Sampling a Stimulated Rock Volume: An Eagle Ford Example


URTec_2670034

ConocoPhillips
Where to begin?
Our Questions

» What is Stimulated versus Drained Rock Volume?
  - Are SRV and DRV identical?
    • What data are sufficient to describe either?
  - What is the spatial extent and variability of SRV/DRV?
    • Well spacing and stacking
    • Cluster spacing

» Are outcomes repeatable?

» Can predictions be improved?
  • Fracture and proppant propagation modeling
Pilot Design

» Spatial sampling … define what is there
  – 2 Pre-completion sample wells
  – 4 Post-completion sample wells

» Remote completion monitoring … extend beyond the known
  – Distributed Acoustic/Temperature Sensing (DAS/DTS)
  – Dual well microseismic

» Production monitoring … establish link to performance
  – Production logs
  – Tracers (oil, water, and proppant)
  – Pressure monitoring within the SRV
<table>
<thead>
<tr>
<th>Well</th>
<th>Producer</th>
<th>Cuttings/proppant</th>
<th>Core</th>
<th>Image Logs</th>
<th>RA Tracer</th>
<th>RA Tracer Log</th>
<th>DTS/DAS</th>
<th>Geophones</th>
<th>Pressure Gauges</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>X</td>
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<tr>
<td>P3</td>
<td>X</td>
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<td>X</td>
<td>X</td>
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<td>P4</td>
<td>X</td>
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<td>S3 ST01</td>
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<td>S3 ST03</td>
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</table>

**Map View**

**Elevation**

**24–26 January 2017**
THE WOODLANDS, TEXAS, USA
The Woodlands Waterway Marriott Hotel and Convention Center
# Completion Design

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Design Type</td>
<td>Limited entry</td>
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<tr>
<td>Clusters /Stage</td>
<td>5</td>
</tr>
<tr>
<td>Cluster Spacing</td>
<td>47 ft.</td>
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<tr>
<td>Pre flush</td>
<td>Acid/linear gel</td>
</tr>
<tr>
<td>Slurry Carrier Fluid</td>
<td>30# borate gel</td>
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<tr>
<td>Flush</td>
<td>Linear gel/slickwater</td>
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<td>Fluid Volume</td>
<td>21 bbl./ft.</td>
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<td>Proppant Load</td>
<td>1500 lb./ft.</td>
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<tr>
<td>Proppant type</td>
<td>White sand</td>
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<tr>
<td>Proppant Size</td>
<td>40/70, 30/50</td>
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</table>
Hydraulic Fracture Characteristics

» Frequency
» Spatial distribution
» Length and height
» Simple or complex
» Vertical or dipping
» Orientation vs principal stresses
Base State: Natural Fractures

- Pilot located in seismically quiet area
  - No mappable faults
  - Few subseismic features (FEV)
- S1 image log – 1 fracture in 216 ft. of section
- S2 baseline core – 5 fractures in 200 ft. core
- S2 image log – 7 fractures in 1,120 ft. log
- Natural and hydraulic fractures are ~ parallel
Hydraulic Fracture Facts

» Abundant
» Not mineralized
» Extensional
» Planar and dipping
» Strike perpendicular to $S_{\text{Hmin}}$
» Smooth, ridged, and stepped surfaces
» No matrix damage
Hydraulic Fracture Branching

» Branching evident in core and FMI

» Complex 3D fracture pattern
  – More prevalent upwards vs outwards
Hydraulic Fracture Swarms

- Swarms of closely spaced hydraulic fractures
- Less intensely fractured between swarms
- 15 – 25 fractures per swarm
- Weak correlation between swarm frequency and cluster spacing
Hydraulic Fracture Spacing

» Fracture count exceeds cluster count

» 20 – 60% of wellbore has fractures at < 5ft. spacing (swarm)

» Larger gaps with distance from producer

Cluster Spacing (~47 ft)
Hydraulic Fracture Density

- Fracture density and count greatest near producer
- Fracture density declines upward and outward

upward
outward
Dip and Orientation

- Perpendicular to $S_{H\text{min}}$
- Strike: N 60° E / Dip: 75-80°SE
- Predominantly parallel fractures at all locations
- More dip variation above the producer
Hydraulic Fracture Composite

<table>
<thead>
<tr>
<th>Well</th>
<th># Hydraulic Fractures</th>
</tr>
</thead>
<tbody>
<tr>
<td>S3</td>
<td>680</td>
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<tr>
<td>ST01</td>
<td>423</td>
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<tr>
<td>ST02</td>
<td>397</td>
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<tr>
<td>ST03</td>
<td>966</td>
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</tbody>
</table>

- Red: Iridium from P2
- Yellow: Scandium from P3
- Blue: Pressure Gauge
- Pink: Cored Interval
Proppant Transport

- 3 proppant filled fractures in 480 ft. of core (7 perf clusters)
- Little evidence for abundant proppant transport at distances greater than 75 ft.
Hydraulic Fracture Character

- Hydraulic Fractures are complex not simple
  - multiple, discrete and parallel
  - dip, but align with in-situ stress
  - spatially distributed unevenly
  - often occur in swarms

- Proppant is rarely sampled, especially far from producer
  - RA tracers indicate limited well-to-well proppant transport

- No matrix permeability enhancement
  - core perm measurements
DAS Completion Monitoring

» DAS response recorded from all monitored stages at P3

» Multiple hydraulic fractures per stage extend >1,500 ft.

» Pre-existing hydraulic fractures at P3 prior to stimulation
A Few Key Points

» Hydraulic stimulation creates fracture complexity
  – Simple concepts of one fracture per cluster are unrealistic
  – Fracture area likely exceeds that predicted by models

» Multiple fractures per stage extend long distances

» Sparse evidence for abundant proppant transport beyond 75 ft.