Applied Geoscience Conference

Estimation of Propped Fracture Geometry Using Electromagnetic Geophysics

Terry Palisch, Global Engr Advisor; Souvik Mukherjee, Sr Geophysicist

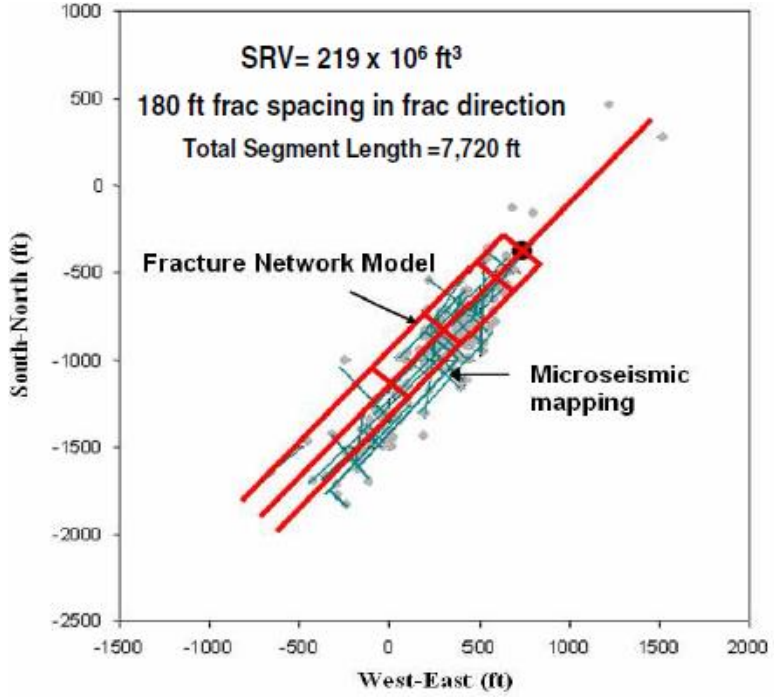
CARBO

Outline

- Introduction
- Far-Field Imaging Technology
- STACK Case History
- Results
- Summary

Current Fracture Diagnostics

- Treating (net) Pressure
  - Minifrac analysis
  - Sonic Logs
- Direct
  - Temperature Logs
  - DTS/DAS
  - Proppant Tracers
- Indirect
  - Microseismic/Tiltmeter Mapping

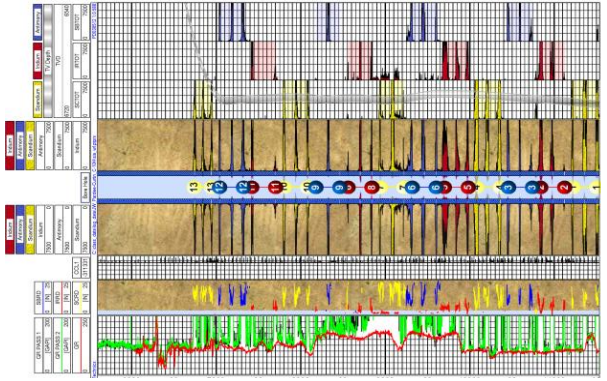


Mayerhofer SPE 119890

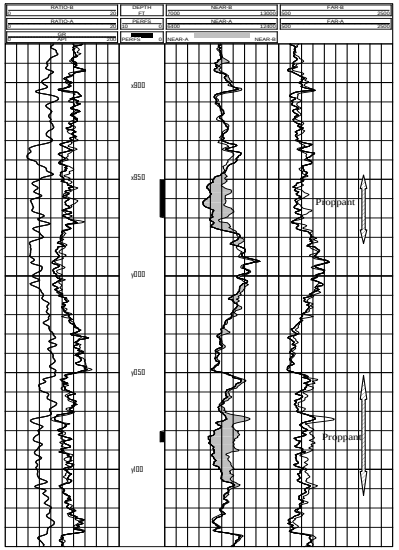
Near-well Proppant Detection

- Radioactive Tracers
  - Spectral GR Log
- Non-Radioactive Tracers
  - Neutron Log
- Limited by Depth of Investigation
  - Typically 18-24”

➢ *What about Far-Field Proppant Detection?*



RA Tracers – Bartuska SPE 155759

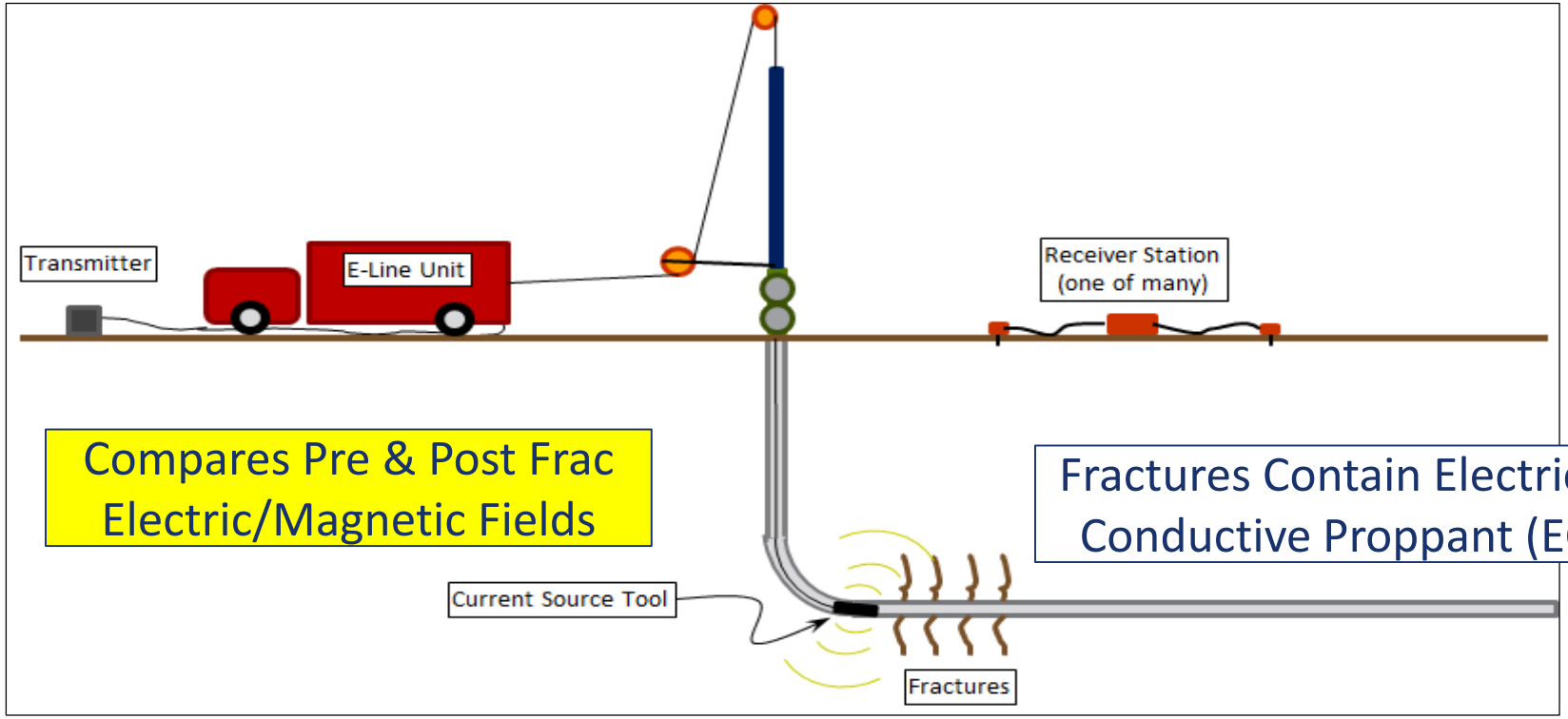


Non-RA Tracers –
Duenckel SPE 146744

Far-Field Imaging Technology

- In development for several years
  - This paper represents 5th application
- Utilizes Electro-magnetic Methods
  - Novel analysis methodology & detectable proppant
- Documented in SPE 179161 & 184880
- SPE 189835 – Vertical STACK science well

EM Components



Fractures Contain Electrically Conductive Proppant (ECP)

UNCONVENTIONAL®
RESOURCES TECHNOLOGY CONFERENCE
FUELED BY SPE • AAPG • SEG

URTeC 2019-1035
Far-Field Proppant Imaging Offsetting Depletion: A STACK Case History

Kyle Haustveit, Mouin Almasoodi (Devon)

Wadhah Al-Tailji, Souvik Mukherjee, Terry Palisch (CARBO Ceramics)

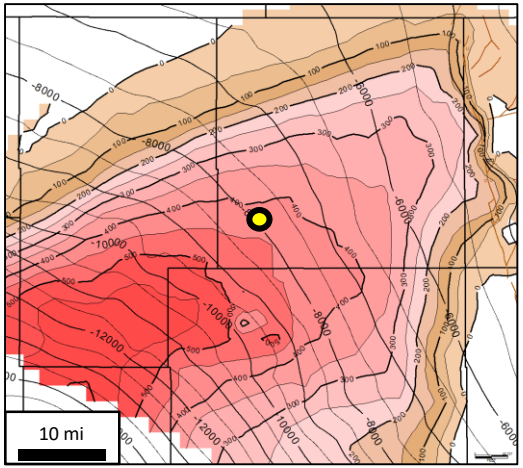
Rusty Barber (formerly Devon)

Introduction

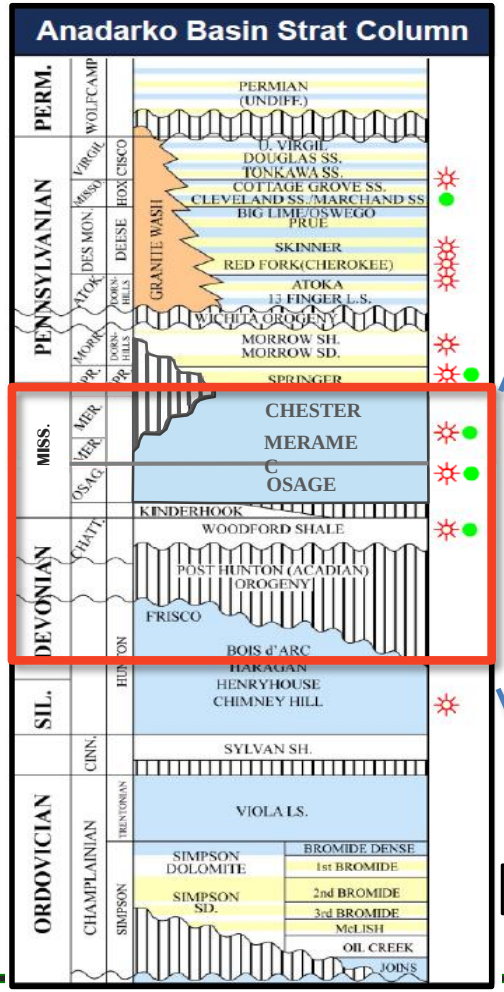
- Full pad development underway
- Depletion questions – Well/stage spacing, etc
  - Proppant location critical
- Proppant location is largely unknown
  - Tracers (near wellbore)
  - MS/TM, Temp logs, DAS/DTS

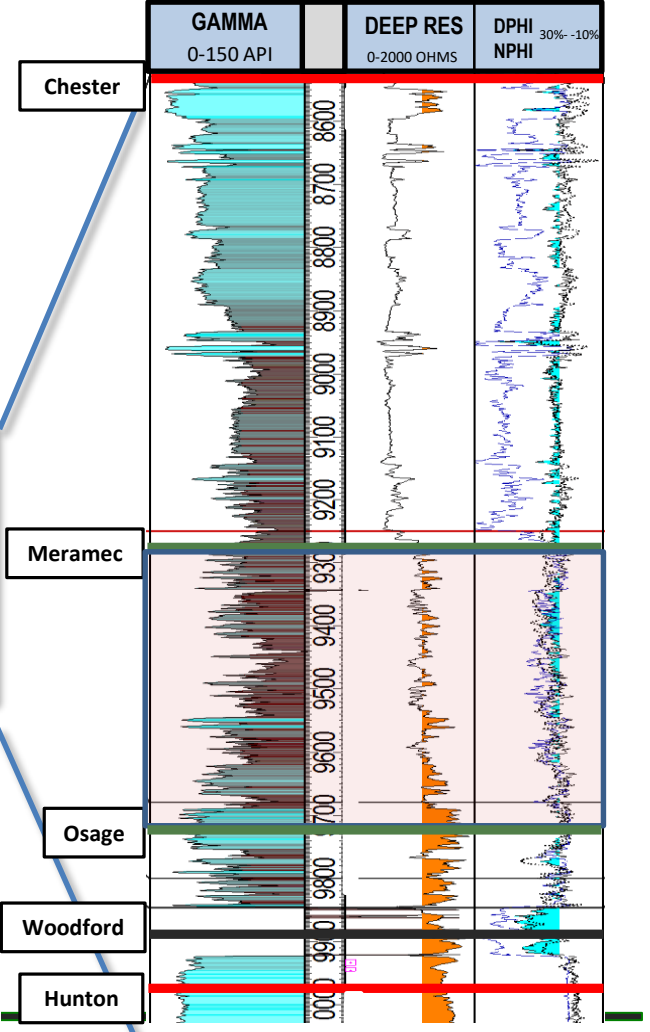
STACK Case History Objectives

- Impact of offset depletion on proppant geometry
- Propped height in two different Meramec zones
- Detectability of “EM” proppant and sand mixture



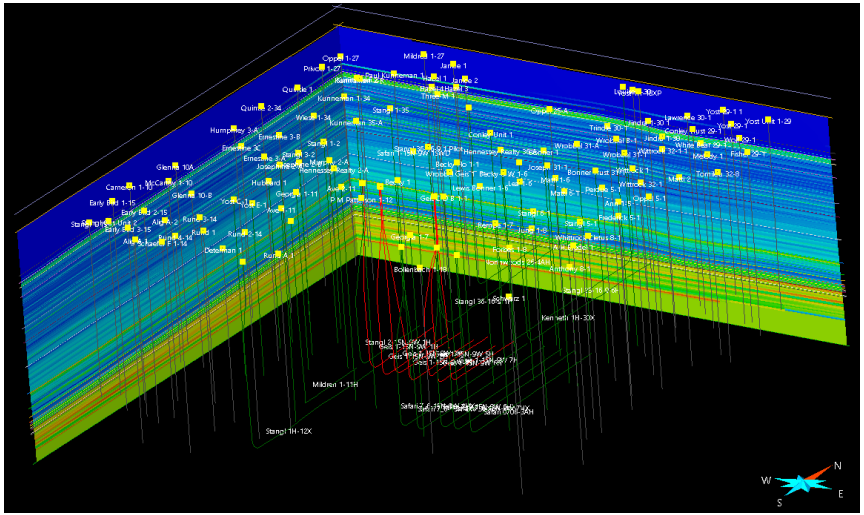
- Siltstone reservoir targets
- Sourced from Woodford Shale
- 400’-600’ gross interval
- High calcite baffles to growth
- Propped height controls number of landing zones



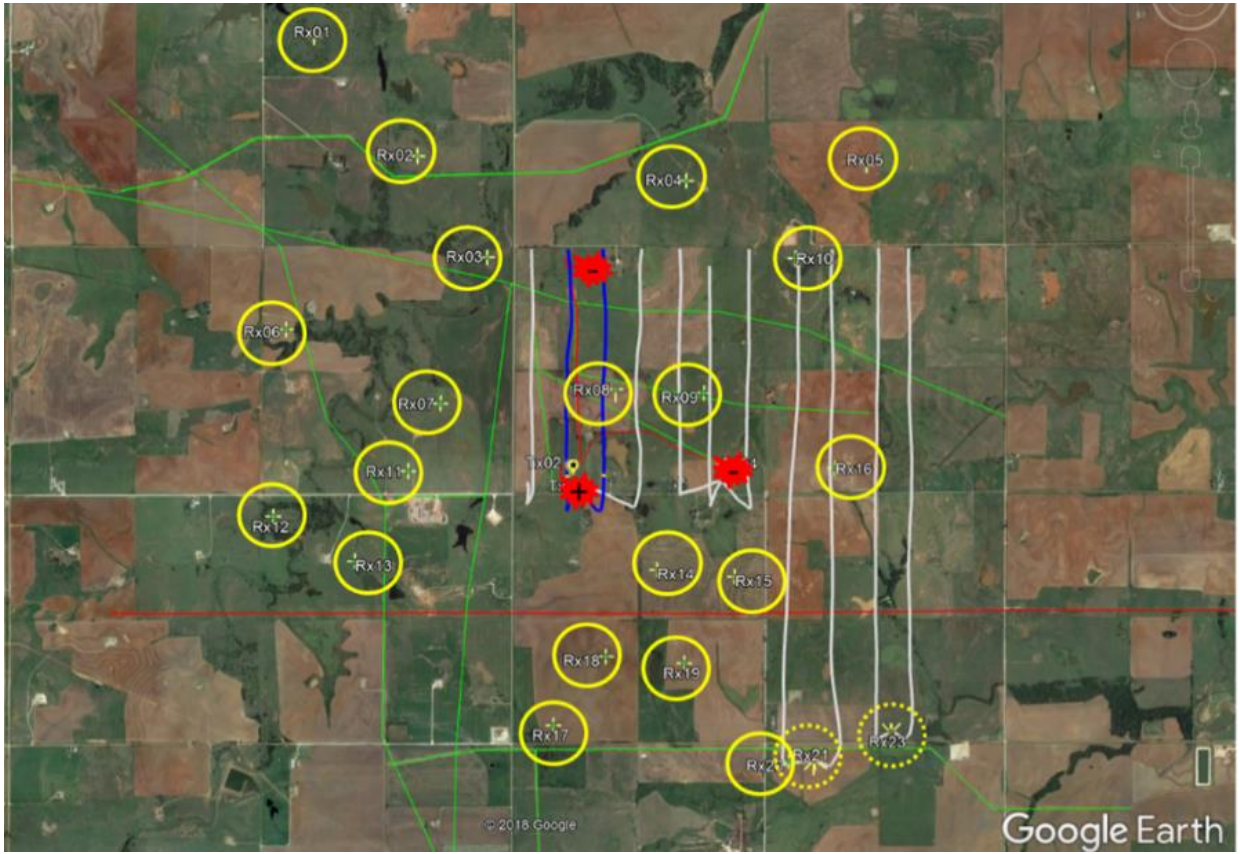


Forward Modeling & Design

- Forward Model built
  - feasibility and job design
- Complex model
  - 8 x 8 km AOI
  - 51 well casings
  - 100 OH resistivity logs
  - >30 km shallow buried pipelines
  - topography

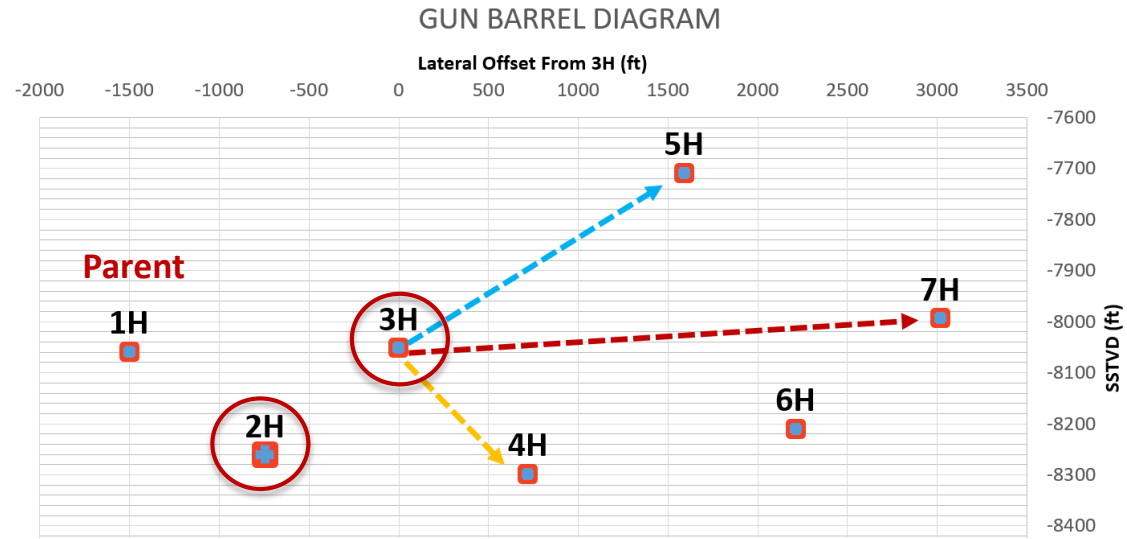


Geophysical Array



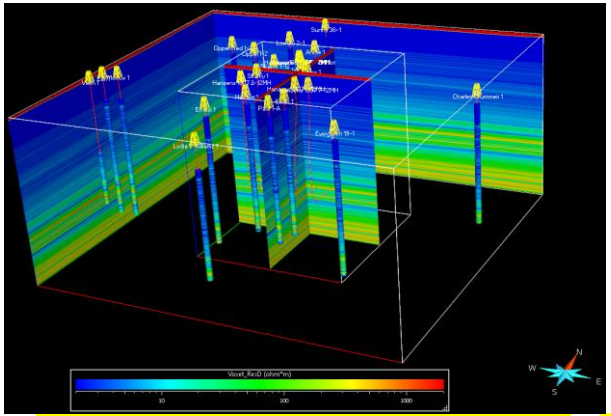
Design Overview

- Single “stage” (heel)
- Two clusters (20’)
- 160,000 lbs 40/70
- High Vis Fric Red (HVFR)



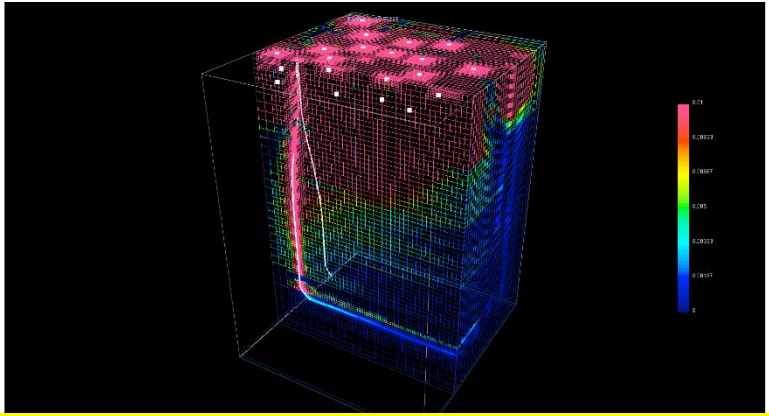
- Well 2H: 100% EC proppant (<60 BPM)
- Well 3H: Mixture – 70% ECP / 30% Sand (70 BPM)

Modeling & Calibration (baseline inversion)



Earth Model from logs, seismic and topography

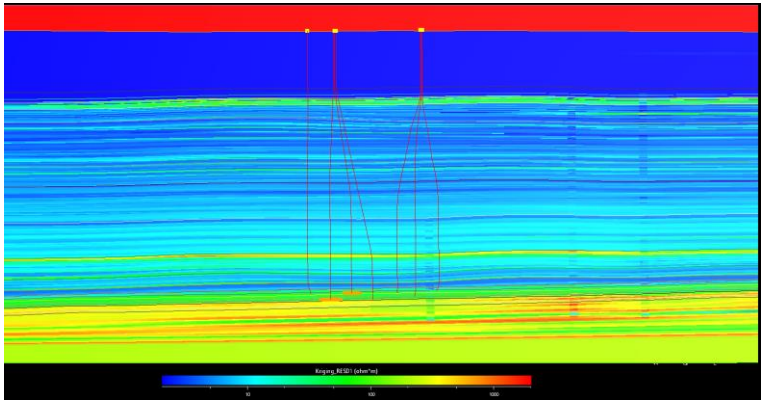
Model Difference



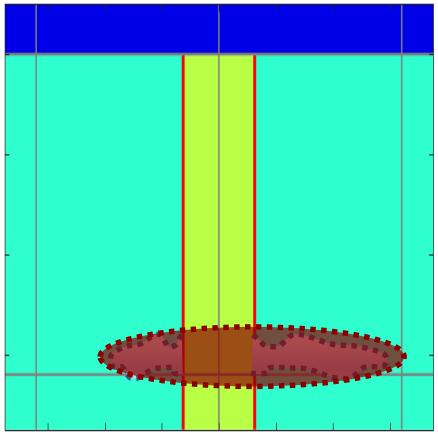
Earth Model after pre frac inversion (colorscale adjusted to highlight change)

- Earth model built from apriori information
- After **prefrac** transmit, earth model is “history matched” until the predicted e-field response matches the actual measured e-field response.

Parametric Inversion (Post Frac)

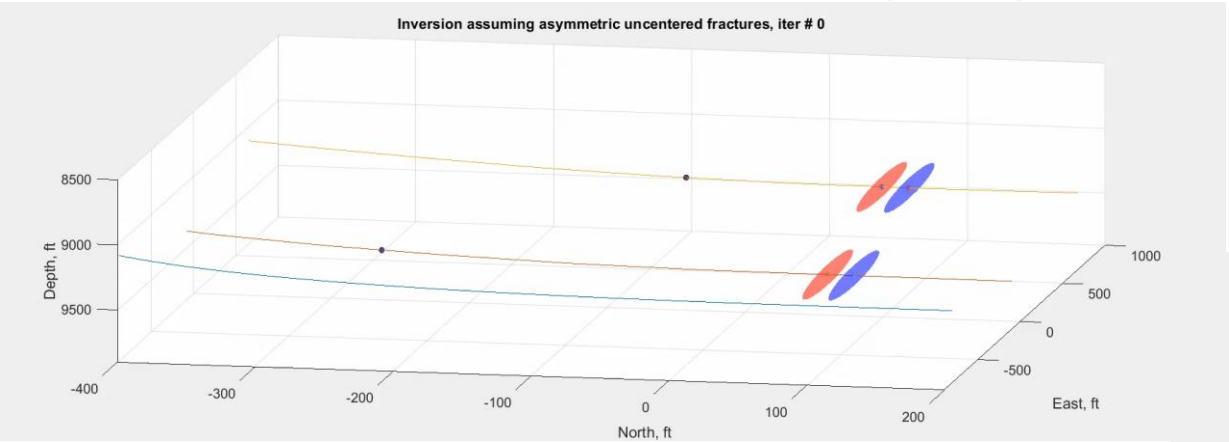


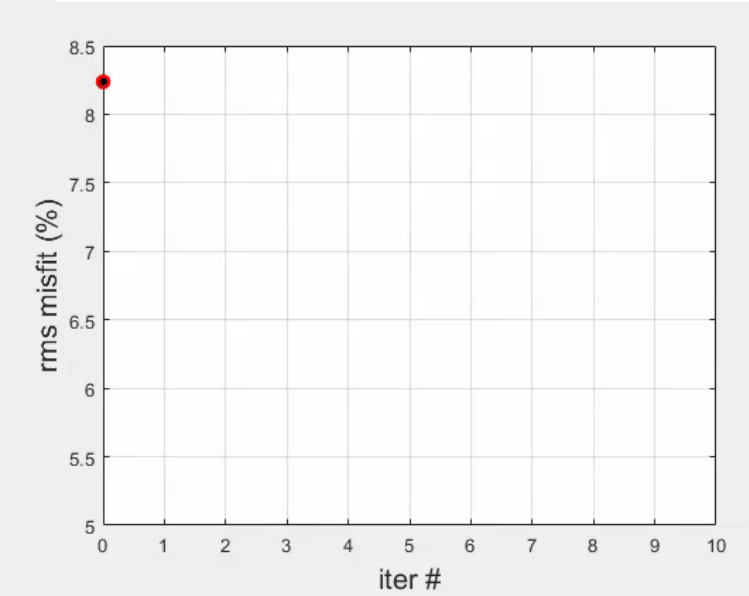
- Interactions between *geology*, *casing* and *proppant* are extremely complicated
- Parametric Inversions employed to solve for first order parameters (such as Xf, Xh, etc)



- Ellipsoid is a *first order approximation* for shape of propped fracture
  - **Frac height, length and width may vary**
  - **Not necessary to be centered** on the wellbore.
- Higher confidence results (estimates of *fracture length*, *height*, and *average proppant concentration*) at the *expense* of *reduced detail*

Post Frac Inversion Highlights

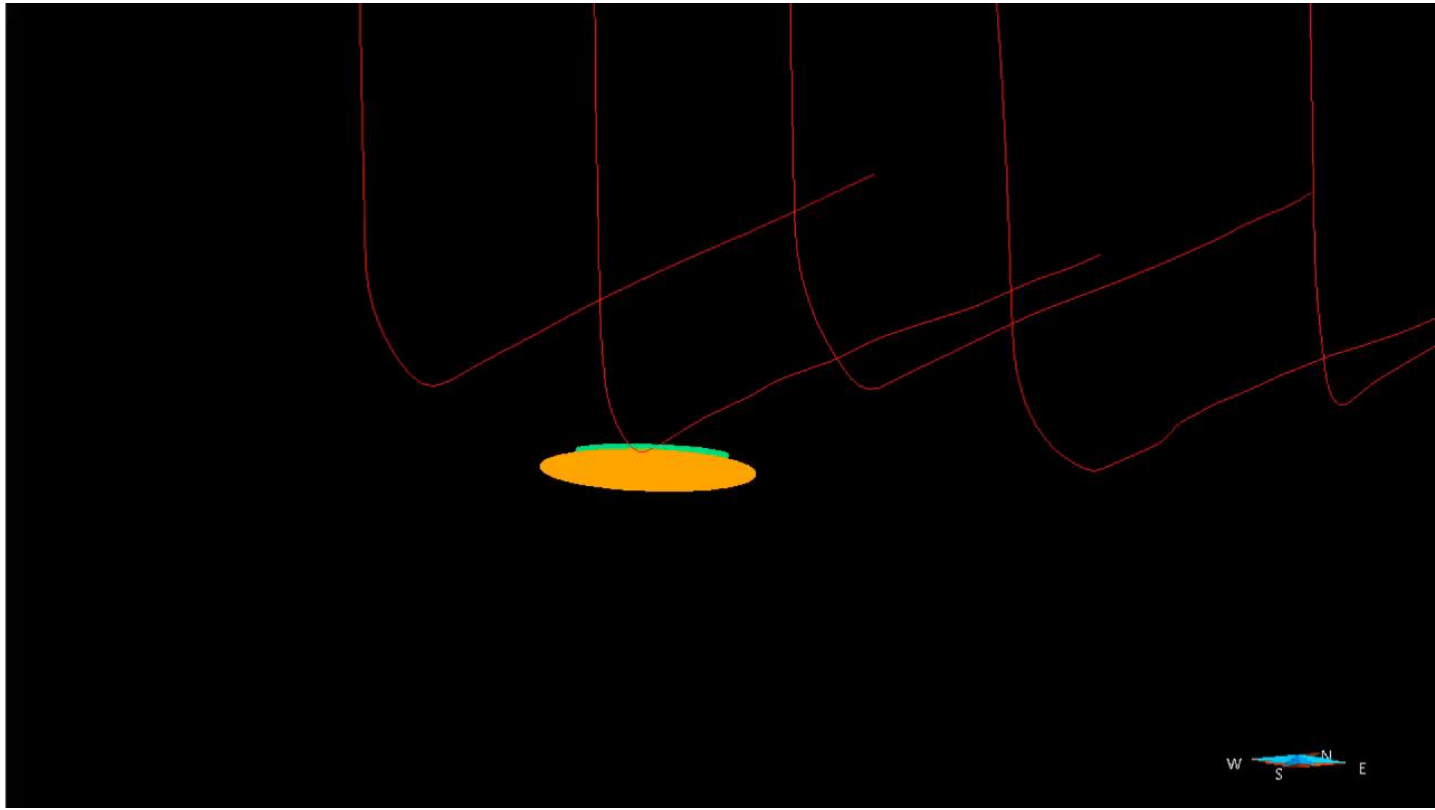




- Parametric Inversion
- Final 5% misfit (fit 95% of data)
- Large drop when allowed to move vertically/horizontally

Well 2H

- 100% ECP
- Lower rate
- High WHTP
- Closest to parent

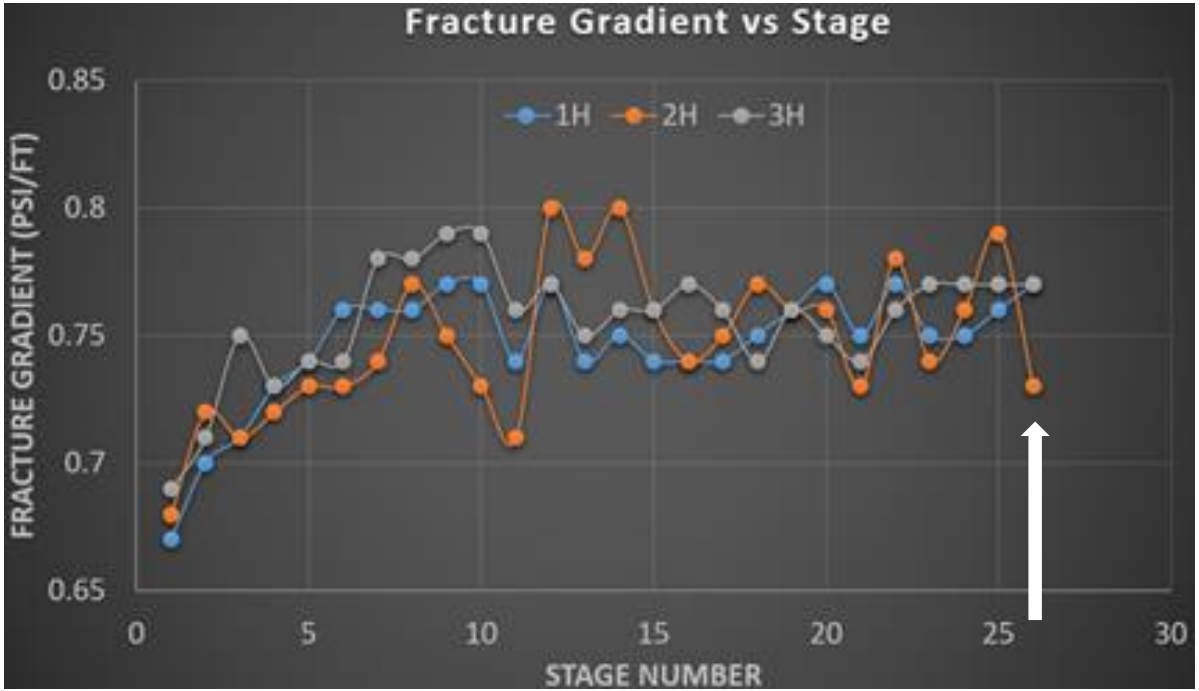


Results Summary

	Well 2H (100%)	
	Frac 1 (heel-side)	Frac 2 (toe-side)
Propped Half-Length (ft)	364	259
Propped Height (ft)	132	50
Max. Width (in)	0.29	0.04
Propped Fracture Volume (ft^3)	1216	43
Easting Offset (ft)	-12	-2
Depth Offset (ft)	70	15
Imaged Fraction of Total Proppant Pumped (%)	76%	

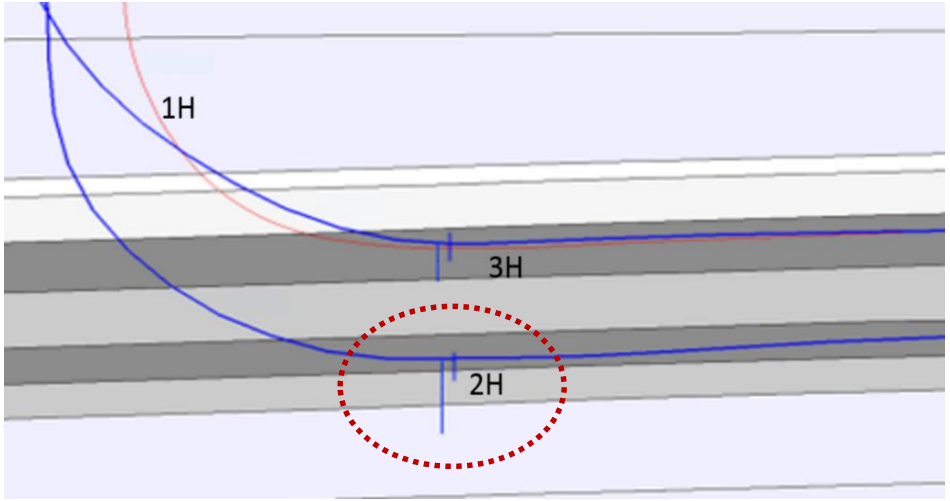
Frac Gradient by Stage

- Detectible stages are last stage (right)
- Frac gradient leveled out after increasing early on
- Suggests that the rock had been repressured by his time, or stress shadowing took over
- Explains lower bias towards parent by this time.



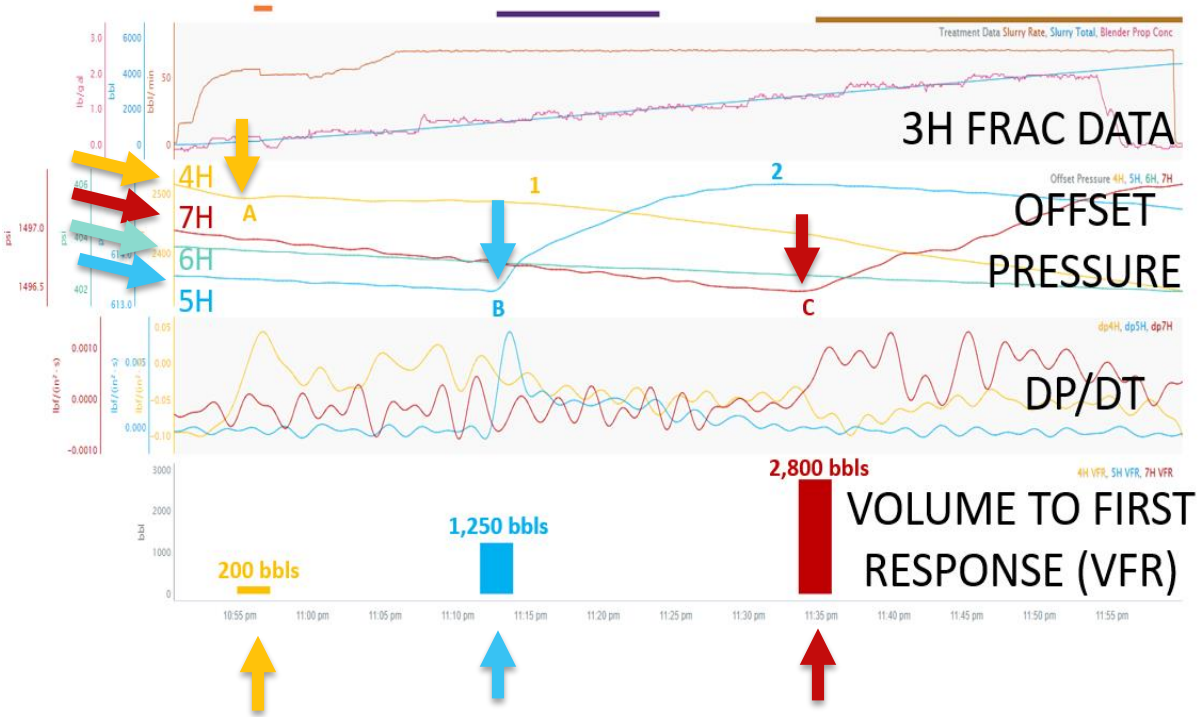
Impact on Landing Zone

- Appeared to place proppant “out of zone”
- Proppant settling, lower rate
- Does this impact where to land the well in wells drilled in lower zone?

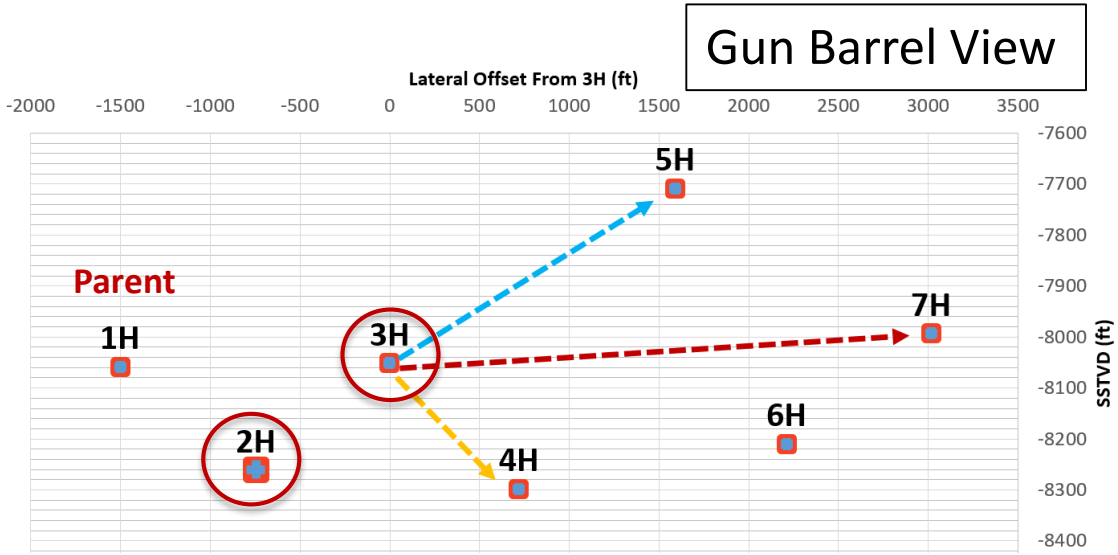


Offset Pressure Analysis

- Four monitor wells
- Three interactions
- Varying VFRs
- Hydraulic geometry
  - Xf > 1,400’
- Hyd Xf ~4x Prop Xf



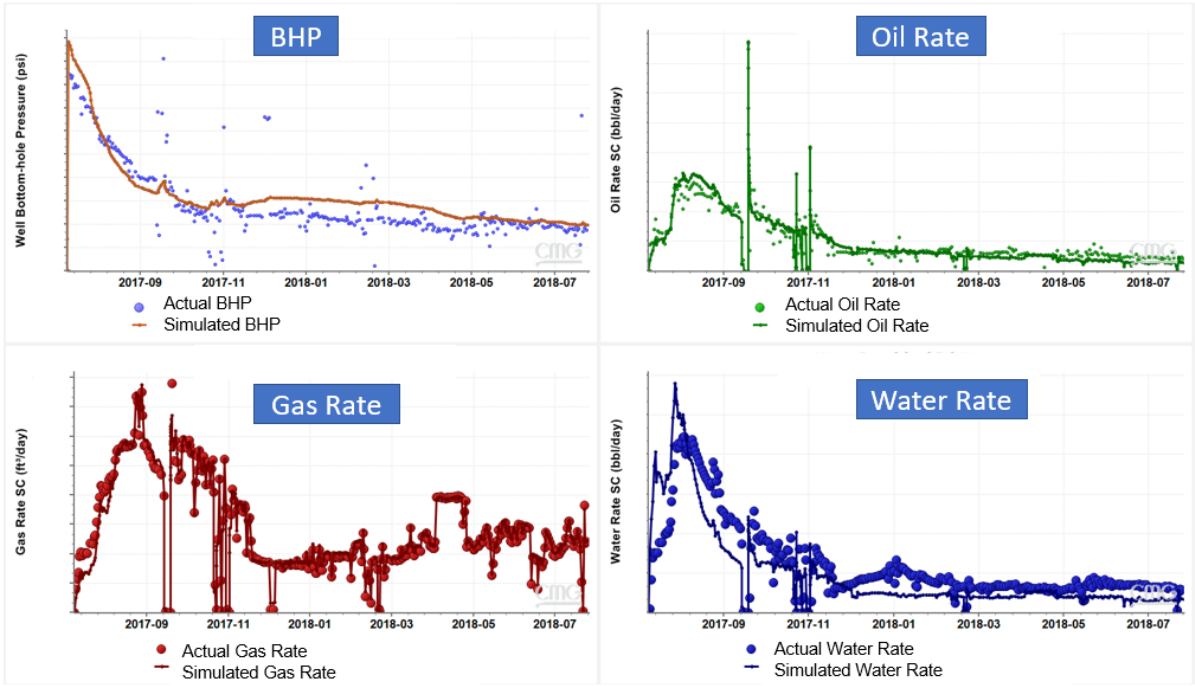
Pressure Communication



- Well 2H: 100% EC proppant (<60 BPM)
- Well 3H: Mixture – 70% ECP / 30% Sand (70 BPM)

Propped Fracture Geometry Validation

- Geologic and petrophysical data based on a vertical data well.
- Multi-phase, multi-layer simulation.
- History match was achieved based on fracture dimensions identified by EM imaging.



Summary

- Proppant biased below wellbore and towards heel perf clusters
- Depletion had little impact on geometry
  - Potential recharging/stress shadowing during previous fracs
- Propped geometries (height/length) << hyd length
  - Production History match supported dimensions
  - Potential propped fracture “out of zone”
- Mixing of proppant (ECP/Sand) reduced signal (as expected)

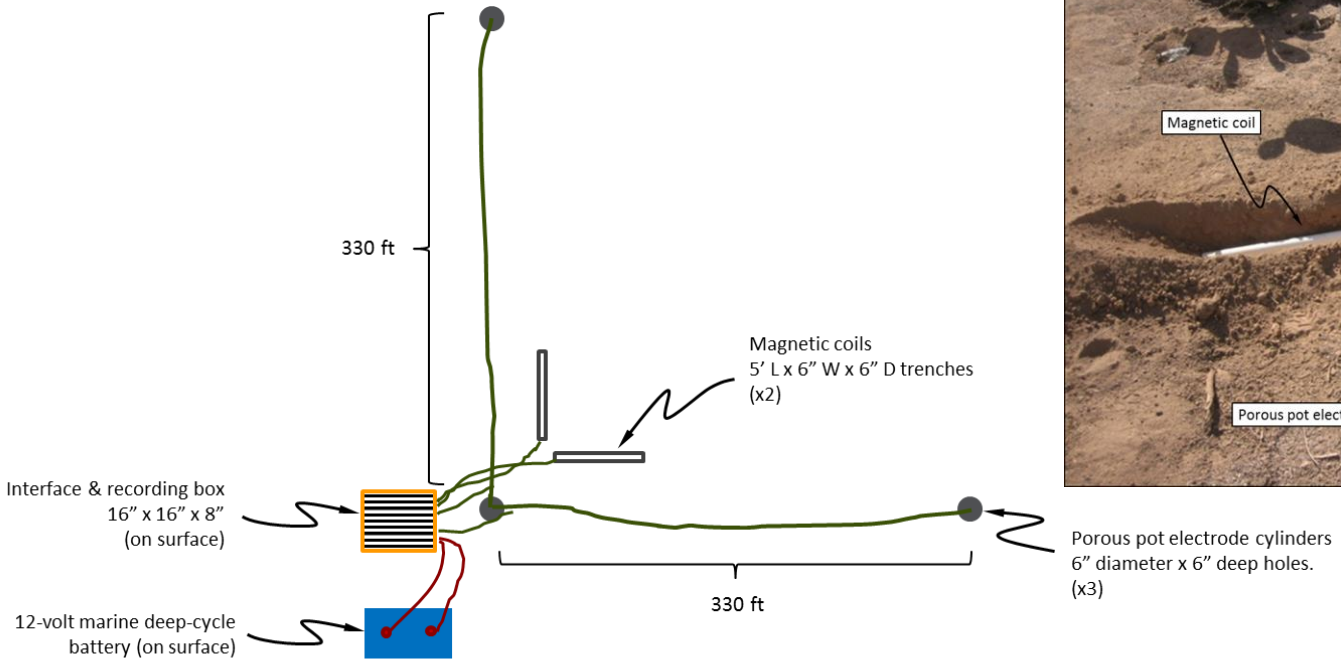
Applied Geoscience Conference

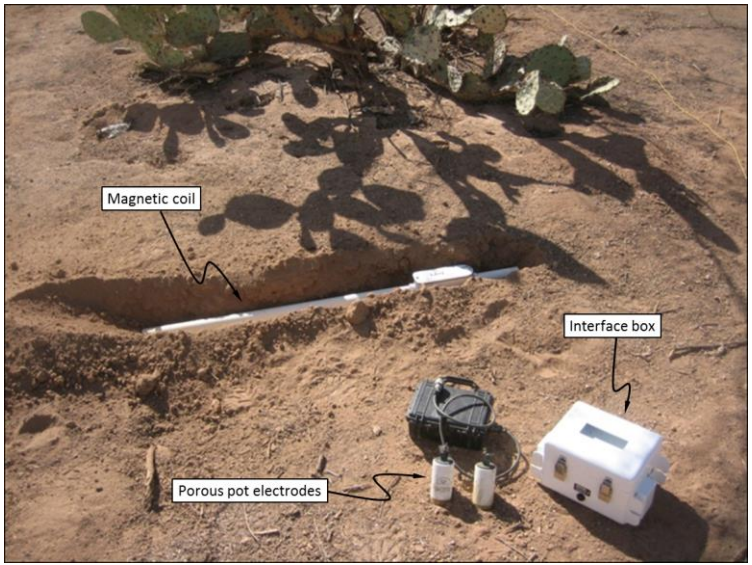
QUESTIONS?

devon

CARBO

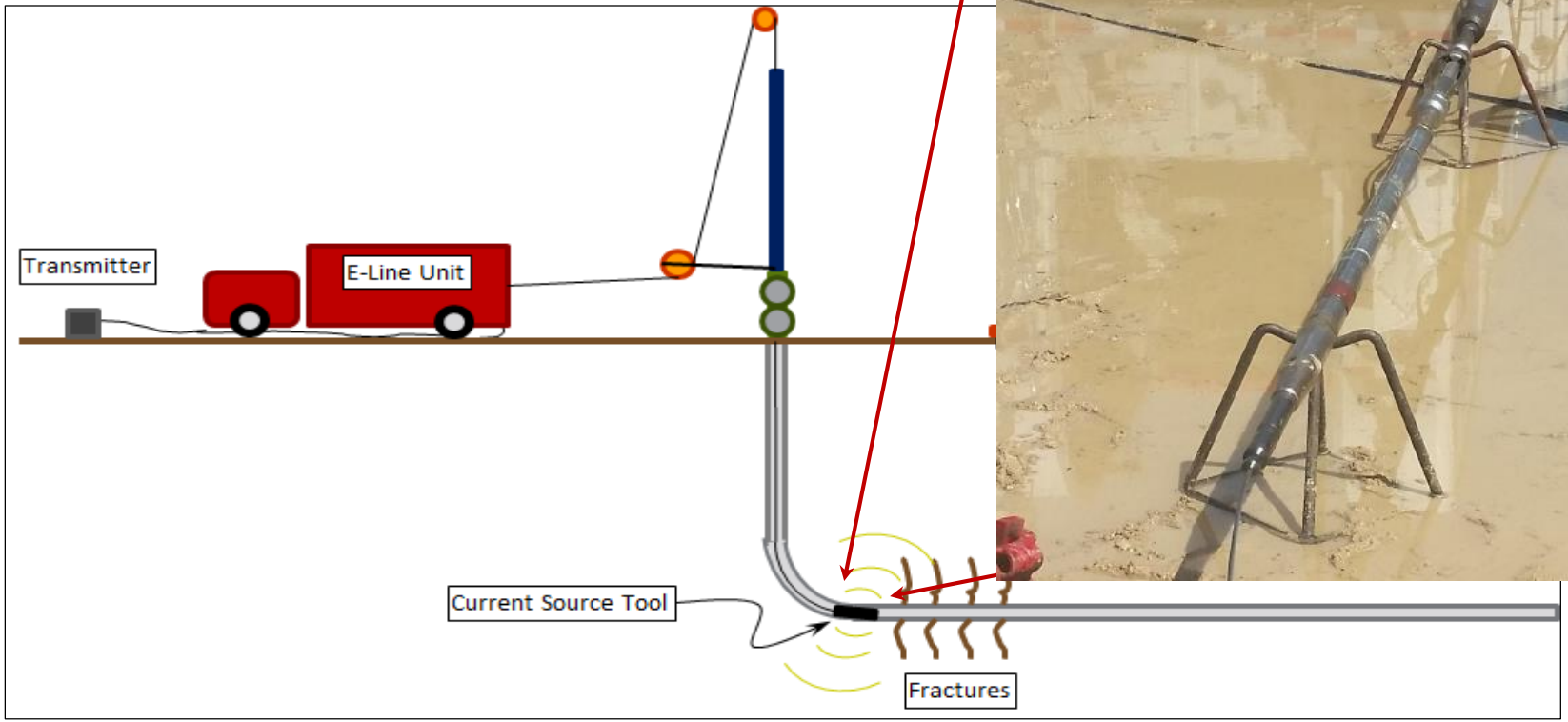
Multi-Component Receiver (each station)





All wires on surface

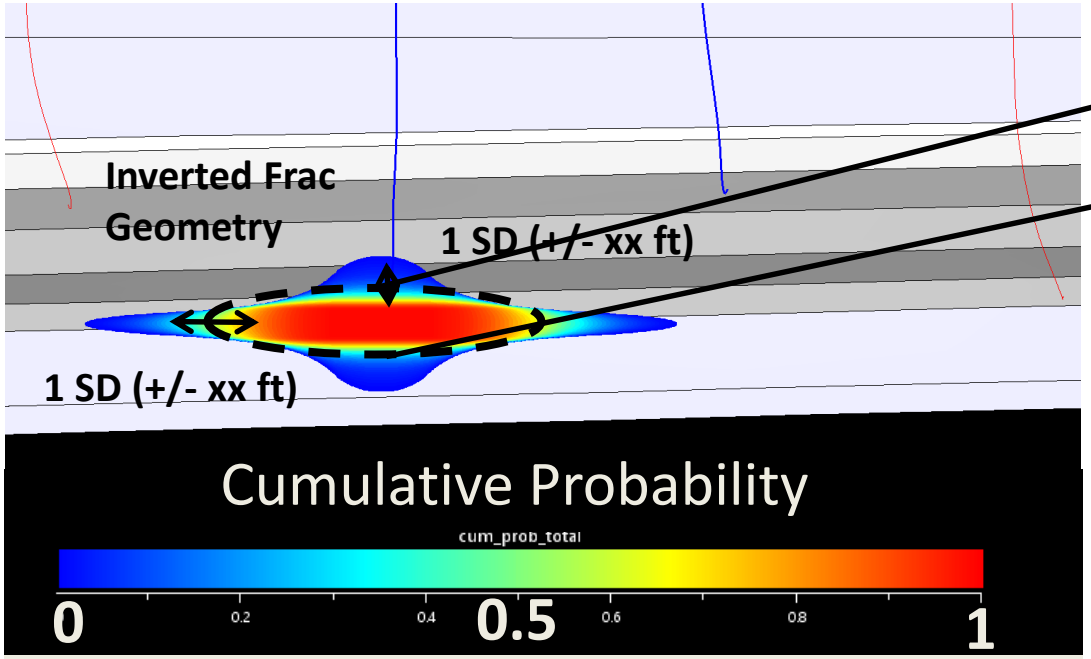
EM Components

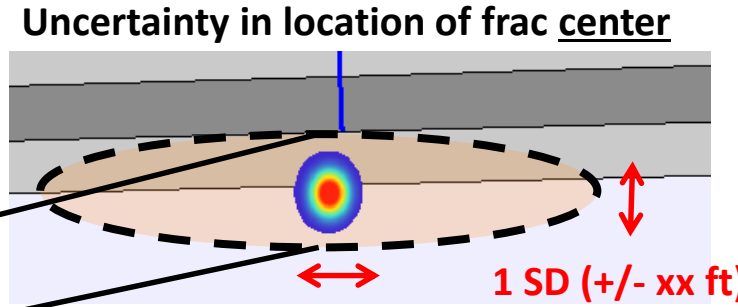


Results Summary

	Well 2H (100%)		Well 3H (70:30)	
	Frac 1 (heel-side)	Frac 2 (toe-side)	Frac 1 (heel-side)	Frac 2 (toe-side)
Propped Half-Length (ft)	364	259	123	131
Propped Height (ft)	132	50	72	50
Max. Width (in)	0.29	0.04	0.29	0.02
Propped Fracture Volume (ft^3)	1216	43	224	10
Easting Offset (ft)	-12	-2	-2	-1
Depth Offset (ft)	70	15	33	6
Imaged Fraction of Total Proppant Pumped (%)	76%		14%	

Cumulative Probability





- **Hot colors** indicate high likelihood that frac geometry is bigger.
- **Cold colors** indicate high likelihood that frac geometry is smaller.

Probability Example