well Production Chart

MULTI-WELL

MMCF/day vs. Normalized Time (Months)
Average/Well Production Gas by Quartile

Average Gas/Well vs. Normalized Time by Quartile

- 1st Quartile Ave. Gas/Well
- 2nd Quartile Ave. Gas/Well
- 3rd Quartile Ave. Gas/Well
- 4th Quartile Ave. Gas/Well
1st Year Ave Production and Forecast Cum. Gas

<table>
<thead>
<tr>
<th>Quartile</th>
<th>First Year Ave Prod (mcf/d/well)</th>
<th>Forecast Cum (mcf/d/well)</th>
<th>On prod cost ($/mcf/day)</th>
<th>F&amp;D Cost (D&amp;C Only) ($/mcf)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4,558</td>
<td>6,638,125</td>
<td>$1,233.87</td>
<td>$0.85</td>
</tr>
<tr>
<td>2</td>
<td>3,325</td>
<td>5,019,497</td>
<td>$1,691.42</td>
<td>$1.12</td>
</tr>
<tr>
<td>3</td>
<td>2,330</td>
<td>3,775,316</td>
<td>$2,413.73</td>
<td>$1.49</td>
</tr>
<tr>
<td>4</td>
<td>1,472</td>
<td>2,310,759</td>
<td>$3,820.64</td>
<td>$2.43</td>
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<tr>
<td>D&amp;C Cost</td>
<td>$5,623,980</td>
<td>n = 85</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Best well Forecast Cum (bcf)</td>
<td>7.1</td>
<td>Best well completion cost ($ M)</td>
<td>$1,793</td>
<td></td>
</tr>
<tr>
<td>Worst well Forecast Cum (bcf)</td>
<td>1.7</td>
<td>Worst well completion cost ($ M)</td>
<td>$4,354</td>
<td></td>
</tr>
</tbody>
</table>
Montney Quartile Distribution Map
1. Set a rig where access is easy.

2. Drill the same well the guy in the township next to you did and expect the same results.

3. React to drilling surprises as they occur.

4. Collect the standard, minimum data required.

5. Pay for as many frac stages as you can afford and cross your fingers.

6. Repeat steps 1 through 5.
1. Start with a field development plan that’s based on a preliminary understanding of your reservoir from seismic and offset well data.

2. Drill an efficient well, proactively addressing any expected issues.

3. Target your data collection efforts to reduce uncertainty in the most important reservoir parameters.

4. Plan your completion to take advantage of the geological and geomechanical setting, avoiding unnecessary frac stages.

5. Use your drilling, well and production data to refine your reservoir understanding.

6. Repeat steps 1 through 5 with increased efficiency and value.
How can Geomechanics help?

GEOMECHANICS is how in situ stresses, pressures and rock properties affect your decision-making in all stages of the reservoir life cycle.

\[
S_x^a = S_{H_{\text{max}}} + A\Delta P_p + \psi_x = S_{H_{\text{max}}} + A\Delta P_p + \frac{A\Delta P_p}{2} (1 - \cos 2\theta)
\]

\[
S_y^a = S_{l_{\text{min}}} + A\Delta P_p + \psi_y = S_{l_{\text{min}}} + A\Delta P_p + \frac{A\Delta P_p}{2} (1 + \cos 2\theta)
\]

\[
S_{xy}^a = \psi_{xy} = -\frac{A\Delta P_p}{2} \sin 2\theta
\]

DECREASE risk and uncertainty

INCREASE your probability for success
How can Geomechanics help?

- Completion design
- Hydrofrac optimization
- Drilling parameters
- Fault stability and reactivation
- Caprock integrity
- Thermal operations, EOR
- Natural fractures, weak bedding planes
Key Geomechanical Parameters

### VERTICAL STRESS
- Density logs
- Pseudo-density from sonic
- Average rock densities

### MINIMUM HORIZONTAL STRESS
- Leak-off tests
- Minifracs or hydraulic fracturing data
- Lost circulation pressures

### HORIZONTAL STRESS DIRECTION
- Wellbore failure observed in image or caliper logs
- Cross-dipole sonic logs
- Regional knowledge/active geologic structures

### PORE PRESSURE
- Direct measurements
- Kicks, inflows
- Log- or seismic-based predictions
- Reservoir engineering data

### MAXIMUM HORIZONTAL STRESS
- Modeling of wellbore failure/ drilling events

### ROCK PROPERTIES
- Tests on core
- Log-based calculations
- Seismic
Stress in Alberta

Heidbach, O., Tingay, M., Barth, A., Reinecker, J., Kurfeß, D. and Müller, B.,
The World Stress Map database release 2008

• Kind of, but not really.
• It should!
• It sure will!
• Most likely, yes...

Uniform?
Will it affect how you drill?
Will it affect your fracs?
Will it affect production?
Production from Natural Fractures in Shale

NATURAL FRACTURE DENSITY

Rates measured by PLT five months later

Histogram of natural fractures with strike +/- 30 deg of perpendicular to wellbore

Acoustic Image

LOG ACQUISITION & INTERPRETATION
• $60-80K

FRAC STAGE
• $300K +

SMART DECISIONS
• Priceless

Based on SPE 145849 and SPE 1469122
Natural Fracture Permeability

- There are no open tensile fractures (**mode I**) occurring naturally at depth.
- Fractures at depth are sliding mode (**modes II and III**) shear fractures.
- Shear fractures that are optimally oriented for frictional failure under in situ or stimulation conditions are the most permeable.

\[ \tau = \text{shear stress} \]
\[ S_n = \text{normal stress} \]
\[ P_p = \text{pore pressure} \]
\[ \sigma_n = \text{effective normal stress} = S_n - P_p \]

Baker Hughes GMI•MohrFracs™

Increase \( P_p \) → decrease \( \sigma_n \) → “turn on” more fractures.
Data from multiple wells and seismic

Individual well, drilled, logged, analyzed

Planned well

Baker Hughes JewelSuite™
Hydrodynamics

Source

Rock

Evaluation

Reservoir

Characterization

Stress

Analysis

Well Planning

Geomechanics

Quantitative

Seismic

Interpretation

Hydrodynamics
Reservoir Properties

Depositional Environment
Quartz and Carbonate Content
Brittleness
Pressure
Stress
Fluid Type
Productivity
Porosity
TOC
Etc...

Attributes Derivable from Seismic

P-impedance
S-impedance
Density
Young’s Modulus
Poisson’s Ratio
Lambda*Rho
Mu*Rho
Etc...
• Conventional seismic interpretation provides geometry.
• **Quantitative interpretation** tells us about rock properties by rearranging the seismic amplitude values to represent geology.
Single Seismic Attribute Correlates to Microseismic Events

Poisson’s Ratio map with and without microseismic events.

Isotropic Closure Stress

Relative Brittleness Highlighted

100/6-10-79-15W6
Lamé Parameters as Proxy for Young’s Modulus vs Poisson’s Ratio

100/6-10-79-15W6

Graphs showing scatter plots of Young’s Modulus vs Poisson’s Ratio and Mu*Rho vs Lambda*Rho.
Remember the 3 Wells?
Rock Property Variation Between Wells

- Young's Modulus
- Poisson's Ratio
Rock Property Variation Between Wells

![Graph showing the variation of Poisson's Ratio and Young's Modulus between wells.](image)

- **Poisson's Ratio**
- **Young's Modulus**

Legend:
- Blue: 2500
- Green: 2550
- Yellow: 2600
- Red: 2700
• QC all wells with dipole sonics
• Compute elastic properties and correlate to reservoir parameters
• Create comprehensive rock physics templates based on deterministic analysis conditioned by regional understanding
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COMING UP NEXT
Caprock Integrity

SAGD (Steam Assisted Gravity Drainage)

SOURCE: Japan Canada Oil Sands LTD.