Understanding Induced Fracture Complexity in Different Geological Settings using DFIT Net Fracture Pressure

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DFITs reveal **Stimulation Complexity**

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...and how stress impacts complexity
Outline

1. Conclusions
2. What is a DFIT
3. How NFP Reveals Complexity
4. Defining Fabric
5. Quantifying Complexity
6. Stacked Cretaceous, Montney, Horn River
Controls on Induced Fracture Complexity

**1st Order TECTONIC SETTING**

- **Gulf Coast**
  - Passive Margin
  - Haynesville, Bossier

- **Foreland**
  - Cretaceous SS
  - Montney
  - Horn River

- **Strike-Slip / Thrust**

**Increasingly Complex Burial and Tectonic histories**

Increasing tectonic fractures, tectonic stress, decoupling pressure-stress
Controls on Induced Fracture Complexity

**1st Order**

TECTONIC SETTING

- Gulf Coast Passive Margin
- Foreland Cretaceous SS
- Strike-Slip / Thrust

**2nd Order**

- Rock Properties
- Wellbore Orientation
- Net Horizontal Stress

Increasingly Complex Burial and Tectonic histories
Increasing tectonic fractures, tectonic stress, decoupling pressure-stress

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Controls on Induced Fracture Complexity

1st Order
TECTONIC SETTING

Gulf Coast
Passive Margin
Haynesville, Bossier

Foreland
Cretaceous SS
Montney
Horn River

Strike-Slip / Thrust

2nd Order
Wellbore Orientation

Increasingly Complex Burial and Tectonic histories
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Controls on Induced Fracture Complexity

**Increasingly Complex Burial and Tectonic histories**
Increasing tectonic fractures, tectonic stress, **decoupling pressure-stress**

**1st Order**

**TECTONIC SETTING**
- Gulf Coast
  - Passive Margin
    - Haynesville, Bossier
- Foreland
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    - Montney
    - Horn River
- Strike-Slip / Thrust

**2nd Order**

**Net Horizontal Stress**
- Passive Margin
- Foreland
- Strike-Slip / Thrust

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DFIT
Diagnostic Fracture Injection Test

pressure vs. time

ISIP (FEP, FG)
closure
Pore Pressure

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DFIT
Diagnostic Fracture Injection Test

Net Fracture Pressure (NFP)  “complexity”
Net Horizontal Stress (NHS)

ISIP

Pore Pressure

Shmin
wellbore

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...why do you like DFITs?
Elastic Properties Of small INTACT Samples

Poorly Predict The Behavior Of FRACTURED Rock

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DFITs sample “Complexity” at more representative scale, $\sigma$ $\varepsilon$ conditions than core/logs

- **Core**
  - Observe fractures (infer failure)
  - Static failure of intact matrix

- **Well logs**
  - Dynamic agitation of limited volume (not at failure)

- **DFITs**
  - In-situ failure of rock “mass”

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How NFP Reveals Complexity

Net Fracture Pressure = ISIP – Closure

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How NFP Reveals Complexity

NFP = ISIP – Closure

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How NFP Reveals Complexity

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How NFP Reveals Complexity

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How NFP Reveals Complexity

NFP = ISIP – Closure

ISIP > ~24 kPa/m

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Key Cause of Increased NFP

Interactions between Hydraulic Fractures and Rock “Fabric”
Rock Fabric
intensity and orientation of fractures/POWs

Non-tectonic

- Brittle, stiff layer
- Ductile, compliant layer
- Intensity related to geomechanical properties
- Regionally pervasive
- \( \uparrow \text{NFP} \) infer \( \uparrow \text{NF} \) infer stiff/brittle

Tectonic

- Intensity related to folding/faulting
- Regionally inconsistent
- \( \uparrow \text{NFP} \neq \text{stiffness/brittleness} \)

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Quantifying Complexity and its Controls

Net Fracture Pressure

Complexity

Net Horz Stress

Confinement & Coupling

NHS vs. NFP

Confined Complexity

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Quantifying Complexity

Cretaceous Sandstones

Non Tectonic Fabric

Geomechanical Properties

NFP Complexity

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Quantifying Complexity

Confidential Strike Slip basin

Tectonic Fabric

Geomechanical Properties

NFP Complexity

DOESN’T MATTER

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Distinguishing Good from Bad Complexity

**Favorable complexity**
- Simple Network of low stress vertical, well connected induced and non-tectonic natural fractures

**Problematic complexity**
- Complex Network of vertical to horizontal highly stressed tectonic, natural and induced fractures

<table>
<thead>
<tr>
<th>ISIP</th>
<th>Favorable (ISIP &gt; overburden)</th>
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<tbody>
<tr>
<td>NFP</td>
<td></td>
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<tr>
<td>gradient</td>
<td></td>
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<tr>
<td>examples</td>
<td>Falher</td>
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</tbody>
</table>

Closure gradient in kPa/m:
- Falher: low closure
- Gething: moderate closure
- Montney: high closure
- Cadomin, Cadotte, Cardium: intermediate closure

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<td>Horn River</td>
<td></td>
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Confidential Strike slip/thrust basins

**Closure gradient kPa/m**

**NFP gradient kPa/m**

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Quantifying Complexity and its Controls

Net Horz Stress
Confinement & Coupling

Increasing NFP, Increasing complexity
Uncoupled - tectonic stress
Uncoupled + tectonic stress
Increasing NHS
Confinement & Coupling

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Net Horizontal Stress: Confinement

Increasing NHS

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Net Horizontal Stress: is closure coupled with pore pressure?

Coupled

Closure = \[ \nu^* (S_v - P_r) \] + Pressure \[ \frac{1}{1 - \nu} \]

Uncoupled

Closure = \[ \nu^* (S_v - P_r) \] + Pressure + \( \sigma \)

Closure = \[ \nu^* (S_v - P_r) \] + Pressure - \( \sigma \)

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Passive Margin, Hayneville, Bossier

Mostly Coupled
Foreland, Horn River

Coupled to Uncoupled (extensional to compressional)
Foreland, Montney

Mostly Uncoupled (compressional)

Closure gradient kPa/m vs. Pore pressure gradient kPa/m
Highly Uncoupled (compressional)

![Graph showing pore pressure gradient vs. closure gradient]
Highly Uncoupled
(highly compressional)
Strike Slip / Thrust  Cooper Basin, Australia

Highly Uncoupled
(highly compressional)

Optimizing stimulation practices in Cooper basin,
Nelson. 2007
Petroleum Geoscience, vol.13, pp3-16
Case Histories

Gulf Coast Passive Margin
Haynesville Bossier

Foreland
Cretaceous SS
Montney
Horn River

Strike-Slip/Thrust

Increasingly Complex Burial and Tectonic histories
Increasing tectonic fractures, tectonic stress, decoupling pressure-\(\sigma\)

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“Plainsville”
Gulf Coast Passive Margin

- High stress
- Lowest complexity
- Simple, soft, weak, = “Biwing-like”
- Highest OP
- Lowest NHS
- Coupled
- Complexity Increases as Pore Pressure decreases
- Local extension
- refracing

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Implications of Pressure-Stress Coupling

Good Predictability
  • frac models
  • stress logs

Relatively Easy Completions
  • repeatable
Case Histories

Gulf Coast Passive Margin
Haynesville Bossier

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Increasingly Complex Burial and Tectonic histories
Increasing tectonic fractures, tectonic stress, decoupling pressure-σ
• **Highest Stress**

• **Highest complexity**

• **NFP ≠ natural fractures ≠ brittleness**

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Strike-slip/Thrust Setting

- Highest Stress
- Highest complexity
- NFP ≠ natural fractures ≠ brittleness

- Moderate OP
- Highest NHS
- Uncoupled compressional

- Complexity Decreases as NHS increases
Implications of Tectonic Uncoupling

Poor Predictability
- need to calibrate stress logs
- difficult modeling

Problematic Completions
- PO, SO
- Repeatability
- erratic SRV
Case Histories

Foreland

Gulf Coast Passive Margin

Tectonic fabric
Remnant Tectonic stress
Decoupled

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• Variable stress & complexity

• Where Unstructured
NFP ≈ non-tectonic fractures
Frac Stimulation Playbook
based on DFIT derived non-tectonic Fracture Intensity
Foreland Basin

- Vague coupling obscured by tectonic decoupling
- Regionally uncoupled resembles SS/thrust
- Remnant coupling like Passive Margin?
Foreland Basin: *location...location...location...*

“...it is critical to recognize when a region resides or resided in a tectonically active setting”

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## Foreland: Montney Bissette, Dawson Creek

**NFP Complexity**

- Low to Moderate complexity
- Biwings?
- Greater complexity in higher stressed regions
- Tectonic fabric

**NHS Confinement & Coupling**

- Moderate to high NHS
- Mostly Uncoupled remnant tectonic compression
- Local SS

**Confined Complexity**

- NHS vs. NFP
  - Low Confinement & Coupling
  - Moderate to high NHS
  - Mostly Uncoupled remnant tectonic compression

**AOF gas rate vs. Net Horizontal Stress gradient**

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Foreland: Montney with Farrell Creek

- Low to problematic complexity
- No/few Biwings?
- Even Greater problematic complexity in higher stressed regions
- Tectonic fabric !!

- Moderate to v high NHS
- Problematic complexity
- Local Highly Uncoupled remnant tectonic compression
- bedding plane slippage
Foreland: Horn River

- Low to **problematic** at all stress levels
- Low NHS
- Uncoupled remnant tectonic compression and extension
- Local SS
- Problematic complexity PO, SO
- Hz wells

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### Horn River

<table>
<thead>
<tr>
<th>Location</th>
<th>Days on Production</th>
<th>Avg Gas/Stage (MMcf/d)</th>
<th>EUR (Pad Average)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70-K South</td>
<td>70</td>
<td>0.56</td>
<td>0.56 Bcf/Stage EUR (Pad Average)</td>
</tr>
<tr>
<td>70-K North</td>
<td>70</td>
<td>0.28</td>
<td>0.28 Bcf/Stage EUR (Pad Average)</td>
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Summary

Induced Fracture Complexity...is Complex!

1st Order
TECTONIC SETTING
Gulf Coast Passive Margin
Foreland
Strike-Slip / Thrust

2nd Order
Rock Properties
Net Horizontal Stress
Wellbore Orientation

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