Applied Geoscience Conference

Sampling a Stimulated Rock Volume: An Eagle Ford Example

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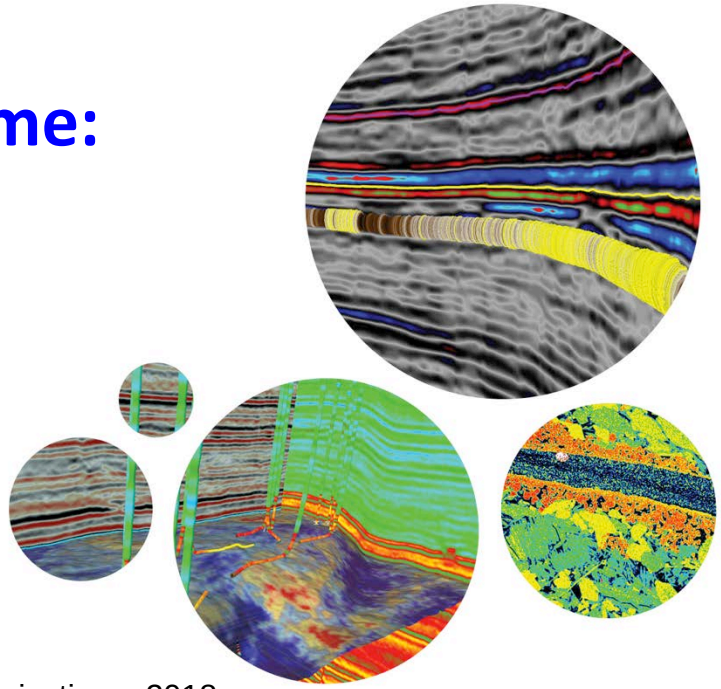

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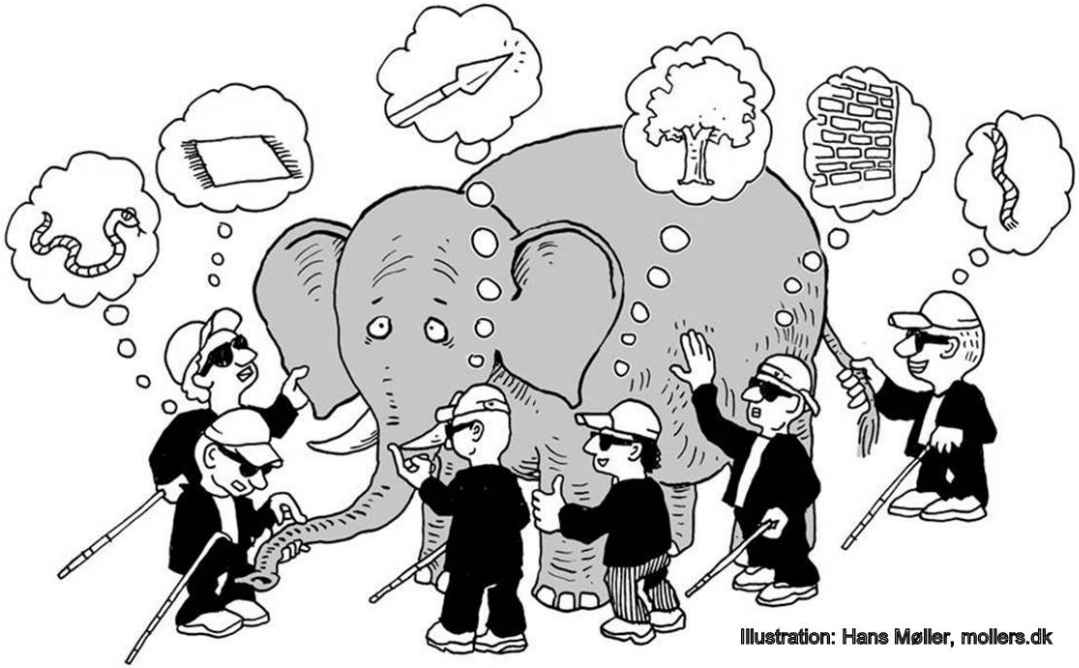
Stimulated Rock Volume… Where to begin?



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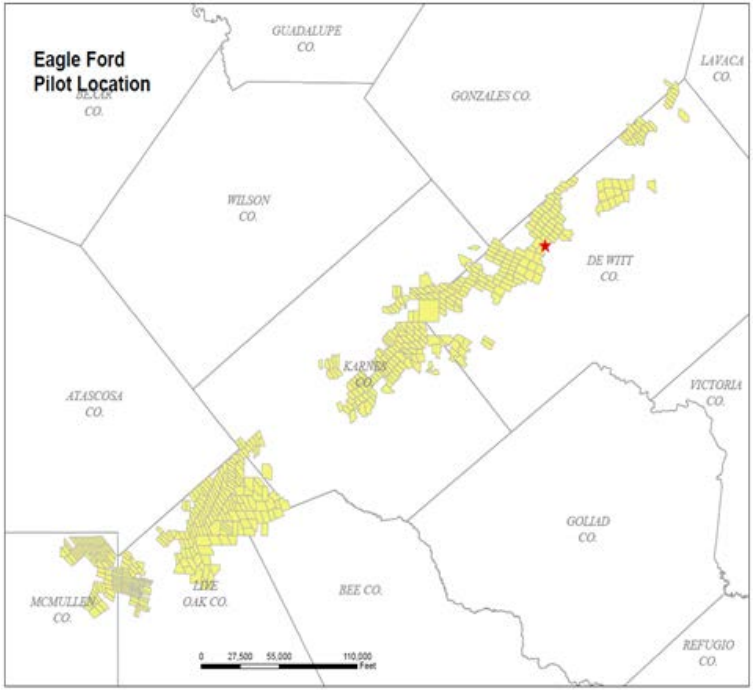
Our Questions

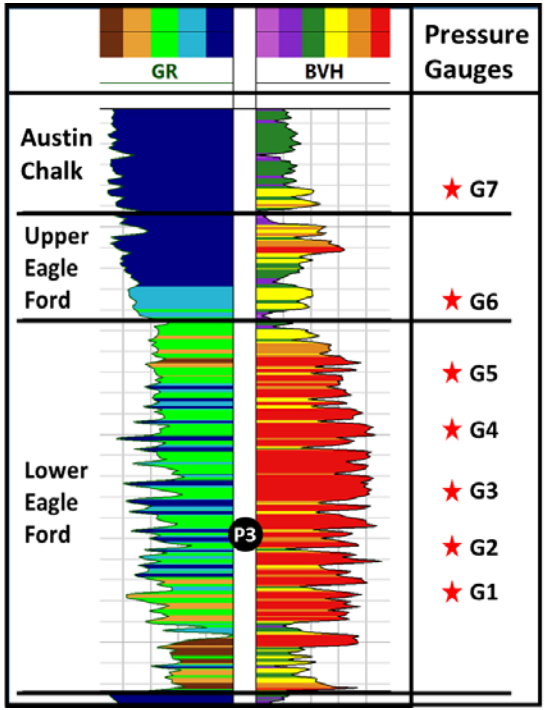
- **What is Stimulated versus Drained Rock Volume?**
  - **Are SRV and DRV identical?**
    - **What data are sufficient to describe either?**
  - **What is the spatial extent and variability of SRV/DRV?**
    - **Well spacing and stacking**
    - **Cluster spacing**
- **Are outcomes repeatable?**
-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

Location and Geologic Setting





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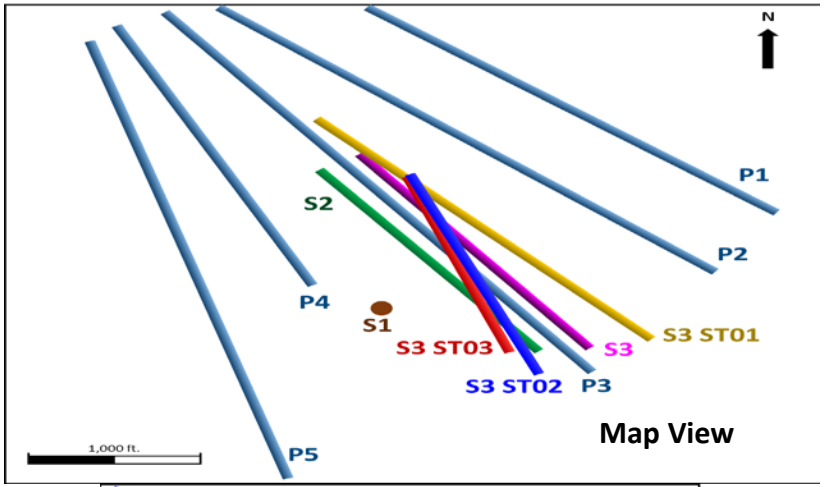
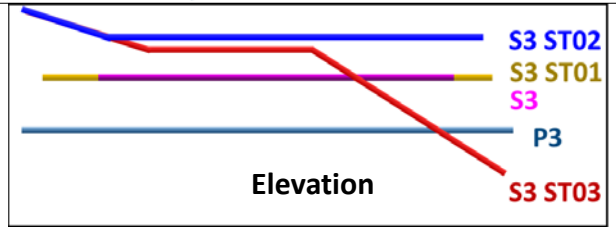
Pilot Layout / Data Acquisition





Well	Producer	Cuttings - proppant	Core	Image Logs	RA Tracer	RA Tracer Log	DTS/DAS	Geophones	Pressure Gauges
P1	X								
P2	X				X	X			
P3	X				X	X	X		X
P4	X					X			
P5	X								
S1				X		X	X	X	X
S2			X	X				X	
S3		X	X	X		X			
S3 ST01		X		X		X			
S3 ST02		X		X		X			
S3 ST 03		X	X	X		X			X

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Completion Design

Design Type	Limited entry
Clusters /Stage	5
Cluster Spacing	47 ft.
Pre flush	Acid/linear gel
Slurry Carrier Fluid	30# borate gel
Flush	Linear gel/slickwater
Fluid Volume	21 bbl./ft.
Proppant Load	1500 lb./ft.
Proppant type	White sand
Proppant Size	40/70, 30/50

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Hydraulic Fracture Characteristics

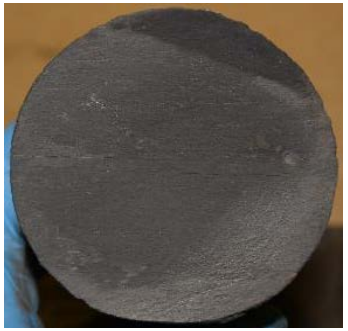
- **Frequency**
- **Spatial distribution**
- **Length and height**
- **Simple or complex**
- **Vertical or dipping**
- **Orientation vs principal stresses**

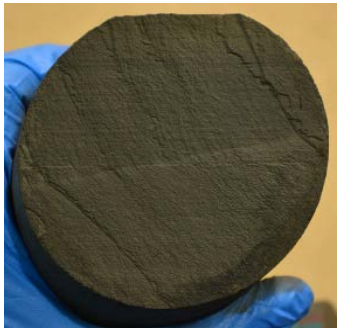
Base State : Natural Fractures

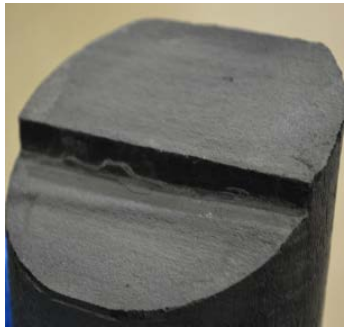
- **Pilot located in seismically quiet area**
  - **No mappable faults**
  - **Few subseismic features (FEV)**
- **S1 image log – 1 fracture in 216 ft. of section**
- **S2 baseline core – 5 fractures in 200 ft.**
- **S2 image log – 7 fractures in 1,120 ft.**
- **Natural and hydraulic fractures are ~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

Hydraulic Fracture Facts

- **Abundant**
- **Not mineralized**
- **Extensional**
- **Planar and dipping**
- **Strike perpendicular to S_{Hmin}**
- **Smooth, ridged, and stepped surfaces**
- **No matrix damage**

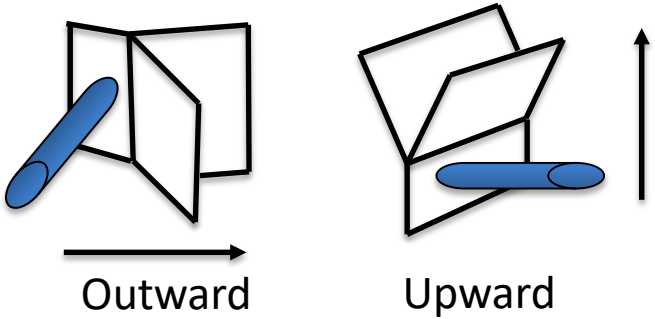






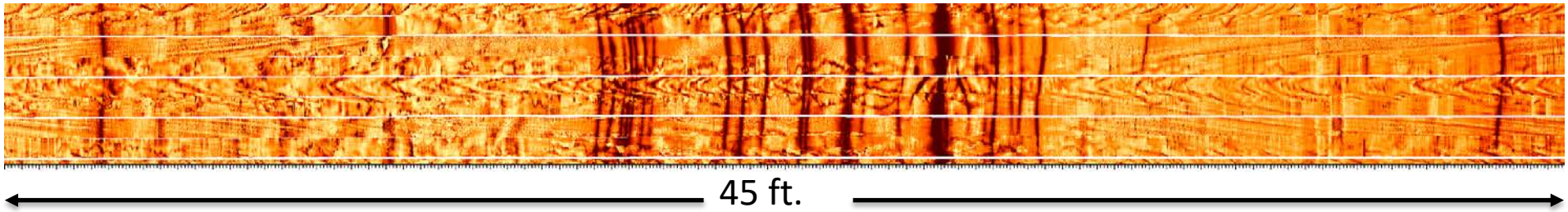
Hydraulic Fracture Complexity

- **Branching evident in core and FMI**
- **Complex 3D fracture pattern**
  - **More prevalent upwards vs outwards**

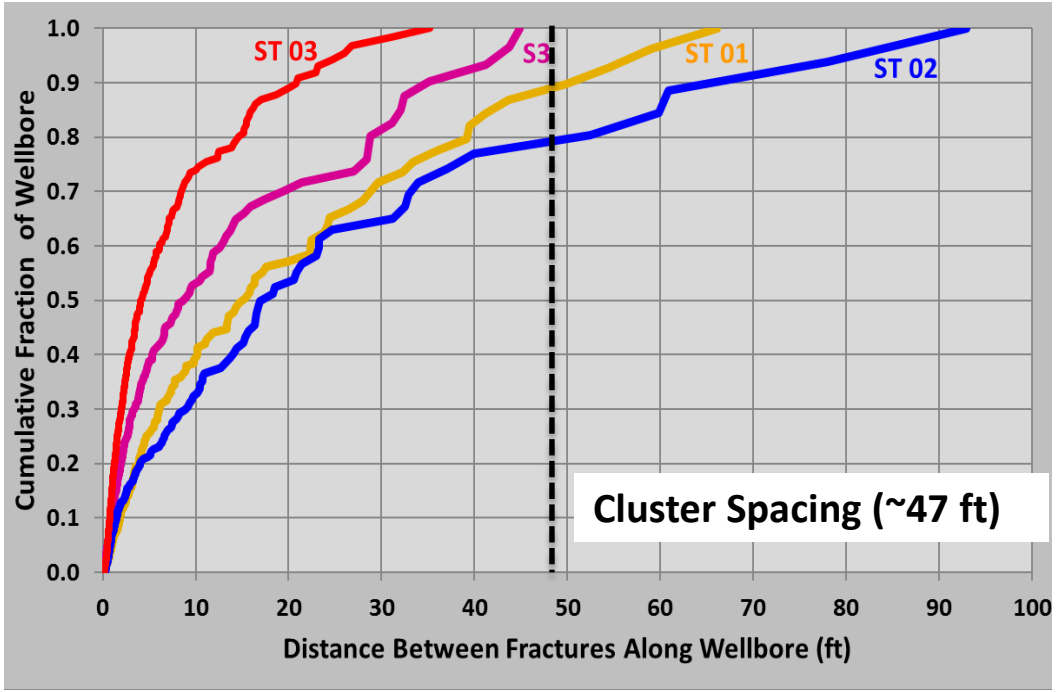


Hydraulic Fracture Swarms

- **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**

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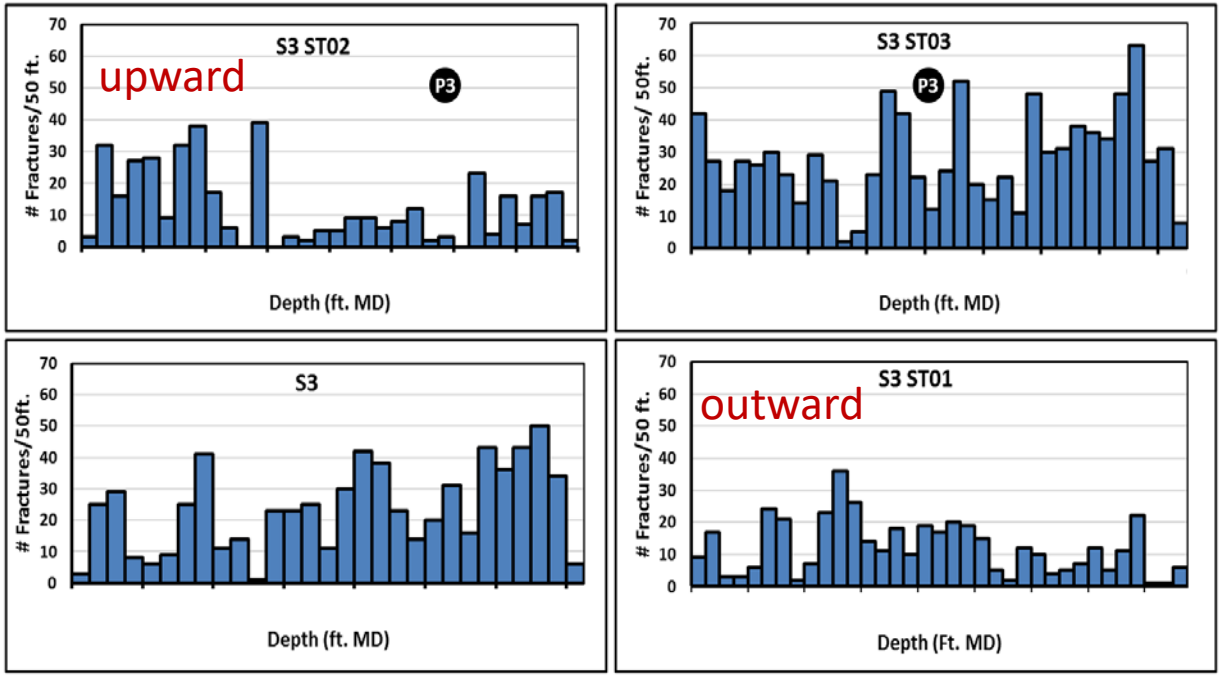
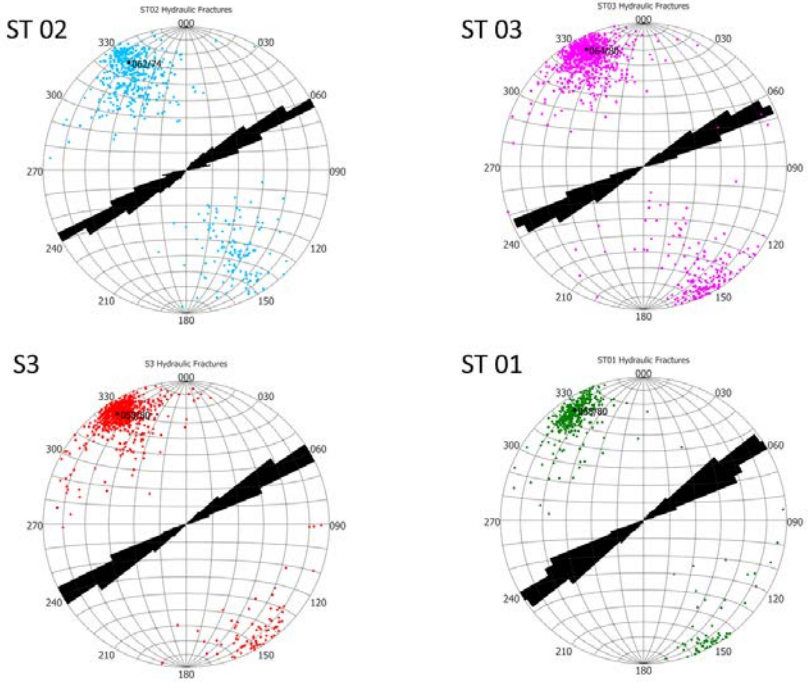
Hydraulic Fracture Density



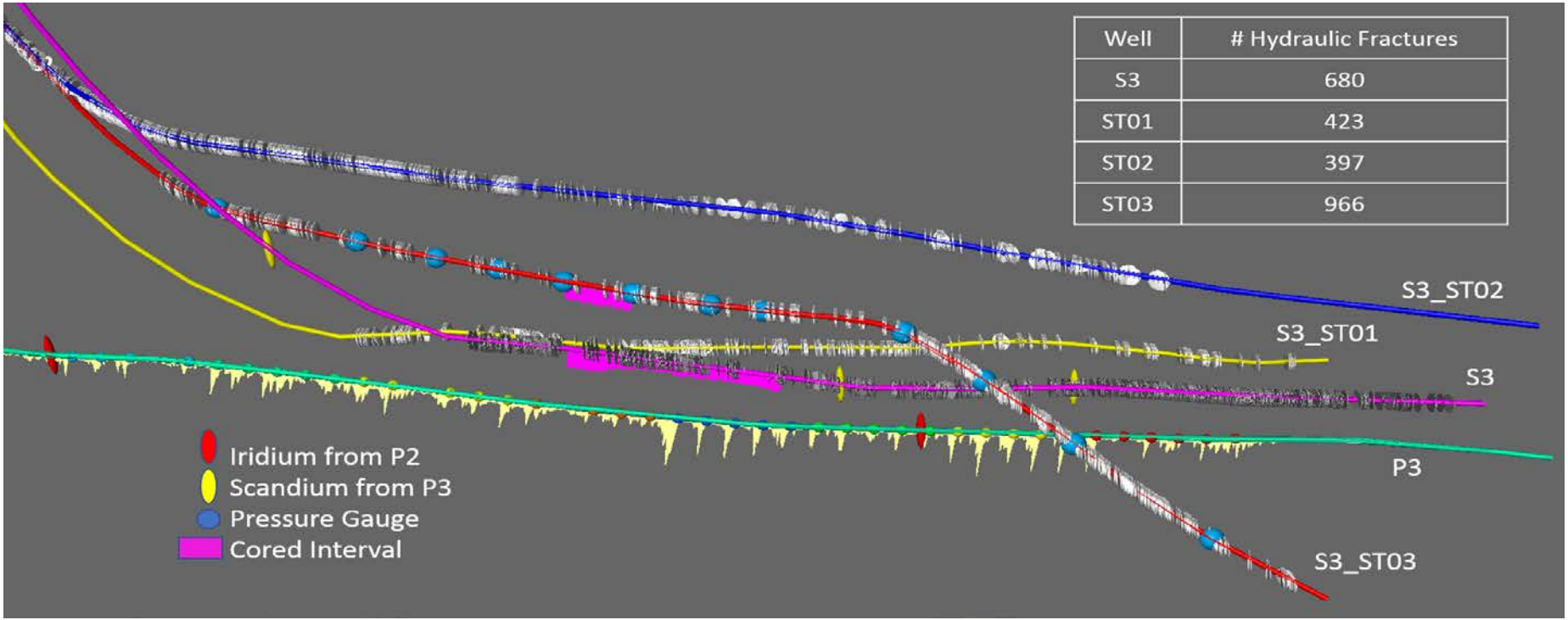
- **Fracture density and count greatest near producer**
- **Fracture density declines upward and outward**

Dip and Orientation

- **Perpendicular to S_{Hmin}**
- **Strike: N 60° E**
- **Dip: 75-80°SE**
- **Predominantly parallel fractures at all locations**
- **More dip variation above the producer**



Hydraulic Fracture Composite



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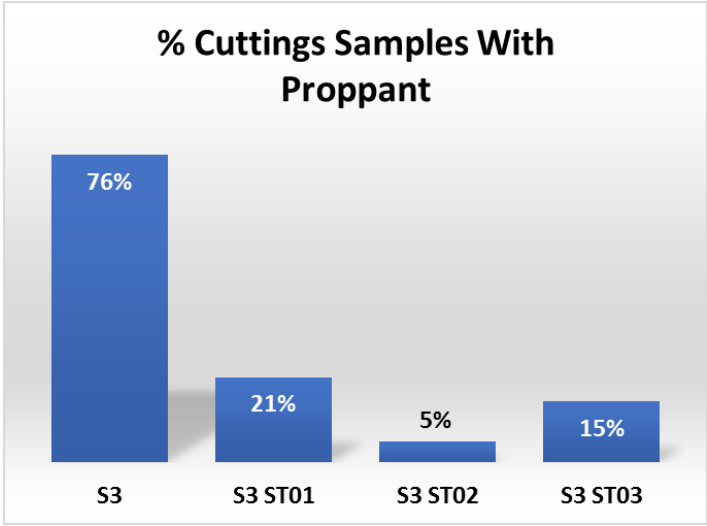
Proppant Abundance

- **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

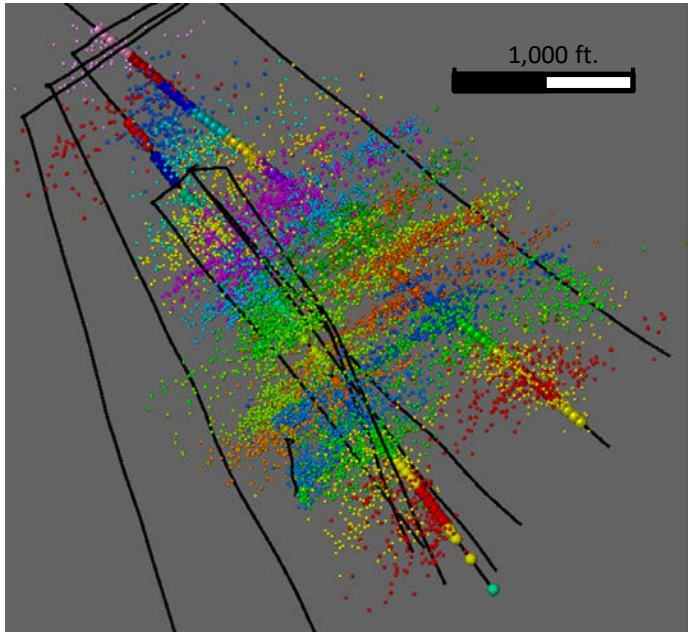
- Hydraulic Fractures are complex not simple
  - multiple, discrete and parallel
  - dip, but align with in-situ stress
  - spatially distributed unevenly
  - often occur in swarms
- Proppant is rarely sampled, especially far from producer
  - RA tracers indicate limited well-to-well proppant transport
- No matrix permeability enhancement
  - core perm measurements

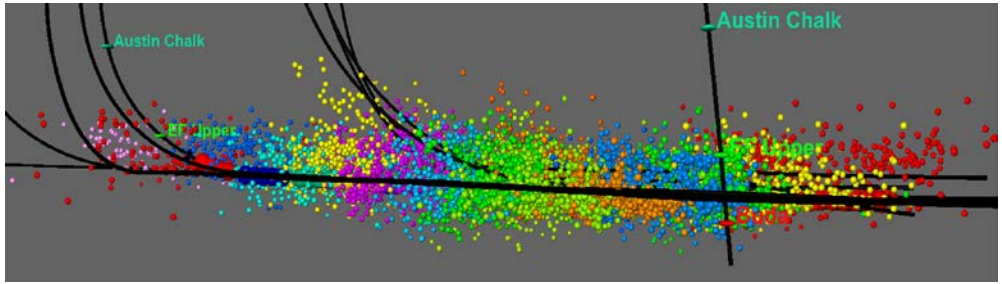
Remote Monitoring

- **What do microseismic & DAS tell us about the SRV?**
  - **What is the relationship between DAS & MS events and hydraulic fractures?**
  - **How should microseismic / DAS data be used?**
    - **SRV dimensions?**
    - **Indicator of permeability enhancement?**
    - **Related to drainage?**

Microseismic

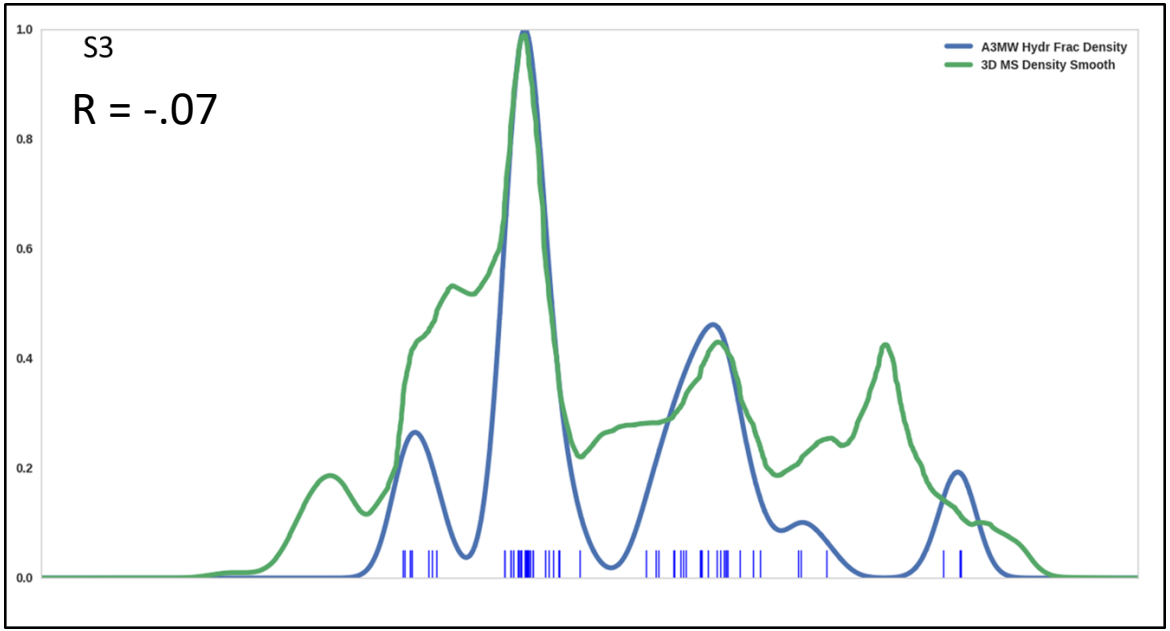
- **Co-located events**
- **90% of events within Eagle Ford**
- **Linear to dispersed stage event patterns**
- **Few events in toe of P3**
- **Events reach adjacent wells (>1000 ft.)**





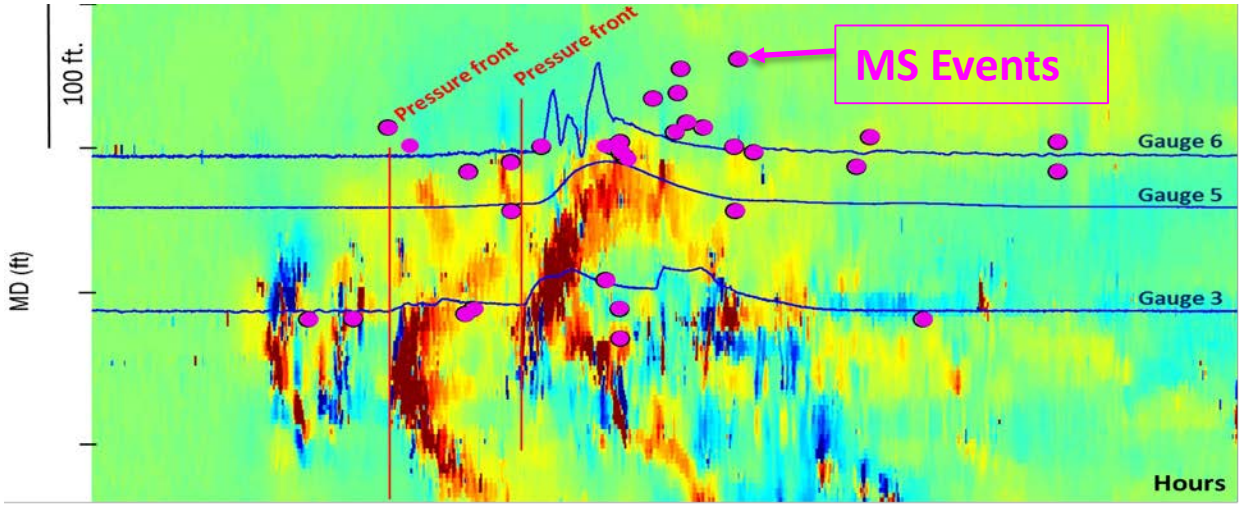
HF Density to MS Density Correlation

- **Poor correlation between MS events and all Hydraulic Fractures**



Cross-Well DAS (vertical well S1)

- **DAS, MS and pressure response concurrent**
- **Pressure exceeds S_{Hmin} indicating fracture event**

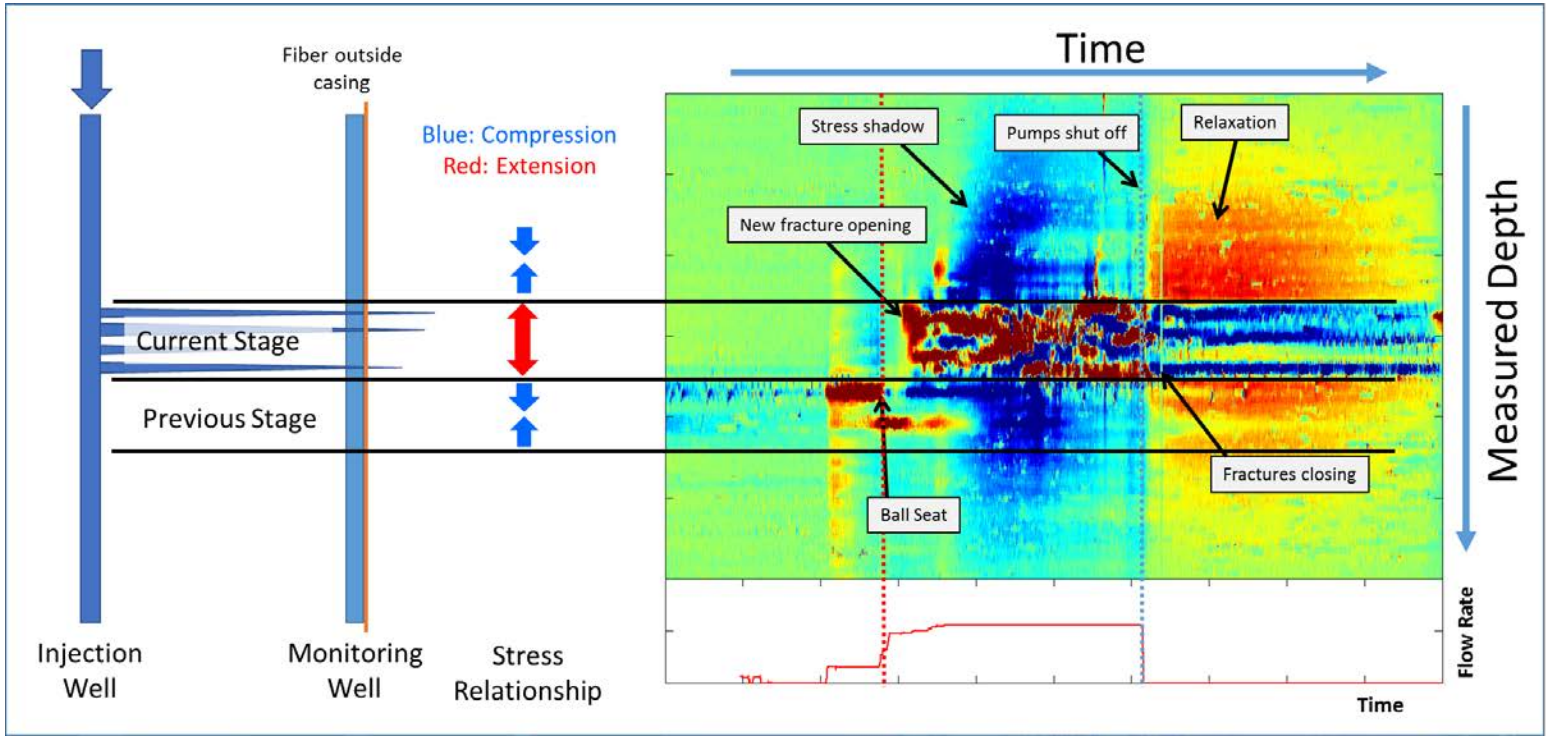


DAS measures a strain rate change

Red = extension

Blue = compression

Cross-Well DAS (horizontal well P3)



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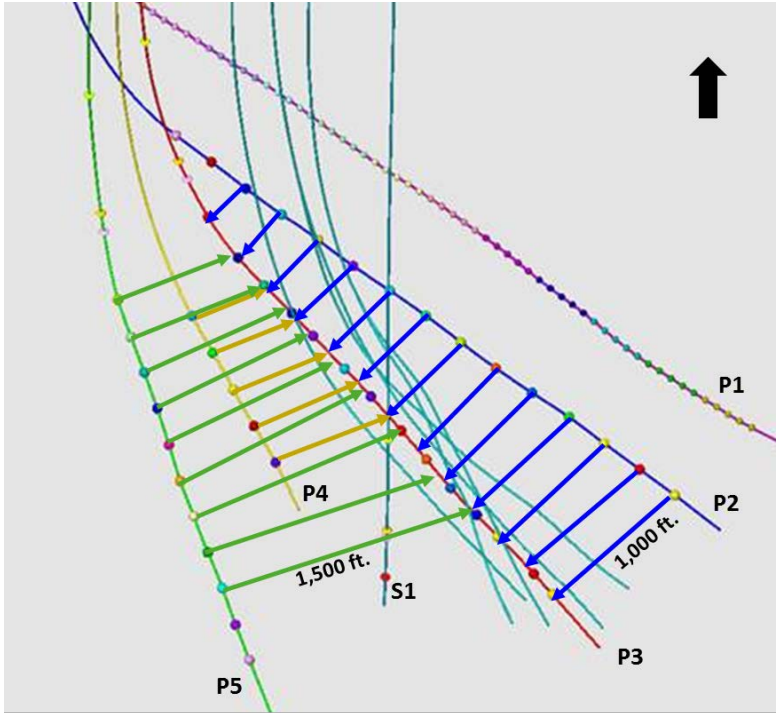
DAS Completion Monitoring

- **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**



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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.**
- **Microseismic events do not adequately represent hydraulic fracture abundance and density**

Acknowledgements

- ConocoPhillips
- Extended technical team, contractors and vendors who met the unique operational and analysis challenges