A Data-Driven Proppant-Filled Fracture Model for Comparing Sliding Sleeve and Plug and Perf Completion Styles*

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Abstract

Microseismicity can be used as a diagnostic tool to identify the nature of the hydraulic fracture stimulation associated with different completion styles and determine which style most effectively stimulates the targeted zone of interest. We coupled a proppant-filled Discrete Facture Network (DFN) model with treatment information (slurry volume and proppant concentration) to compare fracture growth and proppant distribution between two wells targeting the Niobrara Formation. One well was completed with twenty-seven sliding-sleeve stages while the other well was treated with thirty-two plug and perf stages. Differences in slurry volumes (93%) and treating pressures (88%) between wells were small and unlike the other wells in the eleven-well pad treatment they were not zipper-fractured. We extend our proppant-filled DFN model (McKenna and Toohey, 2013) by calibrating the model on the entire pad and employ a data-driven proppant-filling algorithm to account for stress anisotropy. By assuming all fractures are fluid filled at the end of the pad treatment, we avoid differentiating rock-stress from fluid-induced microseisms and set the total hydraulic fracture volume equal to the product of injected slurry volume and fluid efficiency (to account for leakoff). Distal fractures (stage center reference) located near untreated stages likely accommodate injected fluid from those stages.

The calibrated fracture model is filled with proppant volumes stage-by-stage outwards from the stage center. The major stress azimuth (θ) is calculated using a spatial-temporal correlation using chronologically-occurring hypocenters (assuming microseismicity occurring close in times reflects displacement along the same failure plane) which is verified by focal mechanism strike. Proppant fills the DFN elliptically to mimic the shape of the microseismic cloud. The major and semi-minor axes of the microseismic cloud is calculated by stacking fractures from all stages and measuring the distance parallel to θ, perpendicular to θ, and vertically. Plug and perf stages show tight, long trends that continue to increase length while pumping, vertical distribution is skewed toward shallower depths, and energy release rate is more constant during the entire treatment. Sliding sleeve stages show broad, short trends resulting in more near-wellbore complexity, vertical distribution is symmetric about the wellbore, and energy release rate reduces as treatment progresses.

References Cited

McGarr, A., 1976, Seismic moments and volume changes: Jour. Geophys. Research, v. 81, p. 1487-1494.

McKenna, J.P., and N. Toohey, 2013, A magnitude-based calibrated discrete fracture network methodology: First Break, v. 31, p. 95-97.

A Data-Driven Proppant-Filled Fracture Model: Comparing Sliding Sleeve and Plug and Perf Completion Styles

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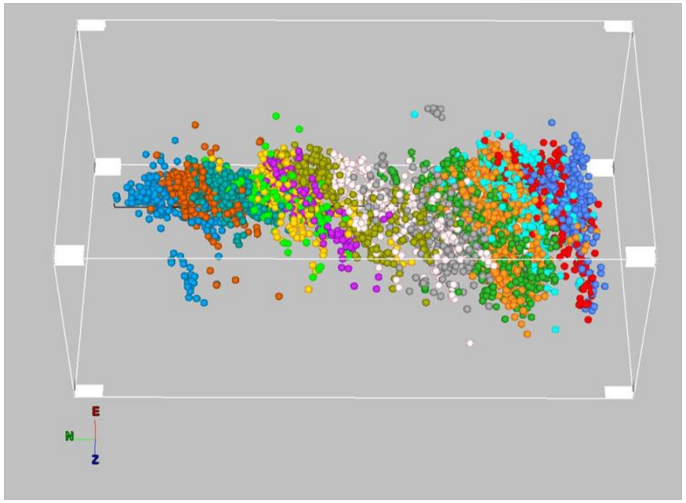
Understanding Drainage Volume

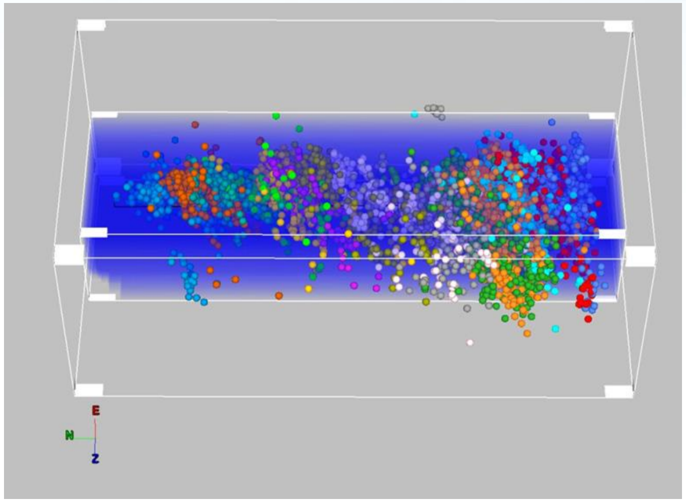
Stimulated Rock Volume (SRV)

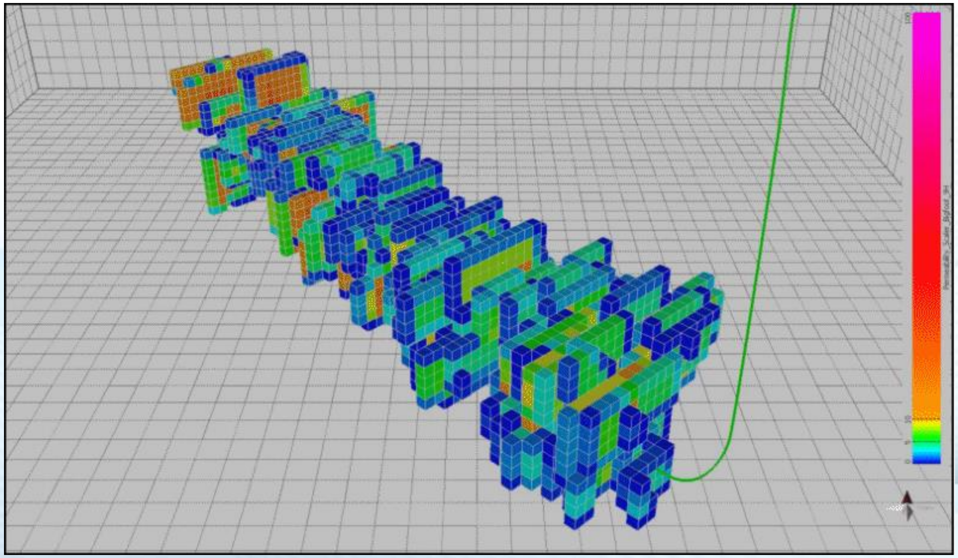
Total volume impacted by hydraulic fracturing



Productive-SRV®

Proppant filled fracture volume





Permeability Enhancement

Effective permeability within the drainage volume

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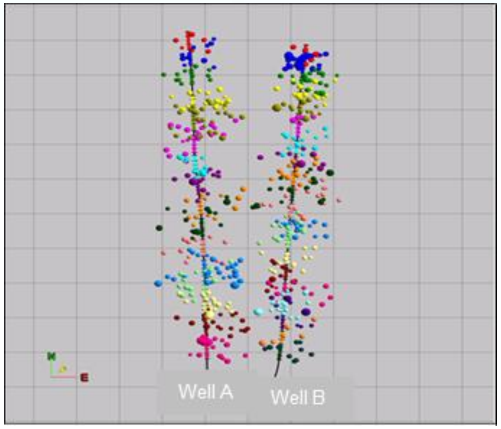
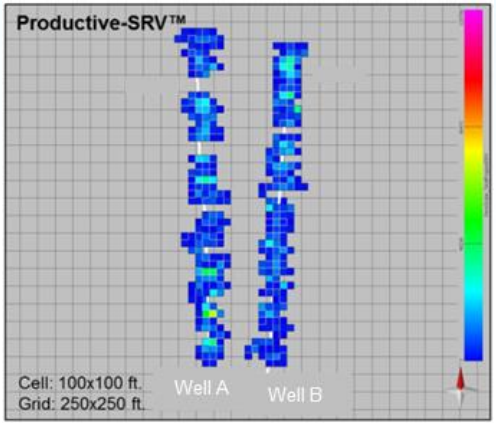
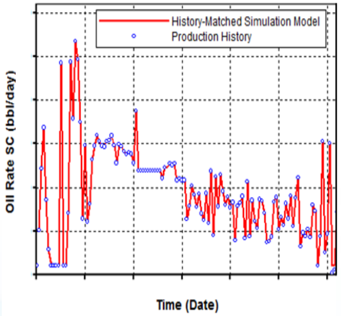
Permeability Enhancement and Production

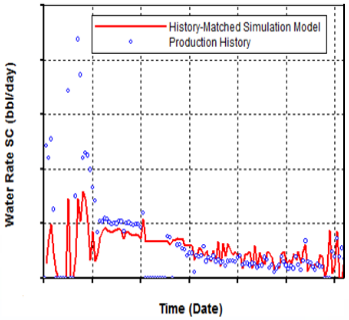


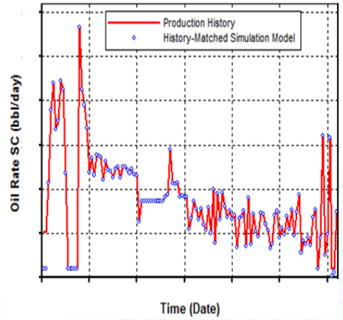


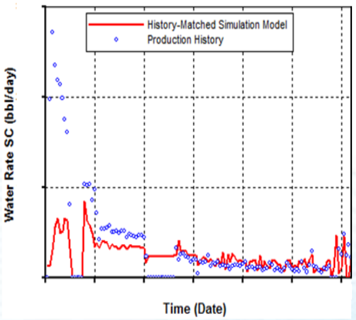
Well A

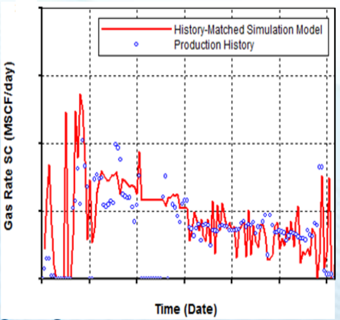
Well B

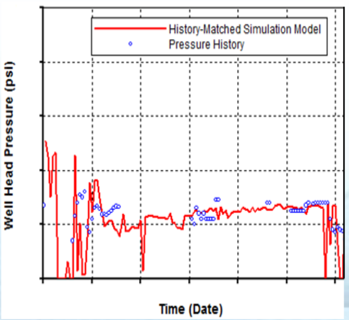


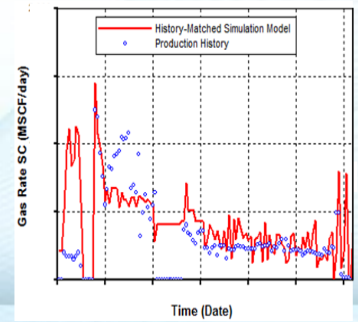


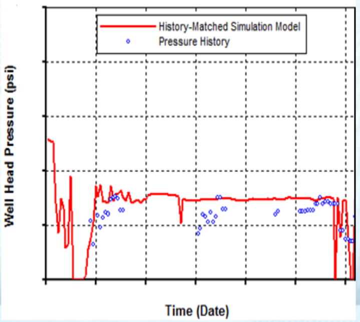












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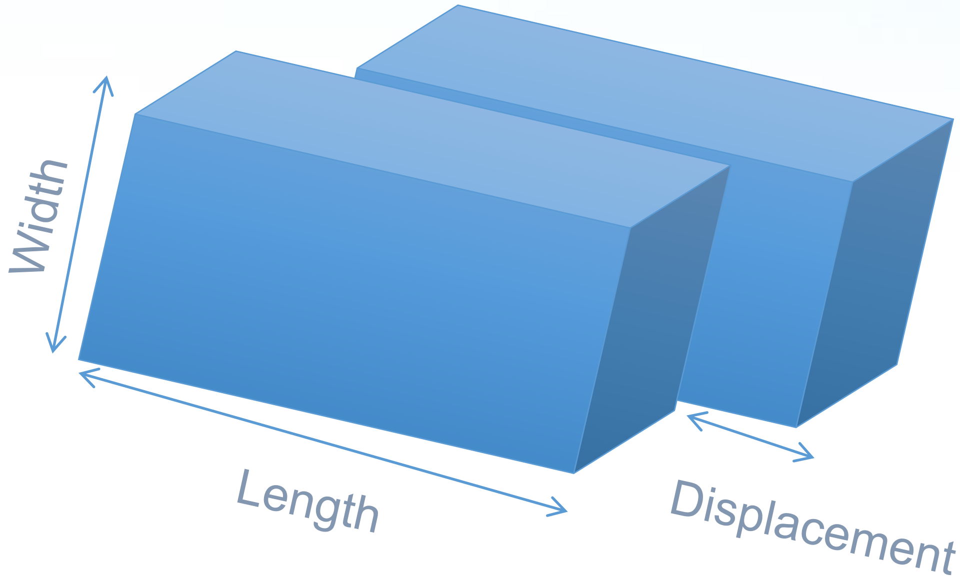
Measure of Fracture Size

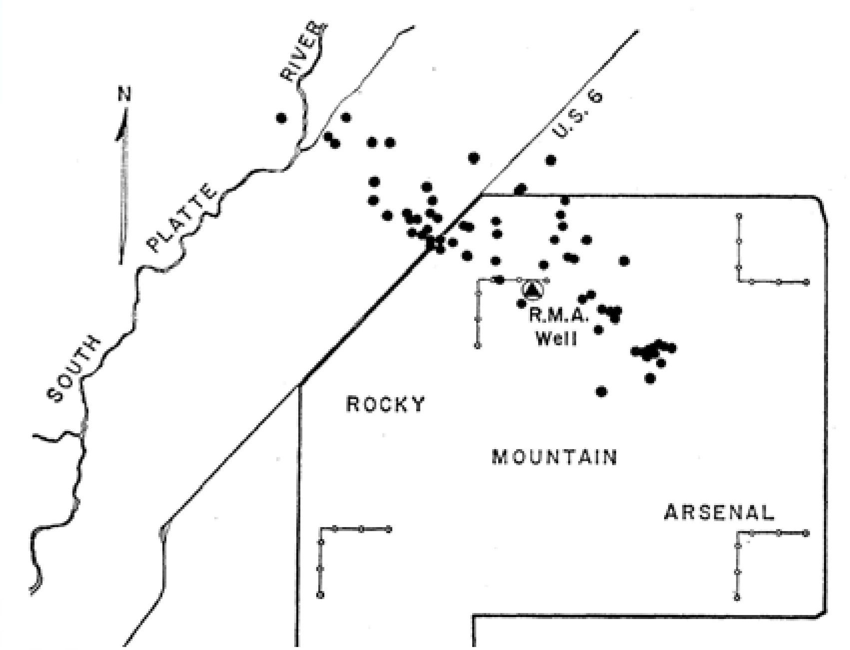


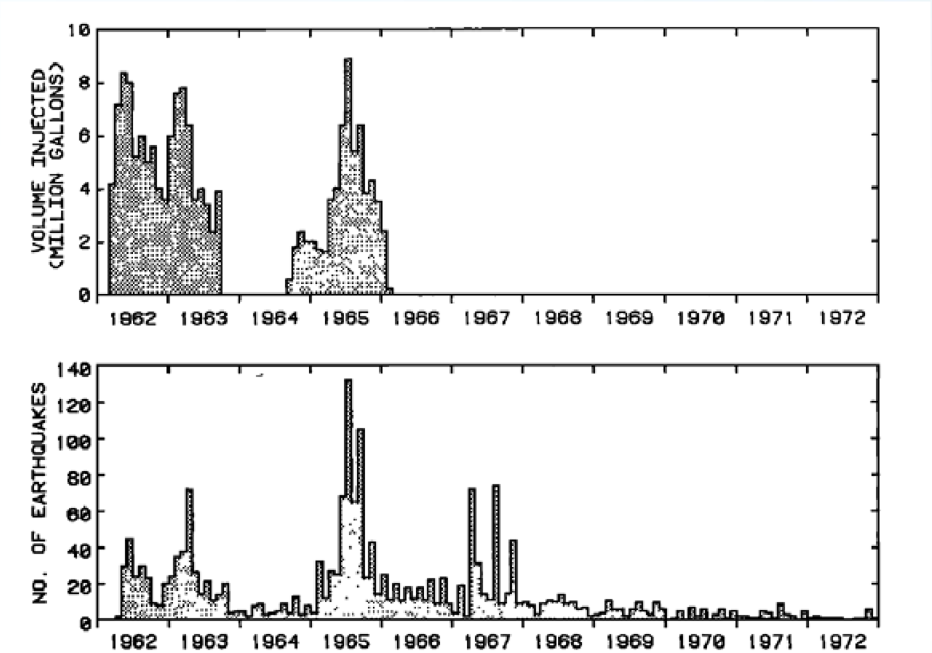
$$M_0 = A\mu\delta$$

Seismic Moment = Fracture Area * Shear Modulus * Displacement

Moment Magnitude (M_w) = 2/3 * $\log_{10}(M_0)$ + constant

Mass Balance





Δ V is related to the volume change by $\Sigma M_0 = K\mu|\Delta V|$
ΣM_0 is the sum of the seismic moments of the seismic population,
μ is the modulus of rigidity, and K is a factor close to 1.

McGarr, 1976

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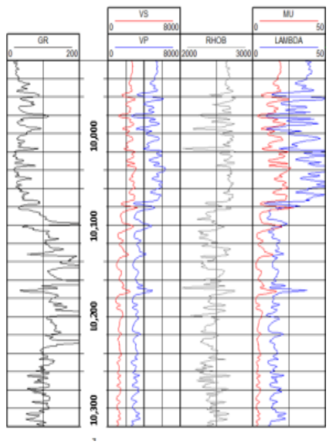
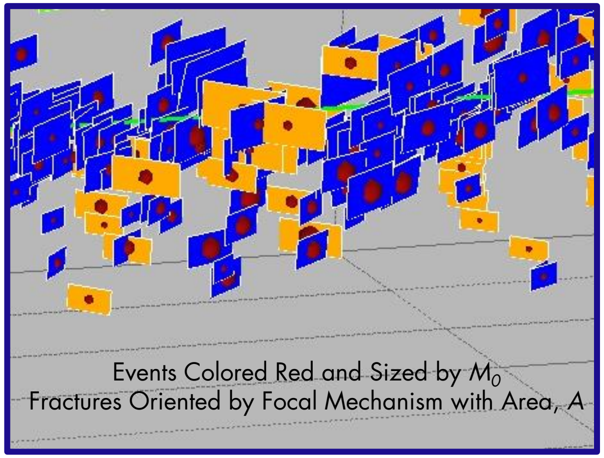
Workflow: Calibrated Discrete Fracture Network

$$M_0 = A\mu\delta$$

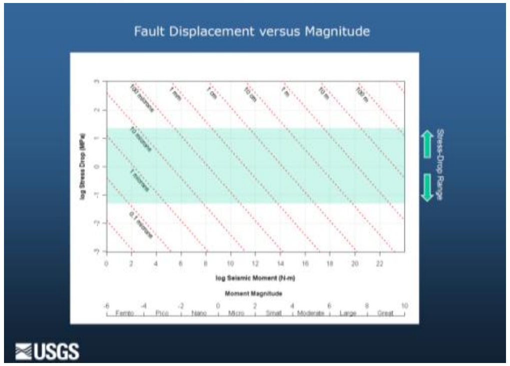
$$\Delta V_f = A * \Delta u = (\Delta V_{inj})\eta k$$

Rock Rigidity, μ

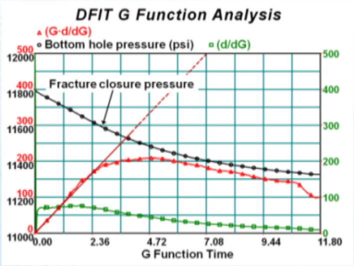




Displacement, δ



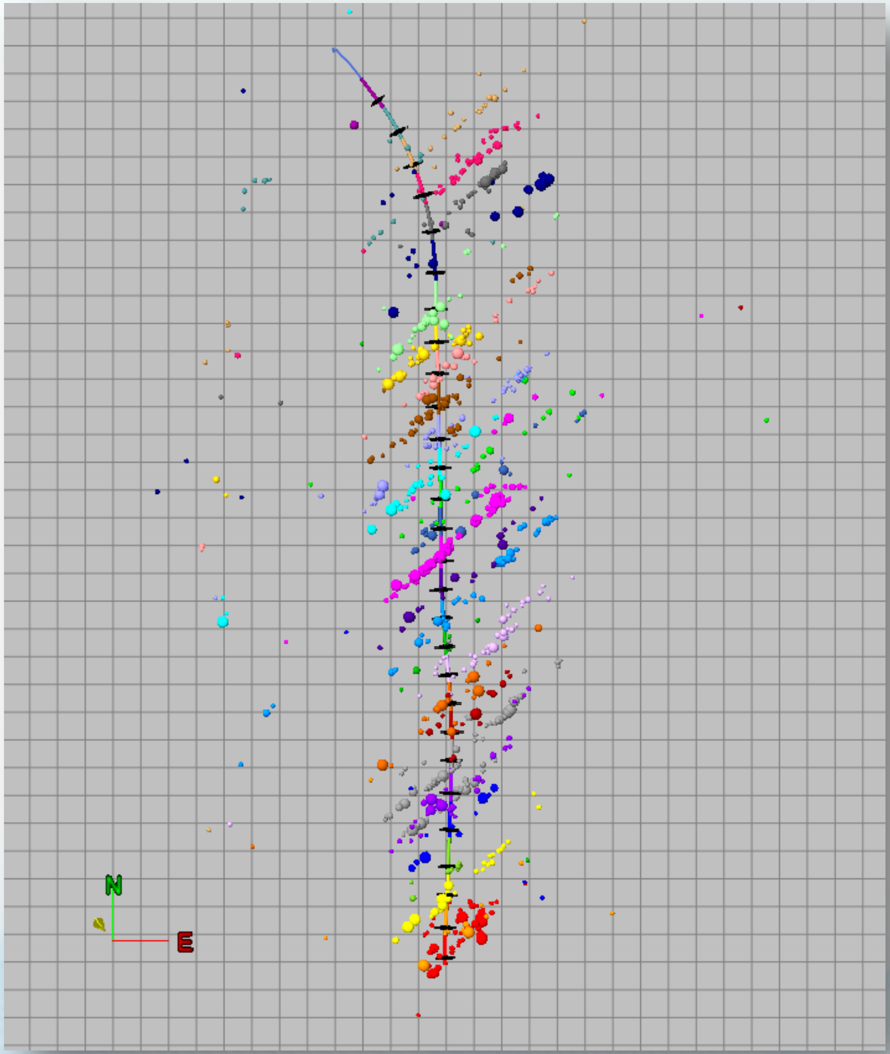
Fluid Efficiency, η

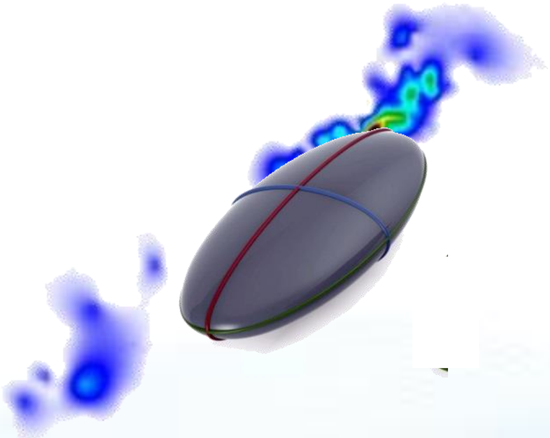


Injected Volume, ΔV_{inj}

Clean Volume + Proppant Volume

Stacking Stages





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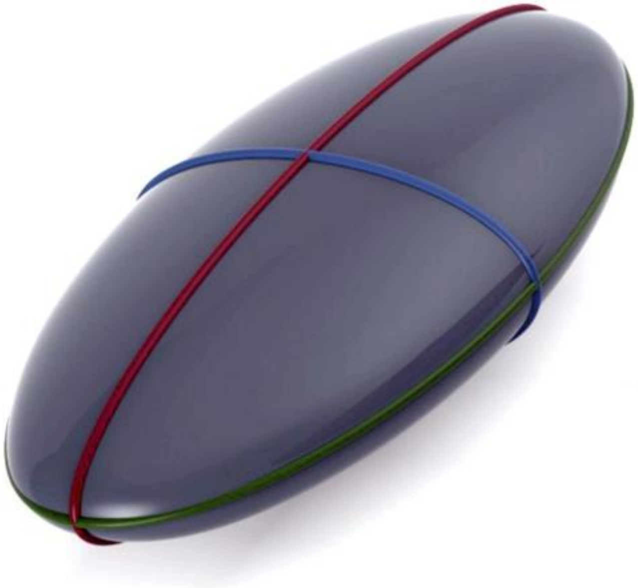
Approximate Event Cloud as Ellipsoid



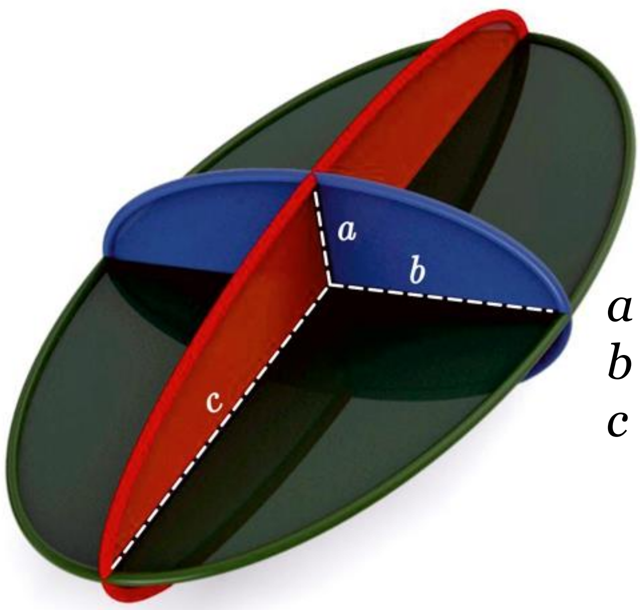
Ellipsoid Equation

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}+\frac{z^2}{c^2}=1,$$

Approximate Event Cloud as Ellipsoid

Ellipsoid Equation

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1,$$



Lengths

a = Vertical
b = Perpendicular to event Tren
c = Parallel to event trend

The ratios of the principle axes are intrinsic properties defining the microseismic event cloud and yield insight into actual proppant distribution as well as natural stress anisotropy

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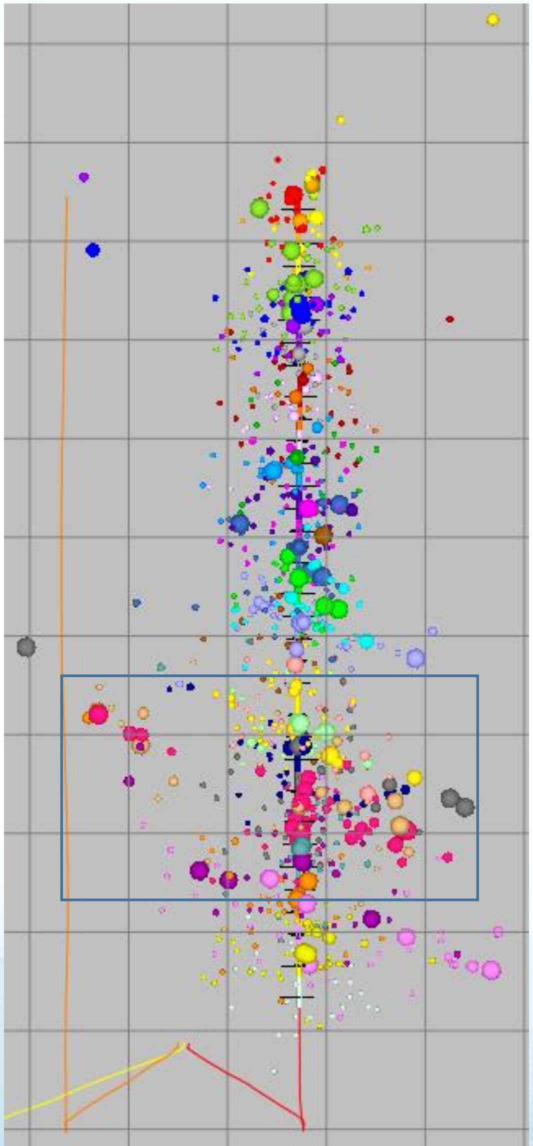
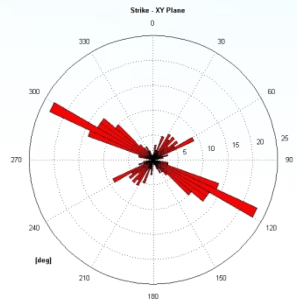
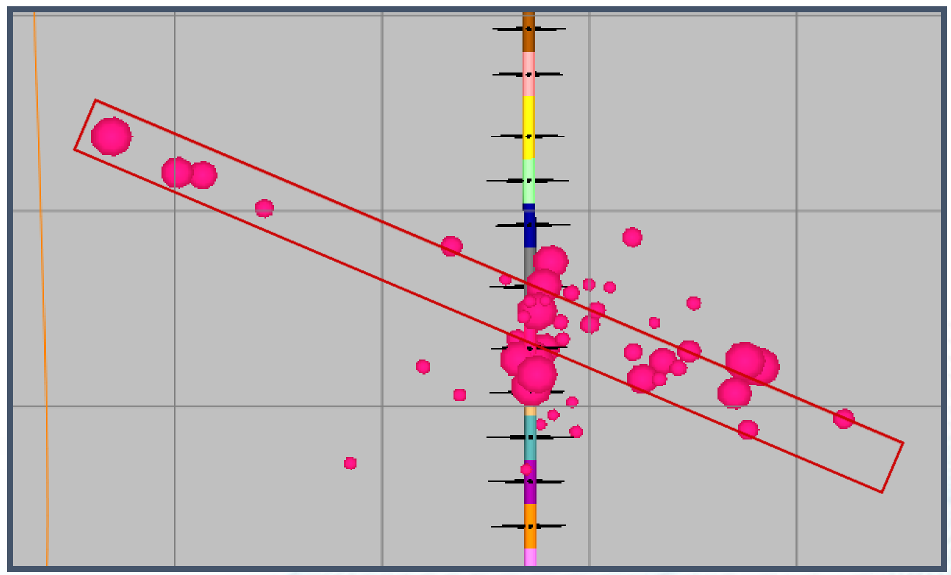
Microseismic Results – Well Spacing





Average Event Trend Azimuth 118°



Determine Event Trend → Calc Event Location wrt Event Trend → Rotate Local Axis

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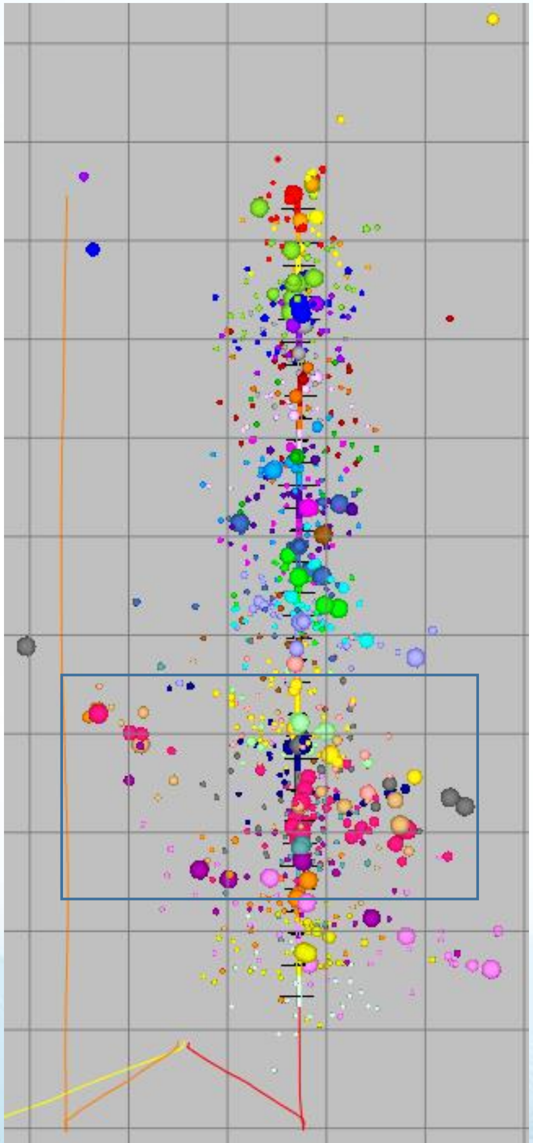
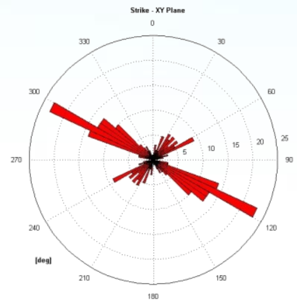
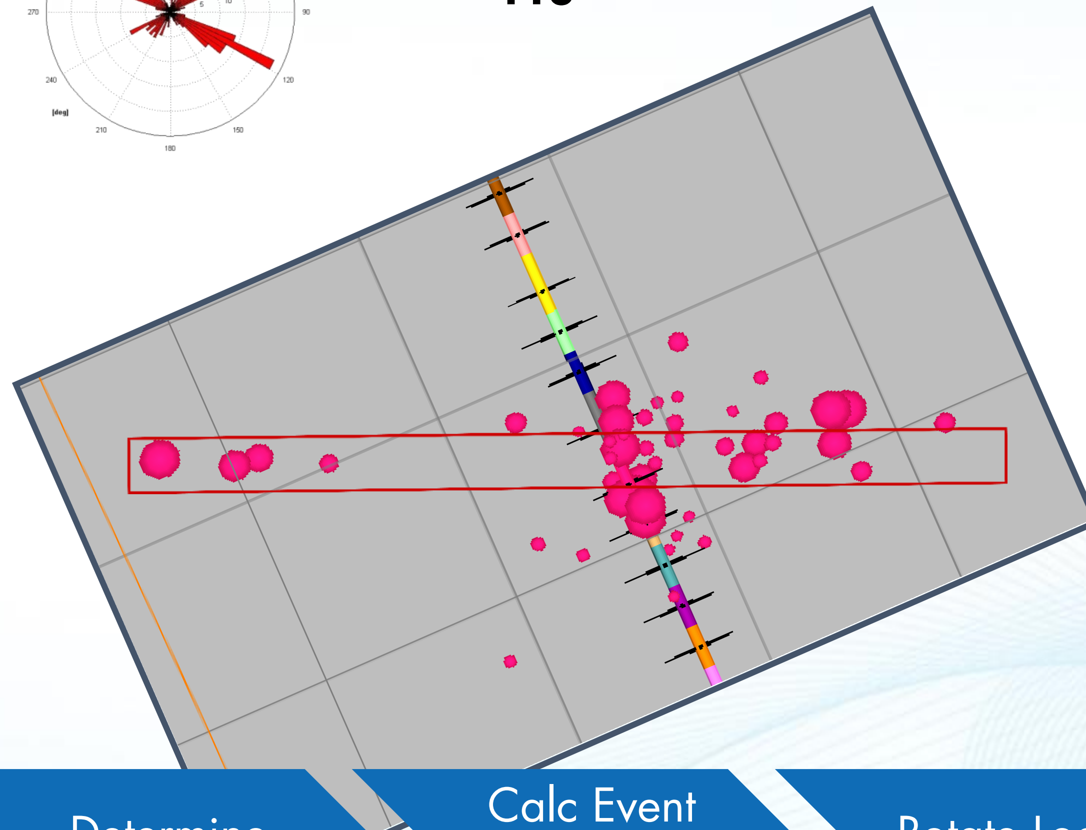
Microseismic Results – Stage Spacing





Average Event Trend
Azimuth
118°



Determine Event Trend → Calc Event Location wrt Event Trend → Rotate Local Axis

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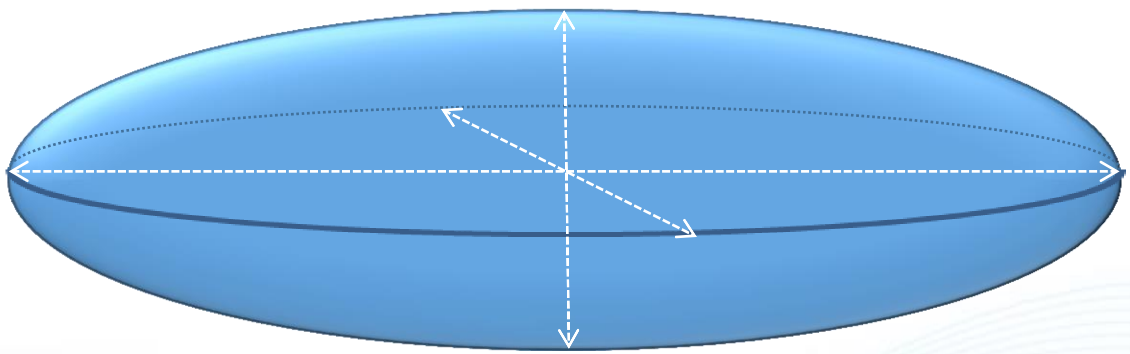
Approximate Event Cloud as Ellipsoid



Proppant fills fractures from stage center outwards in elliptical fashion which is defined by total fracture volume distribution

Example Case Study

- Microseismicity examples from wells with Plug and Perf and Sliding Sleeve completions
- Stack microseismicity: Fracture Density Maps
- Compare and contrast completion techniques using Treatment Design Analysis and Cumulative Fracture Surface Area Plots

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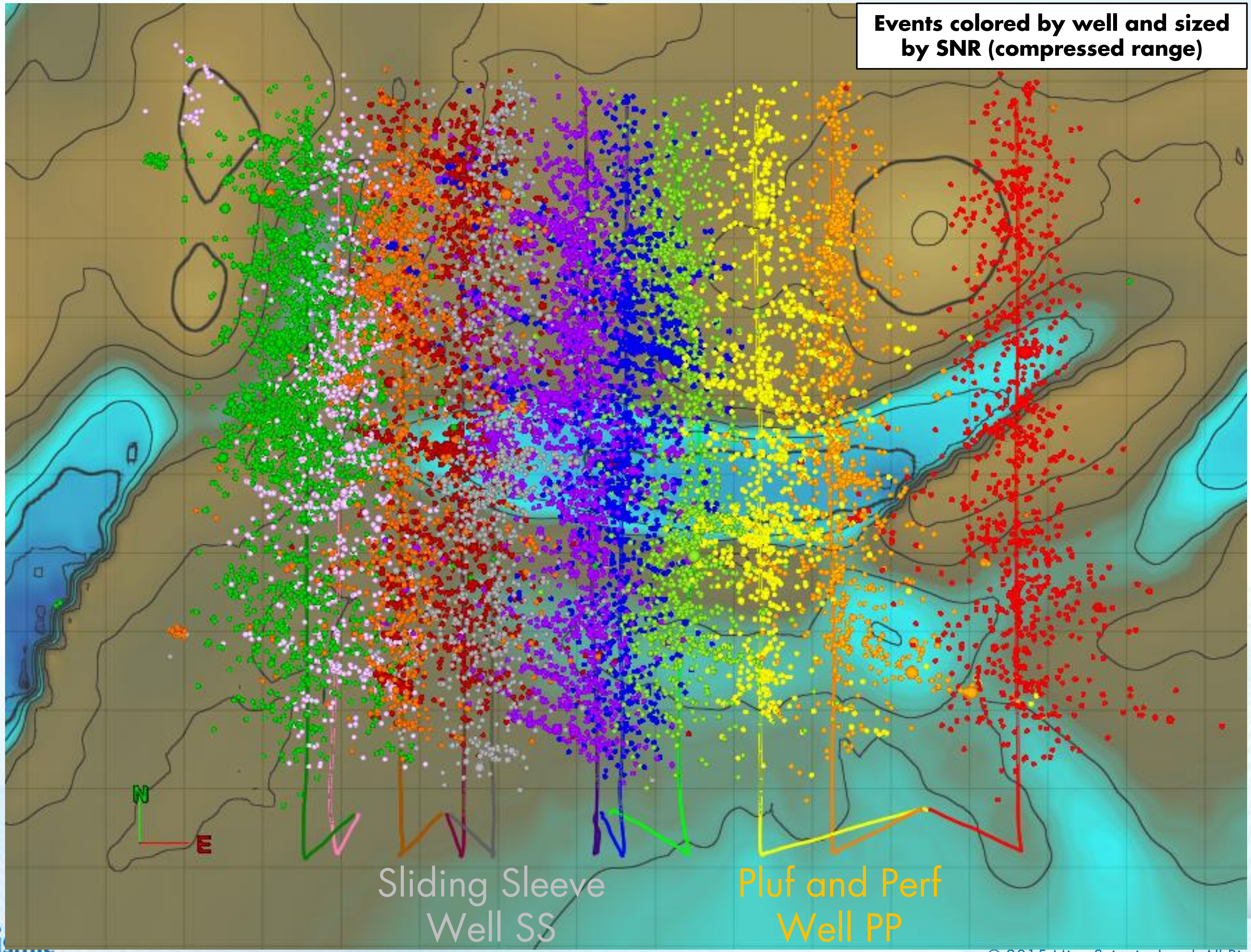
Microseismic Results



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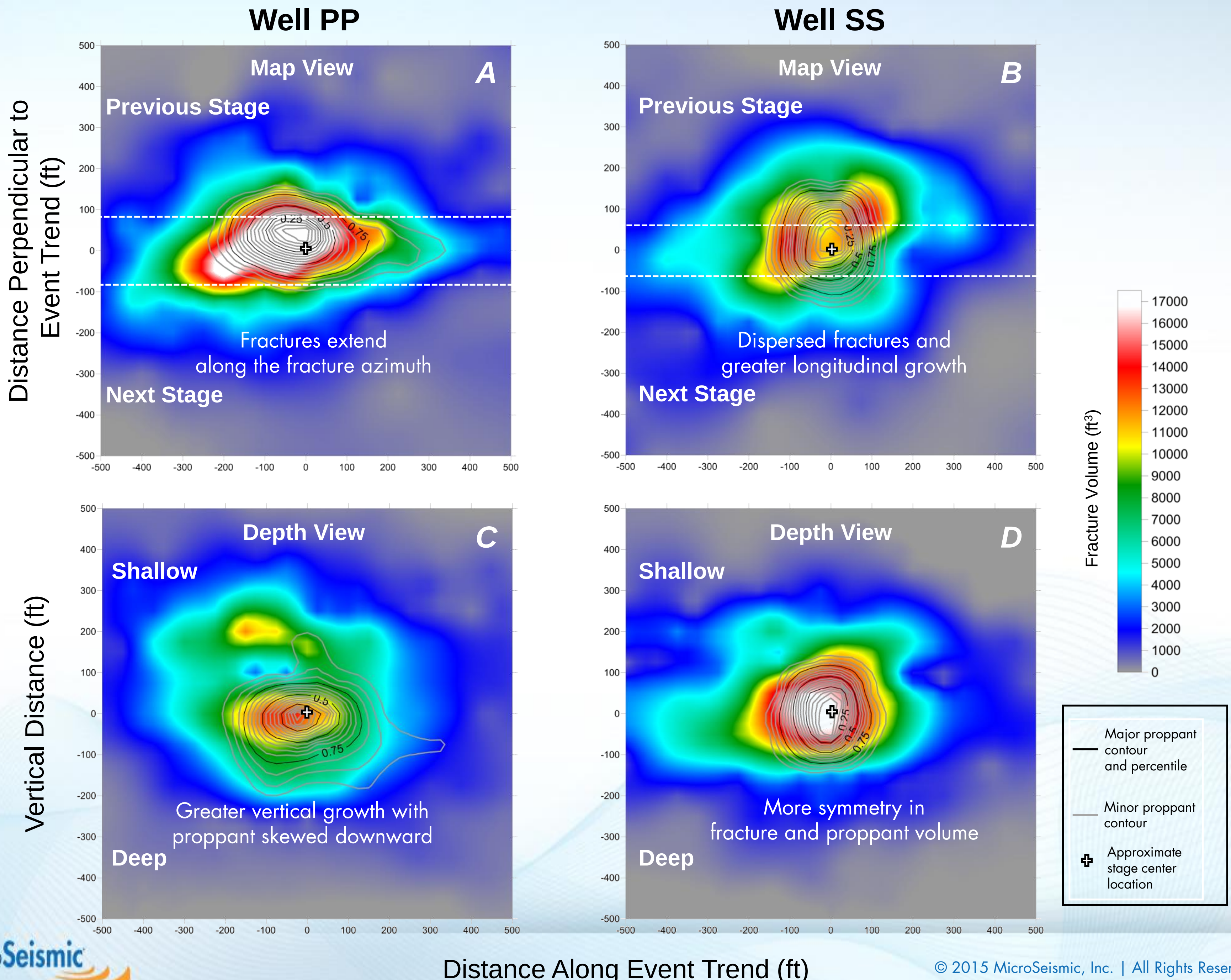
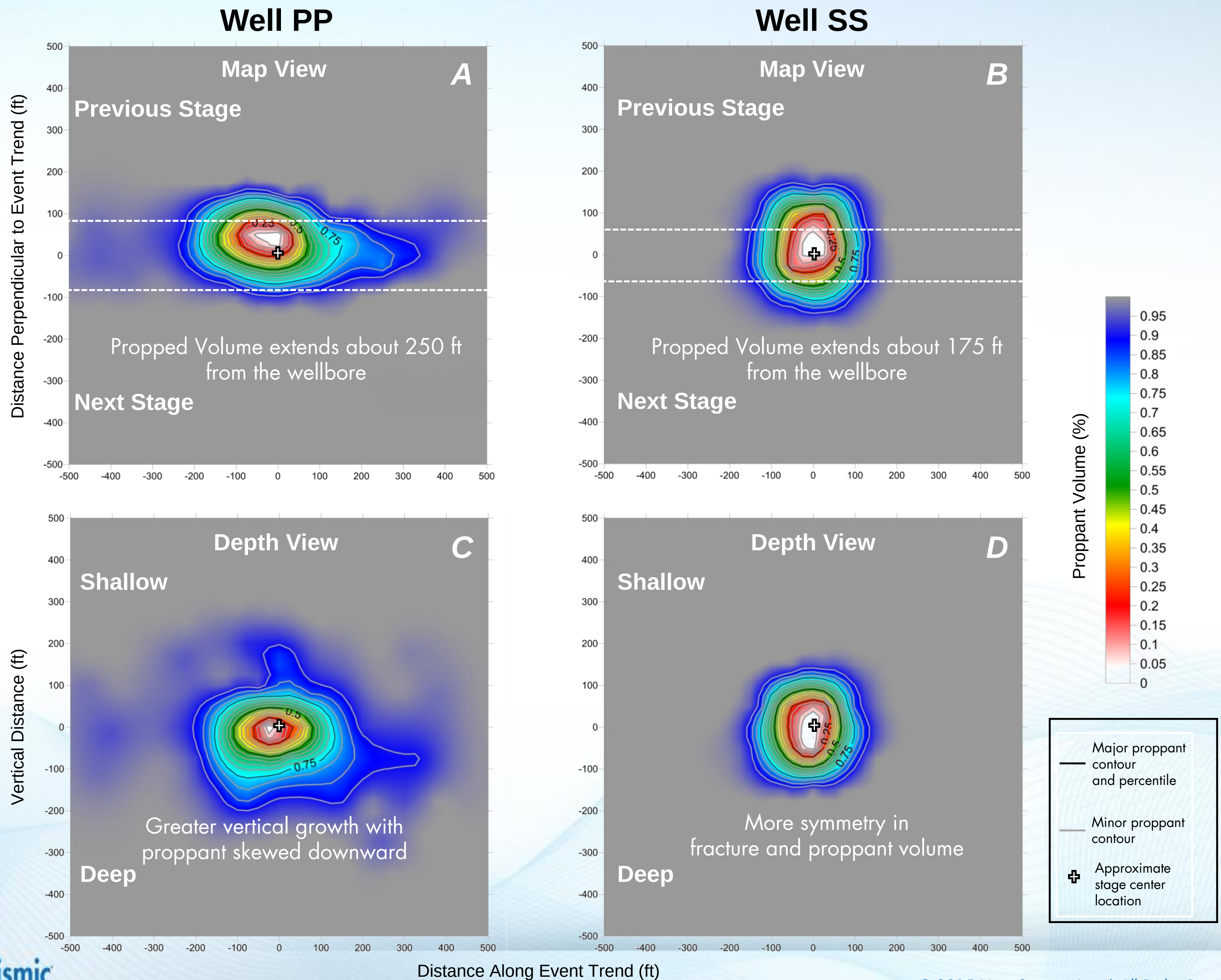
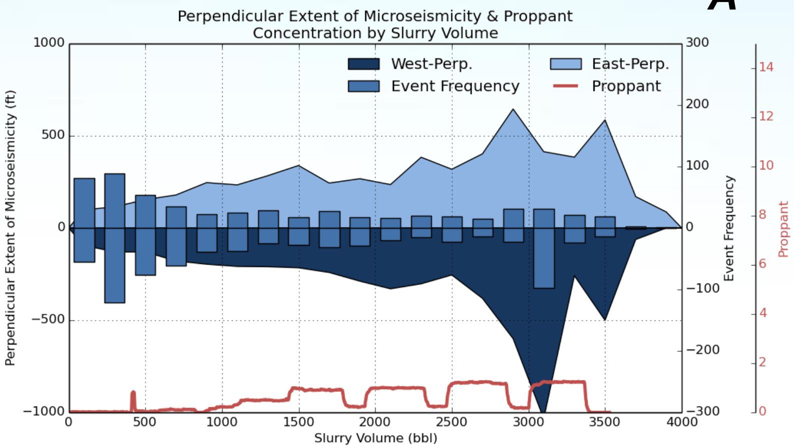


Well PP
Well SS
Map View
A
Previous Stage
Fractures extend
along the fracture azimuth
Next Stage
Map View
B
Previous Stage
Dispersed fractures and
greater longitudinal growth
Next Stage
Depth View
C
Shallow
Greater vertical growth with
proppant skewed downward
Deep
Depth View
D
Shallow
More symmetry in
fracture and proppant volume
Deep
Distance Perpendicular to Event Trend (ft)
Vertical Distance (ft)
Distance Along Event Trend (ft)
Fracture Volume (ft³)
0.25
0.5
0.75
Major proppant contour and percentile
Minor proppant contour
Approximate stage center location

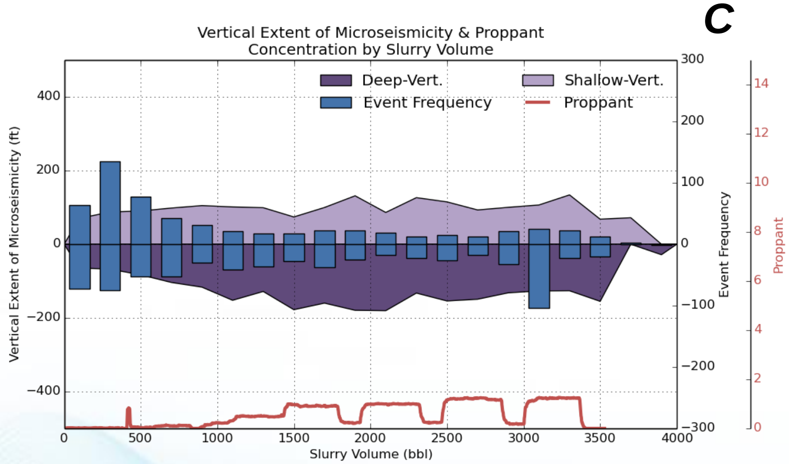

Well PP
Well SS
Map View
A
Previous Stage
Propped Volume extends about 250 ft
from the wellbore
Next Stage
Map View
B
Previous Stage
Propped Volume extends about 175 ft
from the wellbore
Next Stage
Distance Perpendicular to Event Trend (ft)
Depth View
C
Shallow
Greater vertical growth with
proppant skewed downward
Deep
Depth View
D
Shallow
More symmetry in
fracture and proppant volume
Deep
Vertical Distance (ft)
Distance Along Event Trend (ft)
Proppant Volume (%)
Major proppant contour and percentile
Minor proppant contour
Approximate stage center location

Well PP

A



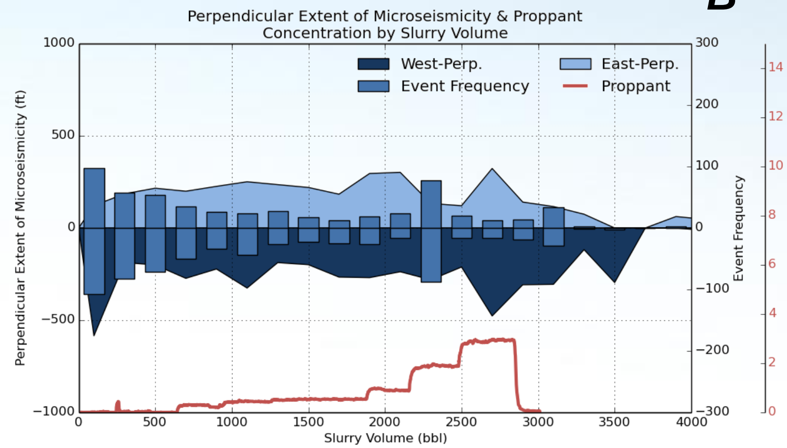
C



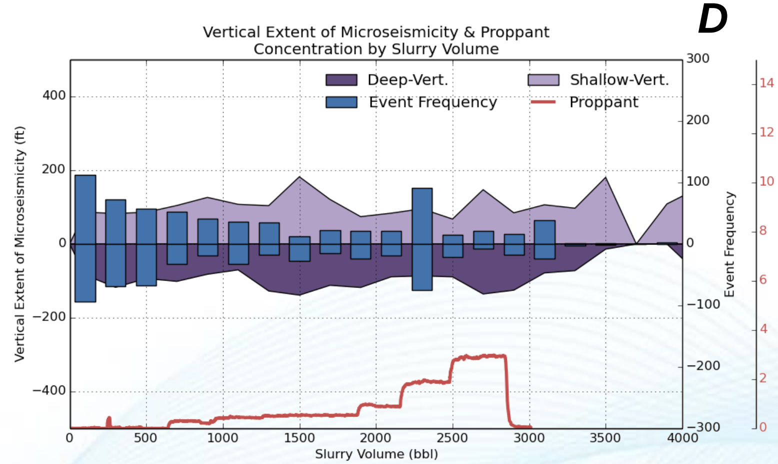
- Continual outward growth as slurry volume increases
- High frequency of events prior to proppant injection
- High Frequency of events following proppant injection
- Distribution skewed to the East

Well SS

B



D



- Outward growth plateaus quickly as near-wellbore activity increases as treatment progresses
- High frequency of events prior to proppant injection
- Population skewed to West

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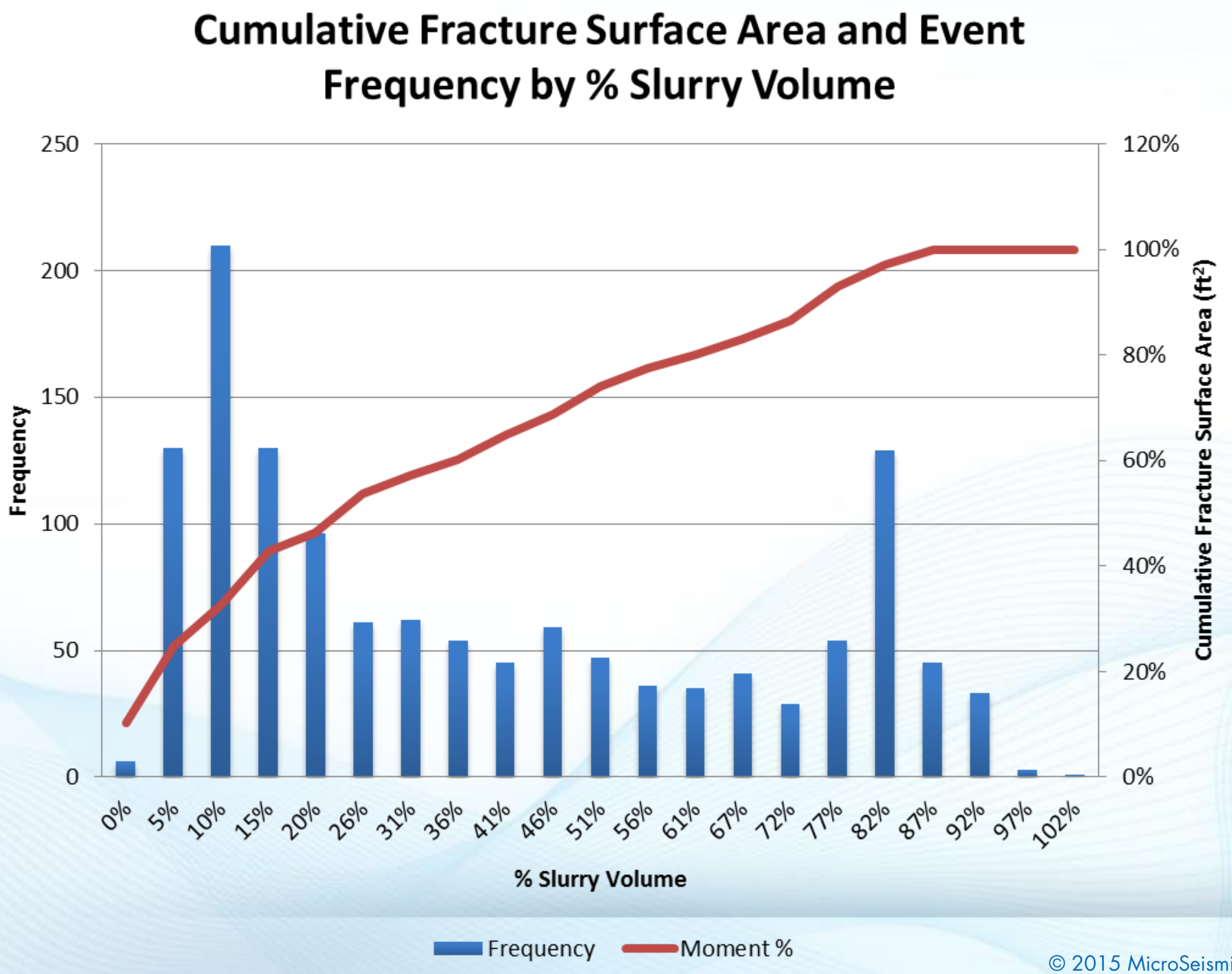
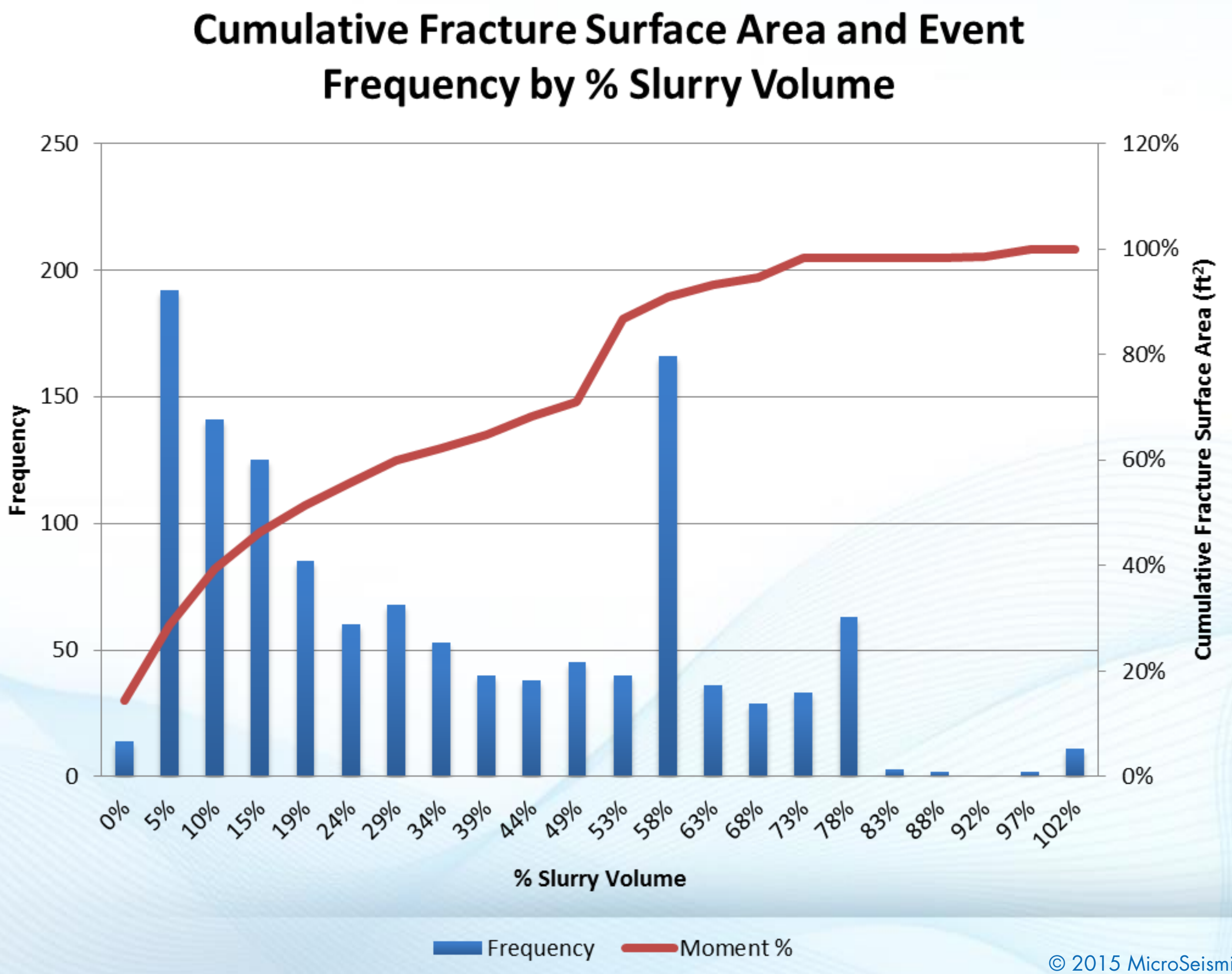
Cumulative Surface Area: Plug and Perf

- Energy release rate remains fairly constant for entire treatment



Cumulative Surface Area: Sliding Sleeve

- Energy release rate is punctuated at 50% of total slurry



Completion Comparison

Plug & Perf

- Tight, long trends that continue to increase in length while pumping
- Vertical distribution skewed toward deepter depths
- Energy release rate is more constant during entire treatment (continual breaking new rock as frac progresses away from wellbore)

Sliding Sleeve

- Broader, short trends
- Vertical distribution symmetric about wellbore
- Energy release rate reduces as treatment progresses

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Acknowledgements

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MSI CE Group

Thank You!

MicroSeismic