Initial Observations on the Relationship of Bakken Stress Measurements to Well Production in the Viewfield Area of Saskatchewan

David Hume P.Geol.,
Neil Watson P.Geol.,
Kaush Rakhit MSc. P.Geol

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Quotes

“Since the late 1950s, the concepts of fluid pressure and effective stress have had as revolutionary an effect on geology as the idea of plate tectonics.”

P. E. Gretener, 1976

“Wow. That’s amazing!”

G. Davies, 2011
Agenda

- Introduction
- Stress Theory - Principle Stress
- Deriving Stress Values - Frac Pressure Curve
- Cardium Case History
  - Foreland clastic wedge (compressional)
- Bakken Case History
  - Intracratic block (tensional)
- Conclusions
- Acknowledgements
Stress Theory
Principle Stresses

Key factors in resource plays:
• Reservoir Characterization
• Hydrodynamics
• Source Rock Evaluation
• Migration
• Stress
Stress Theory

Frac Pressure Curve

- Minimum Principle Stress can be determined from ISIP.
Cardium
Regional Cardium MPS Map – Stress Analysis of Central Alberta Study
Detailed mapping of Pembina Field reveals clearer picture.
• High Stress area (Rat Creek) offsets Low Stress Area (Carrot Creek)
Cardium

Lithological Summary Map

• Cardium RPM Map
• Fine grained sandstones.
• Same pressure regime
• Main variable is stress.

[Map showing Cardium RPM and lithological summary with various color-coded areas and lines indicating geological features.]
### Cardium MPS vs. ROP

- Wells in Low Stress area drill 31% faster

<table>
<thead>
<tr>
<th>Well #</th>
<th>Drilling Days (Spud-Cmpl)</th>
<th>Int. Csg Depth (m)</th>
<th>MD (m)</th>
<th>Hz section</th>
<th>Est. hz drilling days</th>
<th>Est. metres/d</th>
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</thead>
<tbody>
<tr>
<td><strong>Rat Creek Very High Stress</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>23</td>
<td>1959</td>
<td>3175</td>
<td>1216</td>
<td>19</td>
<td>64.0</td>
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<tr>
<td>2</td>
<td>21</td>
<td>2038.5</td>
<td>3300</td>
<td>1261.5</td>
<td>17</td>
<td>74.2</td>
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<tr>
<td>3</td>
<td>20</td>
<td>1964</td>
<td>2737</td>
<td>773</td>
<td>16</td>
<td>48.3</td>
</tr>
<tr>
<td>4</td>
<td>22</td>
<td>1952</td>
<td>2900</td>
<td>948</td>
<td>18</td>
<td>52.7</td>
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<tr>
<td>5</td>
<td>12</td>
<td>1976</td>
<td>2373</td>
<td>397</td>
<td>8</td>
<td>49.6</td>
</tr>
<tr>
<td>6</td>
<td>19</td>
<td>2038</td>
<td>3088</td>
<td>1050</td>
<td>15</td>
<td>70.0</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td><strong>19.5</strong></td>
<td><strong>941</strong></td>
<td><strong>15.5</strong></td>
<td></td>
<td><strong>59.8</strong></td>
<td></td>
</tr>
</tbody>
</table>

| **Carrot Creek Low Stress** | | | | | | |
| 1      | 17                       | 1908               | 2828   | 920        | 13                    | 70.8         |
| 2      | 25                       | 1960               | 3219   | 1259       | 21                    | 60.0         |
| 3      | 34                       | 2035               | 3331   | 1296       | 30                    | 43.2         |
| 4      | 21                       | 1974               | 3243   | 1269       | 17                    | 74.6         |
| 5      | 17                       | 1968               | 3324   | 1356       | 13                    | 104.3        |
| 6      | 22                       | 2148               | 3462   | 1314       | 18                    | 73.0         |
| 7      | 24                       | 2062               | 3290   | 1228       | 20                    | 61.4         |
| 8      | 22                       | 2058               | 3252   | 1194       | 18                    | 66.3         |
| 9      | 16                       | 1962               | 3272   | 1310       | 12                    | 109.2        |
| 10     | 20                       | 1891               | 2786   | 895        | 16                    | 55.9         |
| 11     | 13                       | 1953               | 3235   | 1282       | 9                     | 142.4        |
| **Average** | **21**             | **1211**           | **17**  | | **78.3**             | |

**Estimated days to set Int. Csg.**

![Well Completions & Frac Database Logo]
Cardium
MPS vs. ROP

- Wells in Low Stress area more likely to reach projected TD.
- Greater exposure to reservoir

Percent of Wells Reaching Projected Depth

Percent of Wells

0% 10% 20% 30% 40% 50% 60% 70% 80% 90% 100%

0% 0% 11% 0% 11% 11% 11% 0% 11% 60%

Percent of Licensed Depth at TD

0-2 21-4 41-6 61-8 81-88 88-1

Rat Creek Carrot Creek

WELL COMPLETIONS & FRAC DATABASE
• At 15 mos. Carrot Ck Oil rate per well > 2x Rat Ck
• High Rat Ck initial rate possibly due to charging of reservoir
At 15 months the Carrot Creek cum prod per well is 2x Rat Creek.
Completion AFE Variance vs. Average MPS Gradient

Completion Cost Variance (§)

Average MPS Gradient (kPa./m.)
Bakken First 12 Months Cumulative Oil Production

- Similar SW to NE and NW to SE trends
Bakken First 12 Months Daily Average Production
Bakken First 12 Months Daily Average Production with lineaments

- Reflects established fracture lineament trends
Bakken Siltstone Isopach

- Middle Bakken Siltstone
- Consistent thickness and reservoir facies
Bakken

PE Plot

• Similar pressure setting
Bakken

MPS Gradient Contour Map

- Limited data
- 39 data points vs. 561 for Cardium
- Broad trends are discernable
• Range of MPS Grad. values is similar to Cardium but magnitude is less.
Bakken Completion Cost/Stage vs. Average MPS Gradient

Completion Cost/Stage ($k$)

Average MPS Gradient (kPa./m.)
Bakken First 12 Mos. Av. Rate/well vs MPS Grad.
Conclusions

• Cardium data shows clear relationship between MPS Grad. and
  • Drilling performance
  • Drilling and Completion Costs
  • Production results.
• First pass suggests a similar relationship in some aspects of Viewfield Bakken
  • Tensional vs. Compressional Basins
  • Lower overall stress regime
  • Limited data at present for definitive stress analysis
• Areas of comparable stress show MPS is a significant controlling factor
• Deeper fields such as Parshall might be more affected due to higher overall stress similar to Cardium
Acknowledgement

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• Paul Patton
• Mike Seifert
• Pete Singbeil
Cardium
MPS vs. Drilling & Completion Cost