Fracturing and Refracturing Insights from Microseismic Geomechanics

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Outline

• Quick overview of applications of microseismic in hydraulic fracturing
• Introduction to Microseismic Geomechanics
• Horn River Basin case study to illustrate the workflow
  – Basic inputs
  – Calibration
  – Sensitivity
  – Completion Optimization
  – Reservoir Modeling
• Upper Montney case study to address a specific question
  – Does microseismic asymmetry indicate fracture asymmetry or microseismic "blindspots"?
• Eagle Ford refracturing example
  – Diagnosing Success of Diversion
• Wrap-up
Microseismic Hydraulic Fracture Applications

- Fracture direction
- Height
- Length
- Complexity

**Optimize Stimulation Design**
- height growth
- injection rate and volume
- fluid type, additives, and diverters
- proppant placement

**Validate Completion Design**
- completion types and designs
- stage isolation
- stage sequencing
- refracturing

**Refine Well Plan**
- well orientation
- landing point
- well integrity

**Improve Reservoir Management**
- well spacing
- well placement
- induced seismicity and fault activation
- reservoir characterization
- production optimization
True quantitative interpretation can only be achieved with a geomechanical context of both microseismic and aseismic deformation.
Microseismic Geomechanics Definition

Inelastic shear fracture strain

“microseismic geomechanics”

Entire stress and strains
Complex Hydraulic Fracture Growth

Pore Pressure

Fracture Opening

Fracture Shearing

Synthetic Microseismic
Predictive Workflow

Mechanical Properties
Stress Tensor
Gray et al. 2010

DFN
Horn River Basin Case Study

• Workflow
  • Basic inputs
  • Calibration
  • Sensitivity Study
  • Completion Optimization
Representative Stage: St5 Part 1
Stage 5 - Part 1 - Model Inputs

- Injection Depth: 2460 m (approx. 8000 ft)
- Cluster Spacing: 25 m (80 ft)
- Injection Rate: 60 bpm for 95 min
- Fluid viscosity: 100 cP
- Leakoff Coefficient: $5 \times 10^{-5} \text{ ft/min}^{1/2}$
Stage 5 - Part 1 – Defining the DFN

- Field MS data consistent with 90° strike (parallel to SHmax) and 80° dip => DFN
- Fracture Density: $6.9 \times 10^{-6}$ num/m$^3$
- Fracture element size derived from magnitude distribution
Model Calibration

Mechanical Properties
Stress Tensor
Gray et al 2010

DFN

Pore Pressure
Fracture Dilation
Fracture Shearing
Synthetic Microseismicity

Hydraulic Fracture

DFN
Microseismically Calibrated Model
Calibrated Model – Microseismic Moment

14
Calibrated Model Results
Aperture in Primary Fractures

[Image of fracture clusters with measurements and labels]

Cluster 1
- 128m
- 552m

Cluster 2
- 120m
- 560m

Cluster 3
- 120m
- 592m

Injection Point
Stimulated DFN
Proppant Concentration
Proppant Distribution
Fluid Distributions
Sensitivity Testing

• How much do fracture geometry and microseismic response change if inputs change?

• Are fracture geometry AND microseismic similar to original model?  
  – Model results insensitive to parameter change. Not important to future results.

• Is the geometry the same but the microseismic response changes?  
  – Microseismic depends on reservoir parameters and completion.  
  – Microseismic can be used to define reservoir parameters (e.g. DFN)

• Does fracture geometry AND microseismic change?  
  – Microseismic can be used as a diagnostic in future wells.

• Does the geometry change but the microseismic response stay the same?  
  – NON-UNIQUE CALIBRATION. Need other data to calibrate the model better.
Example – Changed Stress Profile

Stress State

- TVDss (m)
  - Muskwa
  - Otter_Park
  - Keg_River

- Stress (Mpa)
  - Shmin
  - Sv
  - SHmax
  - pp

Stress Profile Before

Stress Profile After

Arrow indicating change from left to right.
Example – Changed Stress Profile
Example – Changed Stress Profile
Sensitivity to DFN geometry

Base

Case 1

Case 2

Case 3

Case 4
Completion Optimization

- A calibrated model can be used to drive field test program or other changes.
Alternate Design – Viscosity, Injection Rate, Clusters
Upper Montney Case Study

- The microseismic data cloud is asymmetric.
  - Is the fracture asymmetric?
  - What could cause this asymmetry?

- Build a 3D hydraulic-geomechanical model using available geologic data, and simulate the injection sequence.
  - Relate hydraulic fracture dimensions (length, height) to microseismic dimensions
  - Do the volumetrics make sense?
Overview

- Open-hole, sliding-sleeve hydraulic stimulation in the Upper Montney
- Microseismic data recorded during stimulation
  - Asymmetric microseismic data about injection point
  - Is the asymmetry real?
  - What causes asymmetry?
Geologic inputs for the geomechanical model:
- Elasticity parameters
- Stress field
  - Shmin from DFIT analysis
  - Corrections due to tectonic effects
- DFN density and fracture characteristics
- Pore pressure
- Injection Schedule
  - Slickwater @ 11 m³/min for 33 min
  - 30/50 proppant ramp
Discrete Fracture Network

Primary fracture set with strike $40^\circ$, dip $35^\circ$
Secondary fracture set with strike $87^\circ$, dip $35^\circ$

Clay+TOC Modeled via Kohli & Zoback, 2013

Friction
Model geometry

Single HF - Plan View

Depth View

- Borehole: 1100 m
- HF plane: 1100 m
- 800 m
- 2000 m
- 600 m
- 300 m
Calibrated Synthetic vs Field Microseismicity

- Good match for both stages 32 and 34 for MS lengths and heights
  => fracture lengths and asymmetry in MS data could be real
Synthetic microseismic mechanisms
Calibrated Model
Height Growth
Fracture and Proppant Extents

Stage 34

Fracture Extent

Proppant concentration

Stage 32

Fracture Extent

Proppant concentration
Fracture Asymmetry – a Stress Shadow Effect?

Stage 34 calibration requires a horizontal stress gradient

5 Perforation clusters

- Model indicates a stress shadow effect between clusters
- Local effects could be responsible

\[ \sigma_{\text{min}} \]

\( \sigma_{\text{min}} \) Gradient

Field MS

Synthetic MS
Refracturing in the Eagle Ford

• Typical Eagle Ford well refractured after 3 years on production
Geometry of initial fractures and DFN
Stress state and pore pressure after depletion

Pore pressure

Minimum horizontal stress

Wellbore

Wellbore

Wellbore

Wellbore

Wellbore

Wellbore

Wellbore
Four Refracture Scenarios

1. Poor diversion with all initial and refracture perforations open
2. Partial diversion, with half the initial perforations closed
3. Perfect diversion with all initial perforations closed
4. Perfect diversion, with a limited number of perforations in the new stage
Geometry of Primary Fractures: Poor Diversion

(a) 10 minutes
(b) 30 minutes
(c) 50 minutes
(d) 80 minutes
Fluid Distribution: Poor versus Partial Diversion

Fluid Volume Distribution Between Stages During Refracturing (Poor Diversion)

Fluid Volume Distribution Between Stages During Refracturing (Partial Diversion)
Final Geometry for Four Cases

- Poor
- Partial
- Perfect
- Perfect (Limited Entry)
MS Signature: Poor versus Perfect Diversion
Microseismic Time-Distance Plots

Microseismic Time-Distance Plot for Poor Diversion

Microseismic Time-Distance Plot for Perfect Diversion
Microseismic Time-Distance Plots - Filtered

Microseismic Time-Distance Plot for Poor Diversion
(Events Outside Refracture Cluster Area)

Microseismic Time-Distance Plot for Perfect Diversion
(Events Outside Refracture Cluster Area)
Cumulative Moment Diversion Diagnostic

Cumulative Moment in Refracture Area
(Last 70 Minutes of Pumping)

Percentage of Total Moment

Time (min)

Poor Diversion
Perfect Diversion
Wrap-up

• Microseismic Geomechanics to understand microseismic data
  – Calibrated fracture model
  – Insights into the complete fracture network including tensile and aseismic parts
• Horn River Basin case study
  – Field data => Calibrated model => Completion optimization
• Upper Montney case study
  – Stress shadowing can cause microseismic asymmetry
• Eagle Ford refracturing example
  – Field diagnostic of diversion success
  – Good example of using model to gain insight and lead to a simple field diagnostic
Questions