Where Did the Proppant Go?*

Jonathan P. McKenna¹

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Abstract

Effective propped fracture half-lengths following a hydraulic fracture stimulation of a wellbore can be difficult to quantify. Therefore, different techniques for modeling proppant distributions must be applied to the same dataset for validation purposes. A proppant-filled Discrete Fracture Network (DFN) model is applied to two wells targeting the Muskwa and Evie Members of the Horn River Formation. Another technique for identifying microseismic signatures associated with the initial slickwater pad and the proppant-laden fluid was applied to both wells to obtain observed proppant distributions. The similarity of the distributions from each technique gives validation to each procedure and results can be used to optimize future completion techniques. The study objective is to compare proppant distributions using a proppant-filled DFN method to the observed proppant distributions using a technique to separate fluid-induced microseismicity from proppant-laden fluid-induced microseismicity. Proppant distributions are broken up by their perpendicular, parallel, and vertical components with respect to microseismic distances from their respective stage centers. The distributions of each component are compared in terms of their mean values ± one standard deviation and results are within ~15% of one another. These propped fracture distributions can be used to evaluate wellbore and stage spacing intervals. This suggests that when these techniques are combined, the proppant distribution in a formation following a hydraulic fracture stimulation can be well constrained to yield good estimates. The model results are used as a completions-diagnostics tool for evaluating the effectiveness of the stimulation and make future completion techniques more efficient and economically more valuable.
Where Did the Proppant Go?

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Agenda

- Problem Statement:
- Background
- Workflow
- Measurements
- Example
- Conclusions
Problem Statement

In order to predict proppant distribution in the formation, a calibrated, physically-based fracture model is required.
Background

- Seismic Moment ($M_0$) and Moment Magnitude ($M_w$) Definition
- Mass balance: Relating $M_0$ to the change in rock volume ($\Delta V$) due to fluid injection ($V_i$)
Measure of Fracture Size

\[ M_0 = A\mu\delta \]

Seismic Moment = Fracture Area * Shear Modulus * Displacement

Moment Magnitude (M_w) = \( \frac{2}{3} \cdot \log_{10}(M_0) + \text{constant} \)
Mass Balance

Inject 1 ft$^3$ of water

Sealed 1 ft$^3$ of solid rock with no porosity

Increased volume to a total of 2 ft$^3$ of water-filled fractured rock
Mass Balance

\[ \Delta V \text{ is related to the volume change by } \Sigma M_0 = K \mu |\Delta V| \]

\( \Sigma M_0 \) is the sum of the seismic moments of the seismic population, \( \mu \) is the modulus of rigidity, and \( K \) is a factor close to 1.

McGarr, 1976
Workflow: Calibrated Discrete Fracture Network

$$M_0 = A \mu \delta$$

$$\Delta V_f = A \cdot \Delta u = (\Delta V_{inj}) \eta k$$

**Displacement, \( \delta \)**

**Rock Rigidity, \( \mu \)**

**Fluid Efficiency, \( \eta \)**

**Injected Volume, \( \Delta V_{inj} \)**

1. Derive Fracture Area, \( A \)
   - Use magnitude from mPGV
   - Determine rigidity from logs, displacement from published tables
2. Calculate scaling factor, \( k \)
   - Compare fracture volume (\( \Delta V_f \)) to product of injected volume (\( \Delta V_{inj} \)) and fluid efficiency (\( \eta \))
3. Refine displacement estimate (\( \Delta u_{\text{new}} \))
   - Apply scaling factor to initial displacement estimate

Clean Volume + Proppant Volume
Propped Volume assumes 100 lbs = 1 ft³
Workflow

1. Events
2. DFN
3. Propped DFN
4. Productive-SRV™
Event Set

Microseismic events are sized by seismic moment
All Fractures

Well Legend

- Muskwa
- Otter Park
- Evie

Fracture Sets

- Green: Propped
- Red: Unpropped

Grid: 100x100x100 m
Muskwa Propped Fractures

Well Legend

- Muskwa
- Otter Park
- Evie

Fracture Sets

- Green: Propped
- Red: Unpropped

Grid: 100x100x100 m
Evie Propped Fractures

Well Legend

- Muskwa
- Otter Park
- Evie

Fracture Sets
- Propped
- Unpropped
SRV: Muskwa Propped Fractures
SRV: Evie Propped Fractures
Propped-SRV Results

<table>
<thead>
<tr>
<th>Well</th>
<th>% SRV Propped</th>
</tr>
</thead>
<tbody>
<tr>
<td>Evie 1</td>
<td>14.5%</td>
</tr>
<tr>
<td>Evie 2</td>
<td>18.9%</td>
</tr>
<tr>
<td>Evie 3</td>
<td>12.5%</td>
</tr>
<tr>
<td>Muskwa 1</td>
<td>18.8%</td>
</tr>
<tr>
<td>Muskwa 2</td>
<td>31.2%</td>
</tr>
<tr>
<td>Muskwa 3</td>
<td>59.2%</td>
</tr>
<tr>
<td>Muskwa 4</td>
<td>27.5%</td>
</tr>
<tr>
<td>Muskwa 5</td>
<td>13.2%</td>
</tr>
<tr>
<td>Muskwa 6</td>
<td>21.6%</td>
</tr>
</tbody>
</table>

- **Evie**
  - ~15% SRV is propped

- **Muskwa**
  - ~29% SRV is propped

- **Completions Efficiency:**
  - Muskwa wells are most effectively propped
  - Difference in behavior requires investigation
Treatment Design Analysis

- Treatment Design Analysis maps the microseismic event cloud as a function of pumped volume.

- Tracking the growth of the fracture network in the horizontal, longitudinal, and vertical direction provides information for:
  - Optimum wellbore spacing
  - Optimum stage length and spacing
  - Vertical coverage and optimum landing zone

![Diagram of microseismic analysis with labels for:
- Vertical distance from wellbore: Vertical coverage (landing zone)
- Distance perpendicular from wellbore: Wellbore spacing
- Longitudinal distance along wellbore: Stage length and spacing]
Treatment Design Analysis: (Evie Well)

Peak in perpendicular component at $\sim 1000m^3$

Event distance from wellbore is lowest when proppant concentration is highest.
Treatment Design Analysis: (Evie Well)

Event distance from wellbore is lowest when proppant concentration is highest.
Comparison of Methods

Fracture Distribution: Perpendicular Component

Events occurring during proppant injection and when pumped volume > 1000 m³

Notice that the apparent proppant distribution matches closely with the proppant-filled DFN modeling results.
Evie Propped Fractures

Well Legend

Muskwa
Otter Park
Evie

Fracture Sets

- Propped
- Unpropped

Grid: 100x100x100 m

Micro Seismic
Comparison of Methods

Fracture Distribution: Perpendicular Component

Events occurring during proppant injection and when pumped Volume > 1000 m³

Notice that the apparent proppant distribution matches closely with the proppant-filled DFN modeling results.
Conclusions

- Calibrated DFN is physically based, calibrated to real data, preserves original shape and distribution of event cloud
- Distribution can be used to analyze appropriate well and stage spacing as well as proppant containment
- Proppant distribution is consistent with other methods
- Can be used to measure Productive-SRV
Acknowledgements
Encana, Kogas
MSI CE Group

Thank You!
Evie: Wellbore Spacing – Propped Length

<table>
<thead>
<tr>
<th>Wellbore Spacing</th>
<th>Most Aggressive</th>
<th>Conservative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Median (+9 m)</td>
<td>86 m</td>
<td>154 m</td>
</tr>
</tbody>
</table>

Avg. half-length = 75 m

Avg. half-length = 79 m

Median - $\sigma$ = 34 m

Median + $\sigma$ = 52 m

Not to scale
Evie: Stage Length and Spacing – Propped Length

<table>
<thead>
<tr>
<th>Stage Length</th>
<th>Most Aggressive</th>
<th>Decrease up to 16 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conservative</td>
<td>Increase up to 41 m</td>
<td></td>
</tr>
</tbody>
</table>

Median $+\sigma = 63$ m  
Median $-\sigma = 31$ m  
Avg. half-length = 75 m  
Avg. half-length = 76 m

Overlap between Stages: -24 m to 21 m  
Overlap between Stages: 8 m to 20 m
**Evie: Vertical Coverage – Propped Length**

<table>
<thead>
<tr>
<th>Recommendation</th>
<th>Land well up to 9 m lower or lower in Target Fm</th>
</tr>
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- Median \(-\sigma\) = 35 m
- Median \(+\sigma\) = 16 m
- Avg. upward growth = 56 m
- Avg. downward growth = 38 m

Target Formation Thickness = 31 m

Top Evie 15 m below Top Evie

Keg River

Not to scale