Role of Reservoir Characterization in Unconventional Resource Developments

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Unconventional Resources
Agenda

- **Introduction**  Unconventional ROC & Eagle Ford Consortium Overview
- **Reservoir Quality**  - Grouping “Like Rock”
- **Completions Quality**  – Evaluating the Near Wellbore Stress
- **Completions Advisor**  - Putting it all Together & Completion Review
- **Consortium Examples**  - PL, Well Path, Production
- **Conclusions**
Technology Has Played a Role, but More Science is Required

**Average Lateral Length (ft)**

- **Horn River**: 8718 ft
- **Montney**: 8627 ft
- **Bakken**: 8415 ft
- **Eagle Ford**: 6910 ft
- **Barnett**: 5206 ft
- **Fayetteville**: 5064 ft
- **Marcellus**: 5159 ft
- **Haynesville**: 5290 ft

**Average Frac Stage Count**

- **Horn River**: 24 stages
- **Montney**: 15 stages
- **Bakken**: 14 stages
- **Eagle Ford**: 17 stages
- **Barnett**: 10 stages
- **Fayetteville**: 11 stages
- **Marcellus**: 15 stages
- **Haynesville**: 10 stages
Best 3 Month Production

Bakken  B3 Average ~ 320 bbl/D

Eagle Ford  B3 Average ~ 510 BOE/D

Haynesville  B3 Average ~ 7,770 Mcsf/D

Fayetteville  B3 Average ~ 1,900 Mcsf/D
Production is Not Uniform

Eagle Ford PL Examples

- Only 64% of the Perforation Clusters contributing
- All well were completed Geometrically
The Consortium

- **Challenge**
  - Efficiency vs. effectiveness
  - Only 64% of clusters contributing
  - Solution that fits existing workflows

- **Approach**
  - Evaluate laterals using new technologies
  - Compute Reservoir Quality & Completion Quality
  - Optimize completion to maximize production
  - Share data among the consortium

- **Evaluation**
  - Compare production results of Engineered vs. Geometric Completions
Pilot to Lateral “like rock” types
Data Inventory
12 Lateral Logs with ThruBit, 3 with sonic scanner, 2 LWD and 1 OBMI
6 offset vertical wells
7 FSI Production logs

<table>
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<tr>
<th>Well</th>
<th>Pilot</th>
<th>Offset</th>
<th>ThruBit</th>
<th>Wireline</th>
<th>LWD</th>
<th>FSI</th>
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Reservoir & Completion Quality

Reservoir Quality
- Permeability
- TOC
- Porosity
- Water Saturation
- Rock Types
- Clay Volume
- Volumetrics
- Rock Strength

Completion Quality
- Frac gradient
- Rock Strength
## Reservoir Quality

### Grouping “like rock” using HRA

<table>
<thead>
<tr>
<th>Color/Rock Type</th>
<th>Best</th>
<th>Good</th>
<th>Fair</th>
<th>Tight</th>
<th>Poor</th>
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<td>Clay Volume Fraction (v/v)</td>
<td>0.134</td>
<td>0.294</td>
<td>0.434</td>
<td>0.055</td>
<td>0.210</td>
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<td>Effective Porosity (v/v)</td>
<td>0.074</td>
<td>0.068</td>
<td>0.034</td>
<td>0.039</td>
<td>0.016</td>
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<td>Permeability (nD)</td>
<td>245</td>
<td>133</td>
<td>23</td>
<td>24</td>
<td>10</td>
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<tr>
<td>Total Organic Carbon (weight %)</td>
<td>4.9%</td>
<td>4.3%</td>
<td>2.2%</td>
<td>3.0%</td>
<td>1.9%</td>
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<tr>
<td>Thermal Neutron Porosity (v/v)</td>
<td>0.162</td>
<td>0.208</td>
<td>0.212</td>
<td>0.086</td>
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<td>Bulk Density (g/cc)</td>
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<td>2.449</td>
<td>2.565</td>
<td>2.519</td>
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<td>Gamma Ray (gAPI)</td>
<td>67.9</td>
<td>87.0</td>
<td>99.4</td>
<td>49.9</td>
<td>69.6</td>
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</table>

HRA – Heterogeneity Rock Analysis
Eagle Ford Shale Frac Stage Pressure Differential

Difference in Average Stage Pressure Differential between Geometric and Engineered Completion = 385 psi
EXAMPLE Well B Engineered Completion

5-1/2 x 4-1/2 Csg / 17 Stg / 102 Perf / 1065 bopd

88.8% Perforation Efficiency
Well B – Production Engineered Completion

- **GOR ~ 700 scf/bbl**
- **Cumulative GOR: 0 – 2,000 scf/bbl**
- **Max Month Average ~ 1,150 BOE/D**
- **88.8% Perforation Efficiency**
- **1 BOE = 1 bbl oil or 6 Mscf gas**
- **51 Offset Wells**
- **Max Month Average BOE, BOE/D**
- **Cumulative Probability**

- **Oil (bbl/D); Water (bbl/D); Gas (Mscf/D); WHP (psi)**
- **Time, Days**

- **Consortium Well**
- **Maverick Zavala Frio Atascosa Wilson**
- **Gonzales DeWitt Karnes Bee Live Oak**
- **McMullen LaSalle Webb Dimmit Lavaca Kinney Uvalde Medina Bexar Guadalupe Goliad OTHER**
- **BHP LEWIS MARATHON SWIFT**

- **Core Details**
  - **Offset Wells**
  - **Perforation Efficiency**
  - **Oil Production**
  - **Gas Production**
  - **Cumulative Oil Production**
  - **Cumulative Gas Production**
Summary Perf Efficiency: Engineered vs. Geometric

Perforation Efficiency*

* Perforation Efficiency is defined as the number of perforation clusters contributing to production divided by the total number of perforation clusters.
Summary Production Comparison – Engineered vs. Geometric

Engineered Wells Averaged in Top Quartile

Cumulative Probability

Engineered

Geometric

B

G

K

A

H

J

I

L

96%

75%

80%

75%

85%

41%

75%

67%

55%
Perforation Efficiency vs. Production

- Engineered
- Geometric

Consortium Well

Average of Other 17 EFS Wells
Pressure Drainage Comparison in 1 Year

Geometric Completion
64% perfs contributing

Engineered Completion
82% perfs contributing
Engineered and Geometric – NPV impact

Basic Financial Model: Cumulative NPV

At Year 1 Investment of <$100K in Lateral Measurements
Nets $1.525 Million return

Assumptions
- Oil Price $100
- Well cost $8 Million
- Discount Rate 10%
Summary

- Reservoir Characterization in the lateral is essential for more effective completions
- Low risk, cost effective lateral measurements — ThruBit Quad Combo and SonicScanner used to derive RQ and CQ
- Perforation Cluster Efficiency improved by 28%
- Wells with Engineered Completions were top quartile wells compared to offsets
- Average value per well $1.525M