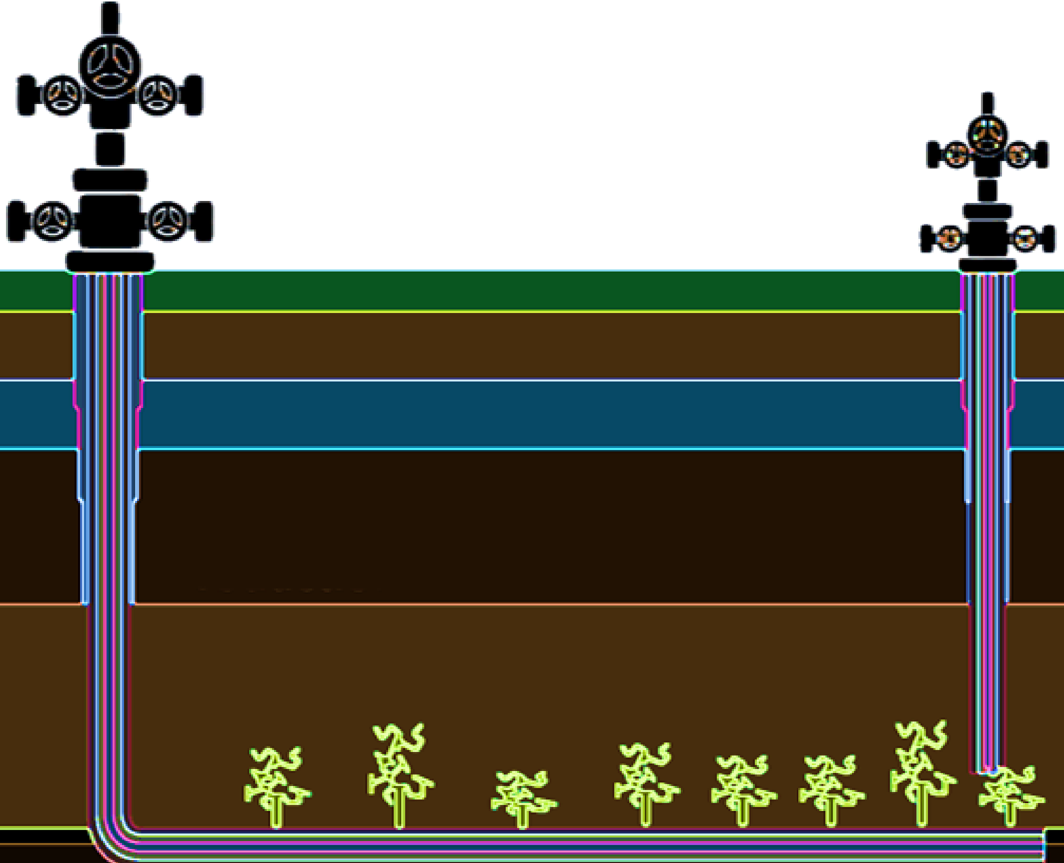
Optimize Completion Design and Well Spacing with the Latest Complex Fracture Modeling & Reservoir Simulation Technologies

A Permian Basin Case Study with Seven Wells



Presented by **Hongjie Xiong**
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UNIVERSITY LANDS

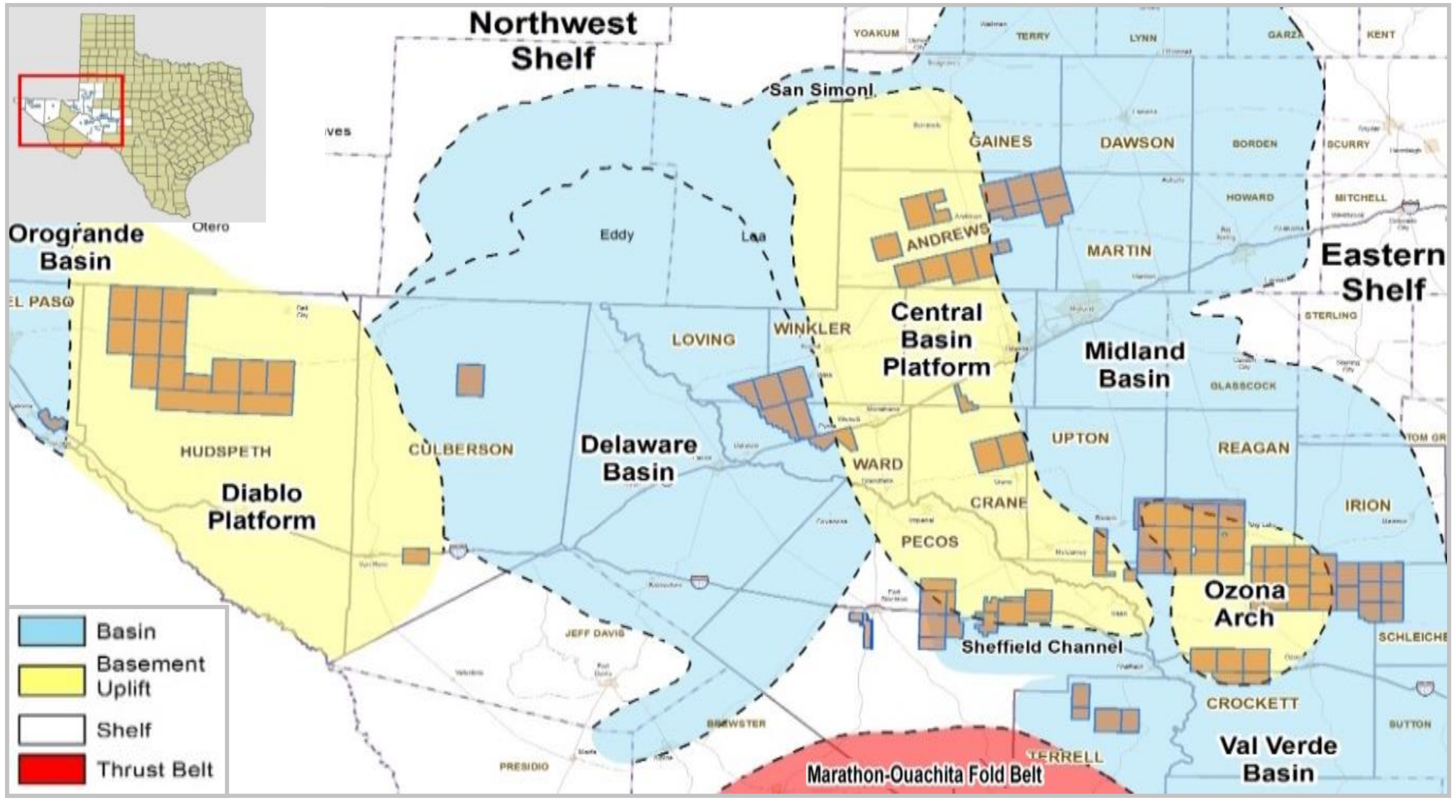
University Lands Introduction

Managing 2.1 million acres in the Permian Basin, West Texas

- Over 200 operators
- 2018 Net Daily Production
  - ~ 60,000 BOE per day
- 2018 Net Revenue: > 1$Billion
- >20,000 potential drilling locations on current leases

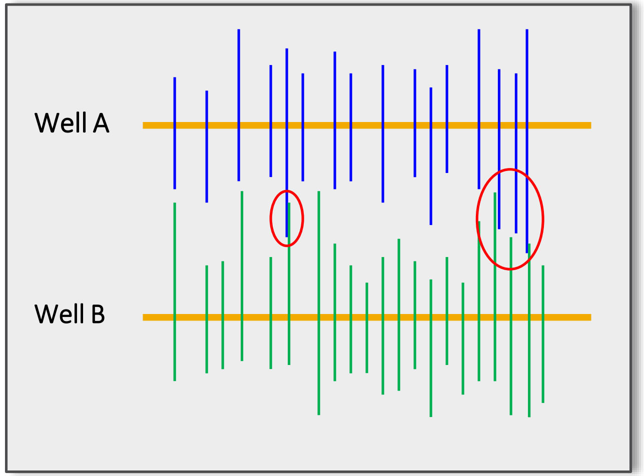
Study Projects Performed since 2016

- Geological study and modeling
- Reserve and Resource assessment
- Well performance analysis and type well curves
- Well Spacing study and optimization
- Completion study and optimization with complex fracturing modeling
- Artificial lift optimization studies
- Underperforming well studies
- Wellbore lateral length and orientation studies

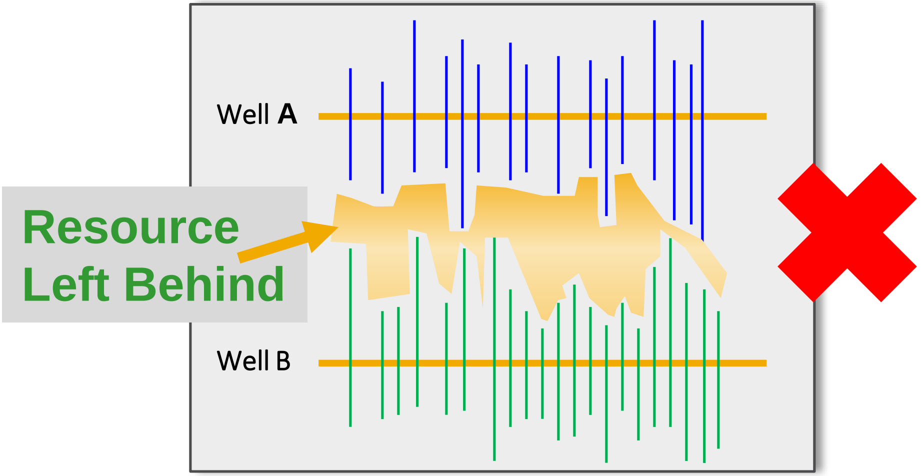


Overview

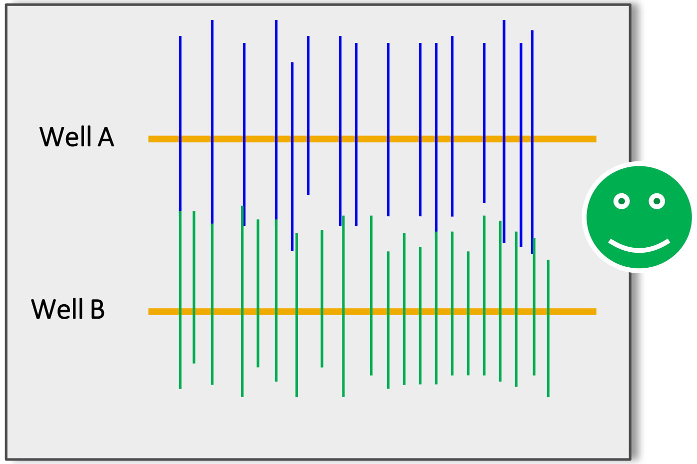
- Introduction
- The Objective
- The Workflow
- The Case History of 7 Wells and the History Match
- Completion Design Optimization
- Conclusions



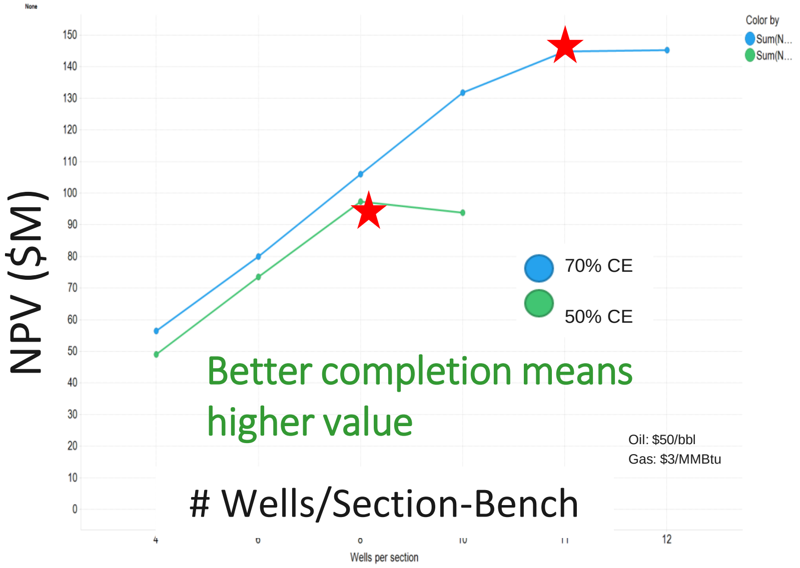
Case A (“False” Interference, leave resources behind)



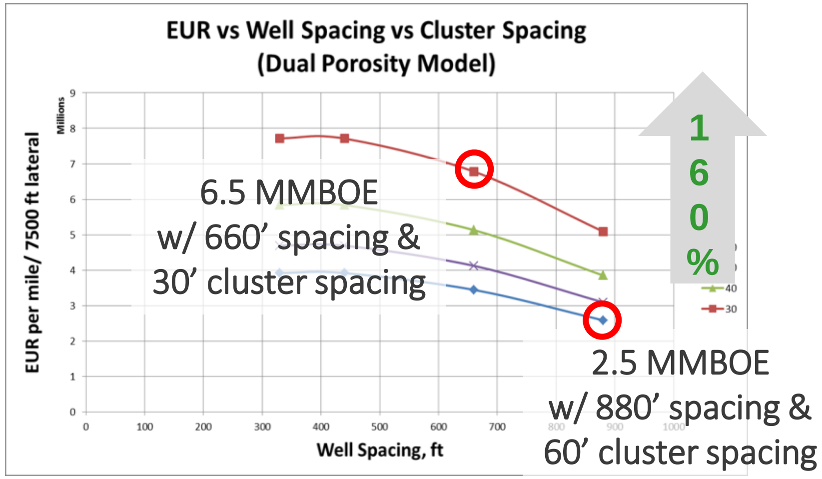
Case B (Wider spacing – leave MORE resources behind)



Case C (Optimal spacing with optimal completion)



Better completion means higher value



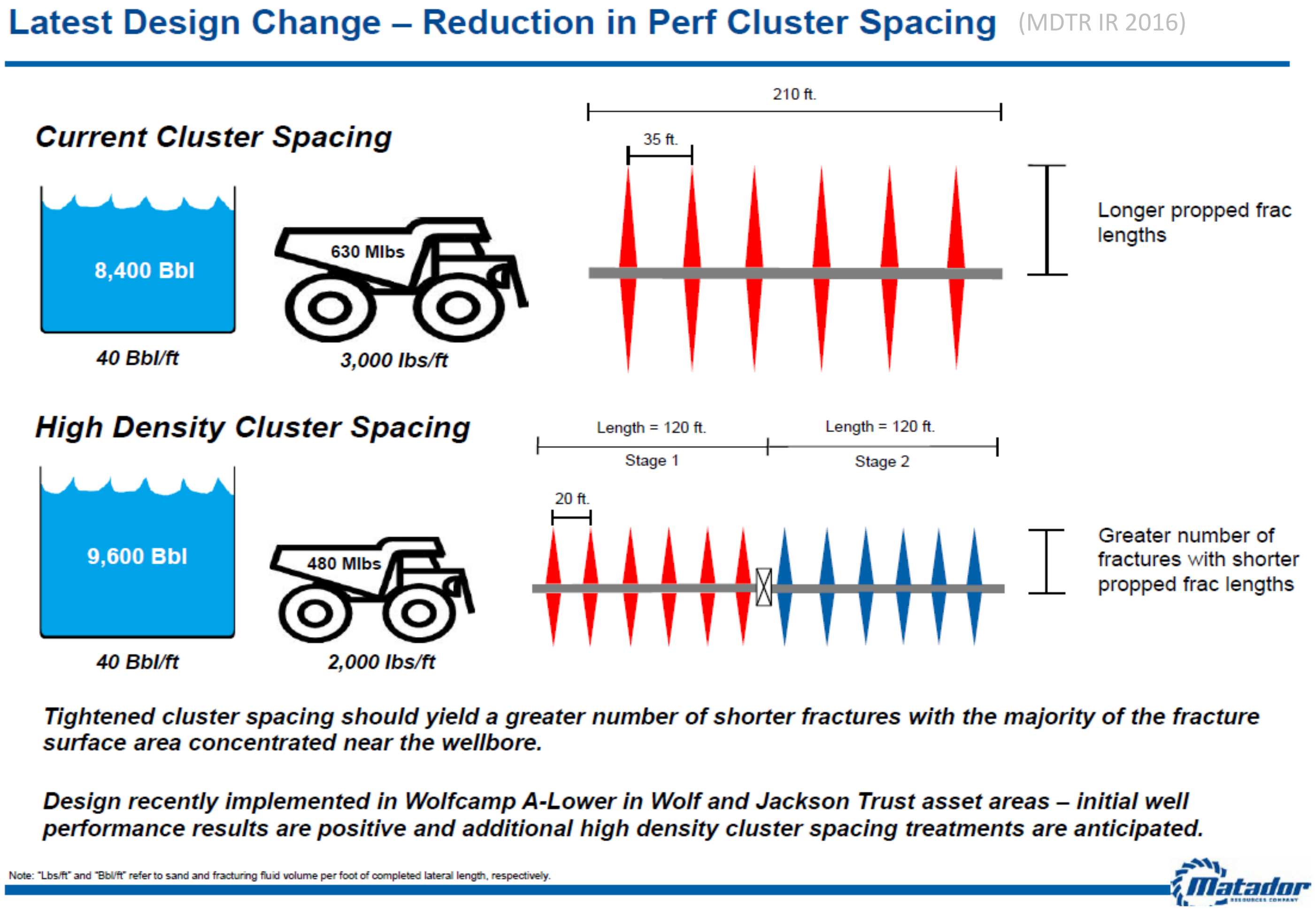
6.5 MMBOE w/ 660’ spacing & 30’ cluster spacing

2.5 MMBOE w/ 880’ spacing & 60’ cluster spacing

Right well spacing and optimal completion will enhance recovery and value

SPE189855, 187485

Permian Basin Operator – HD Completion



Latest Design Change – Reduction in Perf Cluster Spacing

(MDTR IR 2016)

Current Cluster Spacing

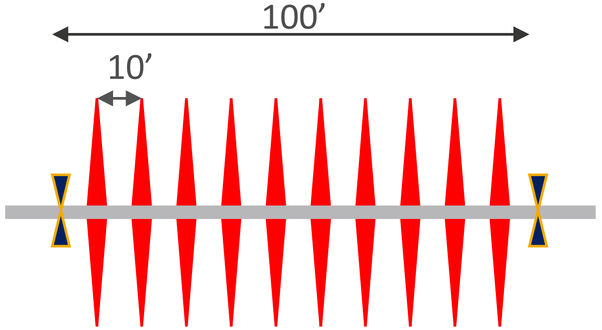
High Density Cluster Spacing

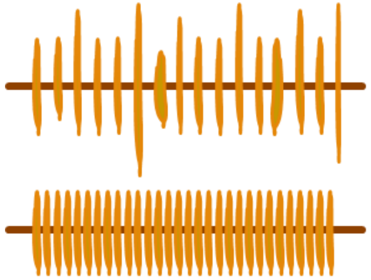
Tightened cluster spacing should yield a greater number of shorter fractures with the majority of the fracture surface area concentrated near the wellbore.

Design recently implemented in Wolfcamp A-Lower in Wolf and Jackson Trust asset areas – initial well performance results are positive and additional high density cluster spacing treatments are anticipated.

Note: "Lbs/ft" and "Bbl/ft" refer to sand and fracturing fluid volume per foot of completed lateral length, respectively.

Current

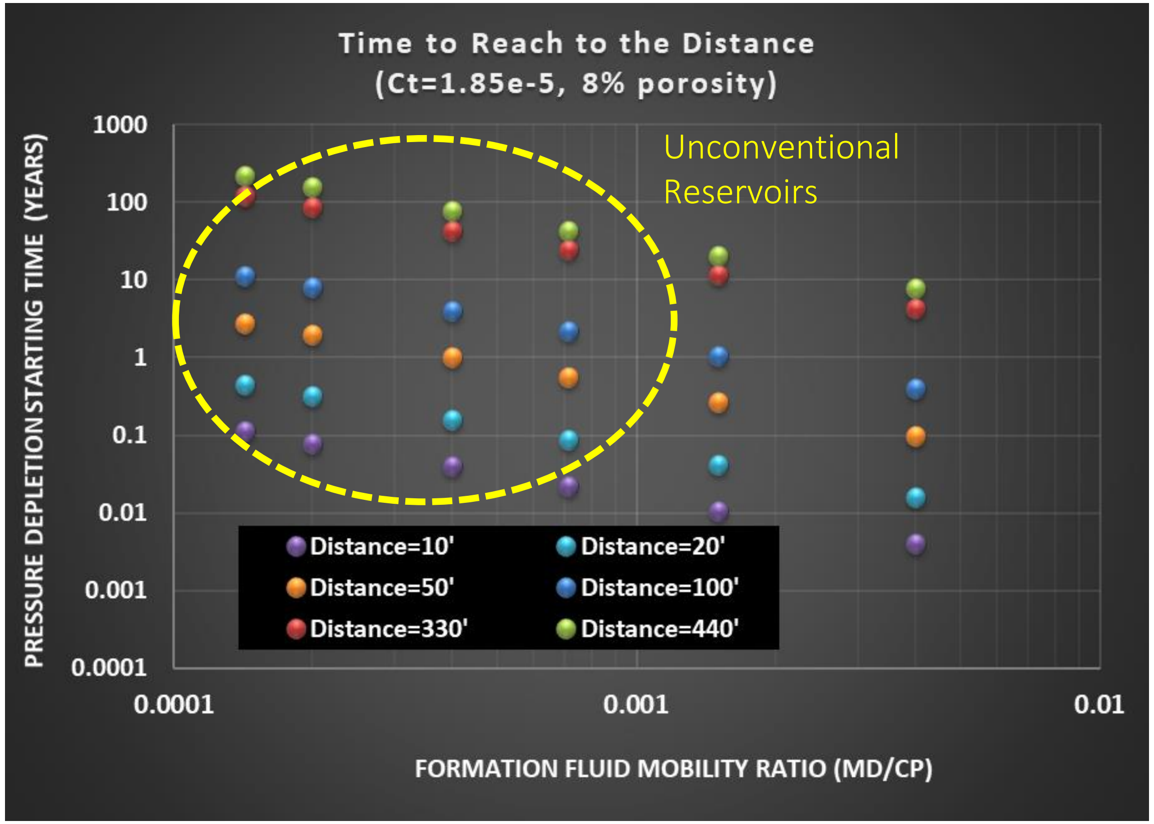




It is **hard** to create **uniform long** fractures for all perforation clusters

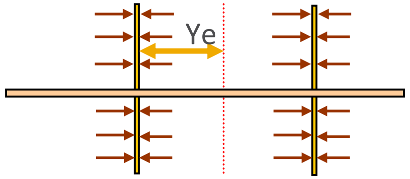
it is a **better strategy** to target more effective fractures with shorter cluster spacing – HD Completion

Pressure depletion propagation is very **slow** in the unconventional reservoirs!



Pressure Depletion Time Depending on Reservoir Mobility Ratio - k/μ

$$t = \frac{948\emptyset C_t d_i^2}{\boxed{\frac{k}{\mu}}}$$



$$q \approx \sqrt{\frac{\emptyset C k_m}{\mu B^2}} * \boxed{A\sqrt{k}} * \Delta p * \frac{1}{\sqrt{t}}$$

Thus, we need

1. **larger fracture surface area** for higher rate; and
2. **tighter fracture spacing** for faster depletion

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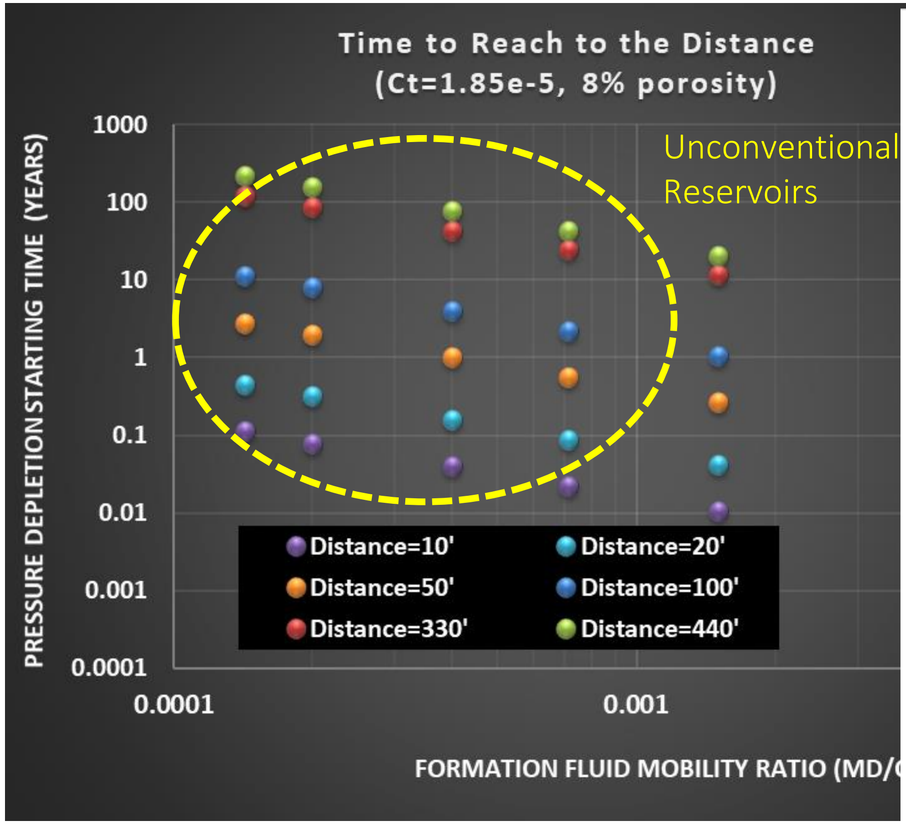
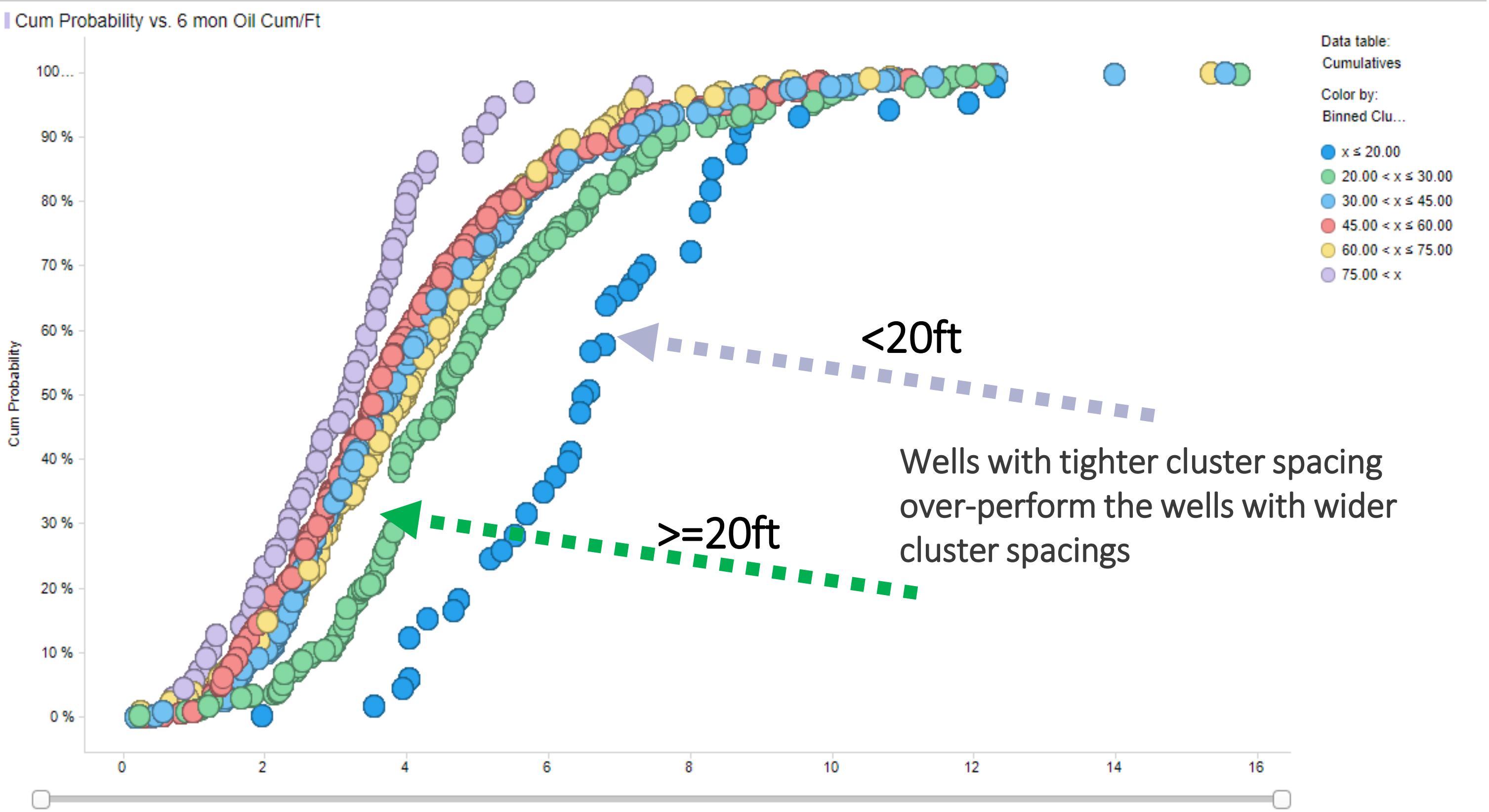


Pressure Depletion Time Depending on Reservoir Mobility Ratio - k/μ

Field Data Set - Tighter Cluster Spacing Wells Over-Perform

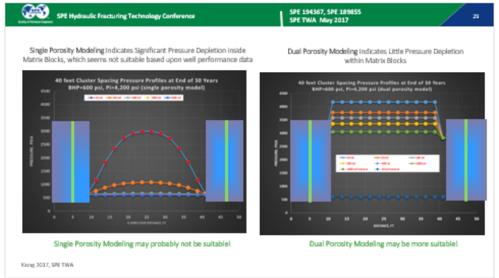


Wells with tighter cluster spacing over-perform the wells with wider cluster spacings

Thus, we need
(1) **larger fracture surface area** for higher rate; and
(2) **tighter fracture spacing** for faster depletion

Tighter Cluster Spacing Shows More Depletion Area (the same depletion condition)

Dual porosity modeling



SPE Hydraulic Fracturing Technology Conference

SPE 194367, SPE 189855
SPE TWA May 2017

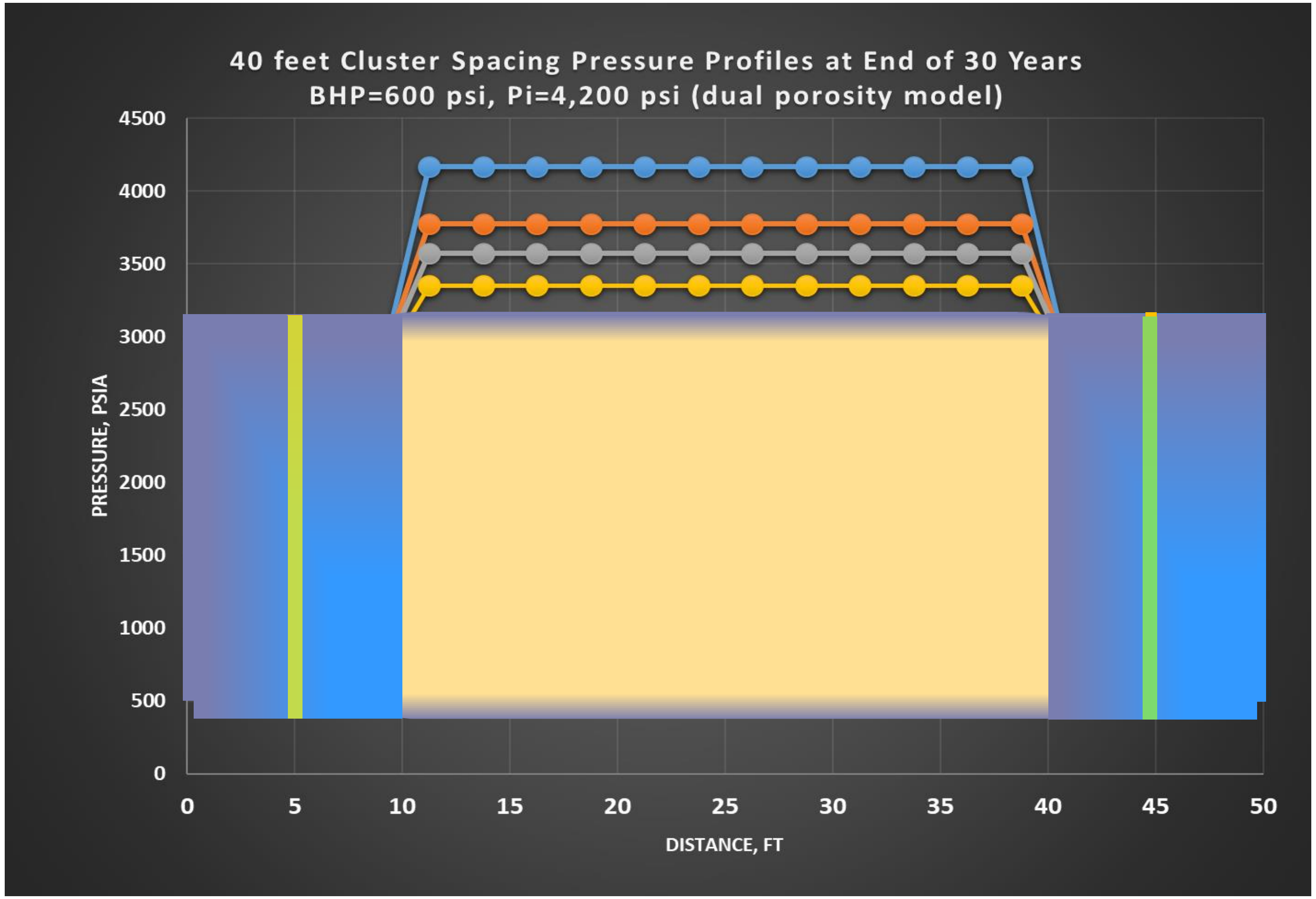
Single Porosity Modeling Indicates Significant Pressure Depletion inside Matrix Blocks, which seems not suitable based upon well performance data

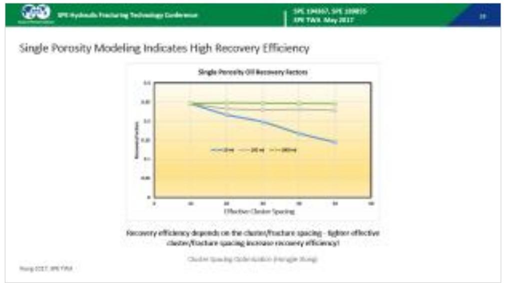
Dual Porosity Modeling Indicates Little Pressure Depletion within Matrix Blocks

Single Porosity Modeling may probably not be suitable!

Dual Porosity Modeling may be more suitable!

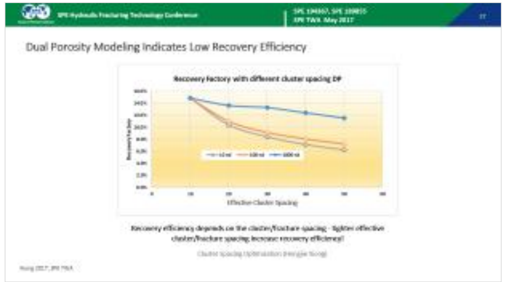
Xiong 2017, SPE TWA





Single Porosity Modeling Indicates High Recovery Efficiency

Recovery efficiency depends on the cluster/fracture spacing - tighter effective cluster/fracture spacing increase recovery efficiency!



Dual Porosity Modeling Indicates Low Recovery Efficiency

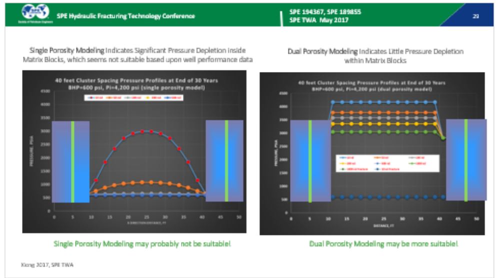
Recovery efficiency depends on the cluster/fracture spacing - tighter effective cluster/fracture spacing increase recovery efficiency!

Given Cluster/Fracture Spacing of 20ft, There Is More Depletion Area Comparing to the 40ft Cluster Spacing.

$$\text{EUR} = \int f(Rqi, A, k)\Delta p dt$$

Tighter Cluster Spacing Shows More Depletion Area
(the same depletion condition)

Dual porosity modeling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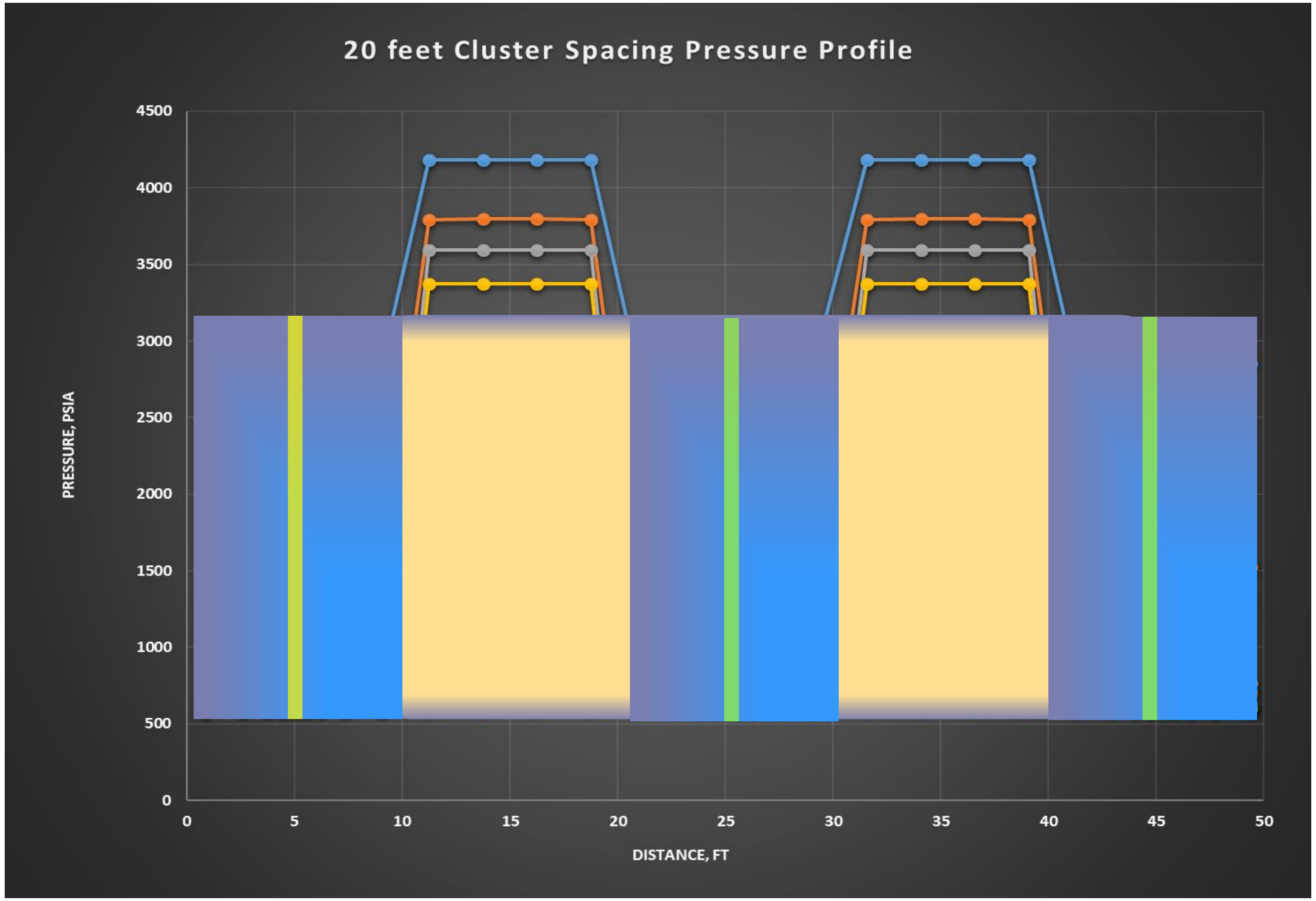

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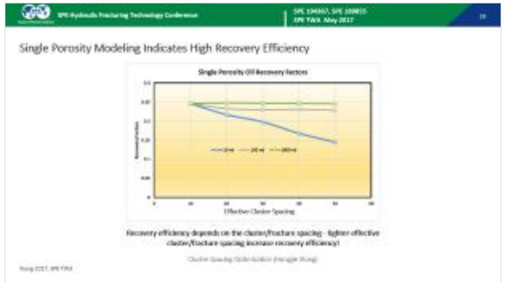
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It takes many different completion designs to reach an "optimal" one!

- Let try different of completion designs
  - 4 different cluster spacings: 10, 15, 20, 30 ft
  - 4 different clusters/stage: 3, 5, 8, 10
  - 4 different fluid intensities: 40, 50, 60, 75 bbl/ft
  - 4 different proppant intensities: 1000, 2000, 2500, 3000 lbm/ft
  - 2 different pumping rates/cluster: 6, 12 bpm/cluster
  - 2 different fluid types (viscosity): 1 and 10
  - 2 different proppant size combinations: 25:75, 50:50 of 100 mesh and 40/70
- The total combinations would be 4x4x4x4x2x2x2 = 2,048 possible designs
- The total cost would be 2048x6 $MM/well > $12 billion
- It may take LONG time - 2,048/100 wells/year - > 20 years to implement/test the designs
- **It is prohibitively expensive and time-consuming by field trial-error approach**
- **Plus, the inability to understand the unexpected results**

Problem Statement

Could we use the latest complex fracture modeling technologies to speed up the well completion optimization and well spacing optimization?

The Objective

- To test and demonstrate using the latest modeling technologies to help us **cost-effectively speed up** optimization process of well completion and well spacing in the unconventional reservoir development
  - Build and calibrate the models with 7-well completion and production history
  - Optimize well completion designs with the calibrated models

Workflow

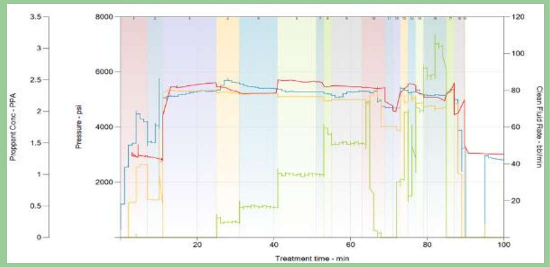
Geological Model

Geomechanical Model

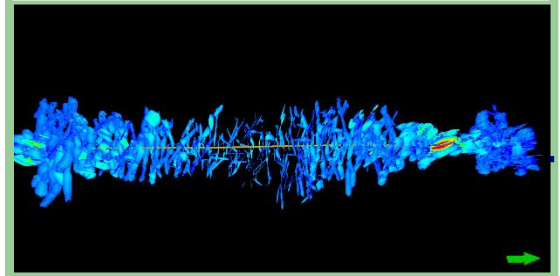
“DFN” Model

Well Completion

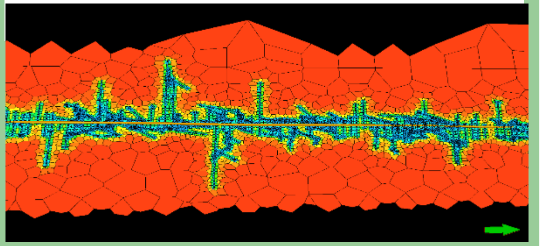
Completion History Matching



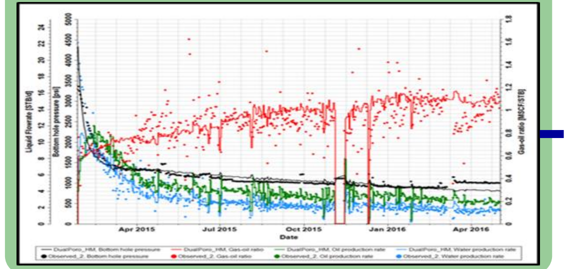
Complex Fracture Model



Dynamic Fluid Simulation Model



Production History Matching



NO

YES

Production Forecast

Completion Design Optimization

- Fracturing fluid systems
- Proppant type/amount
- Cluster spacing
- Well spacing

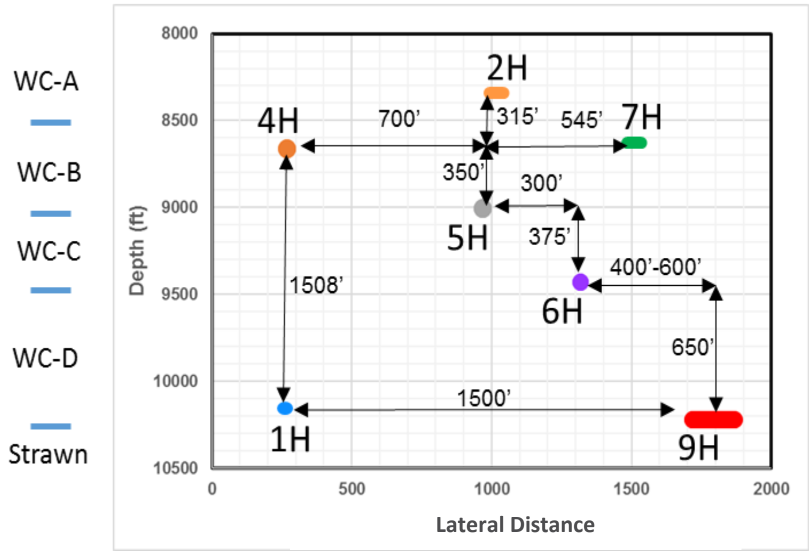
SPE 189855

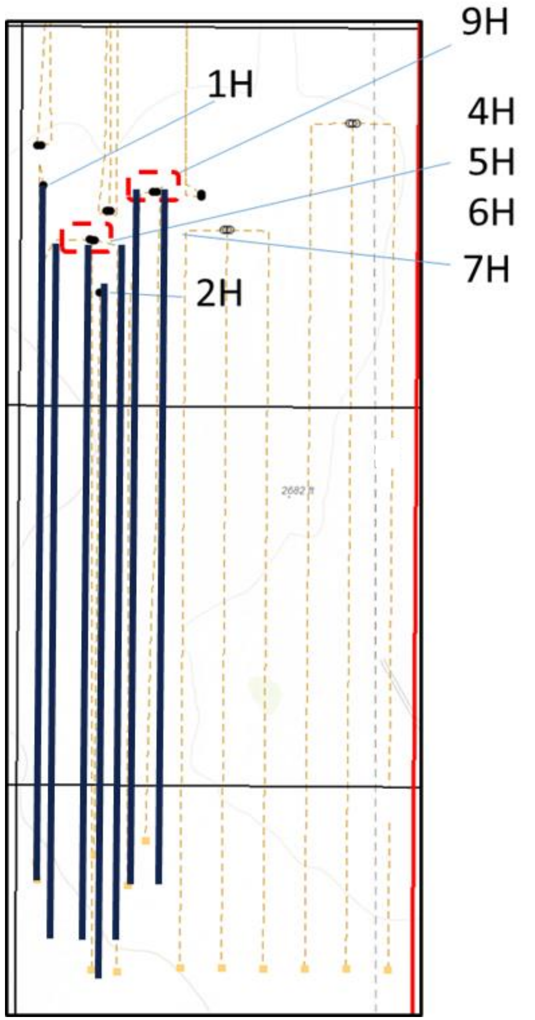
The Case History of 7 Wells and the History Match

Well Location and Basic Information

- HZ Wells placed in the Wolfcamp formation, Upton county
- Completed and started producing in 2014

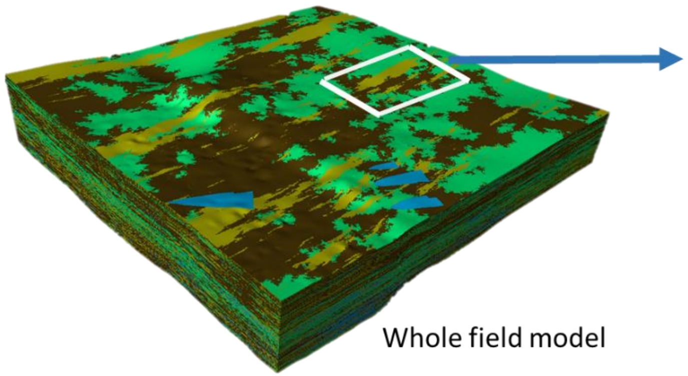
Side View

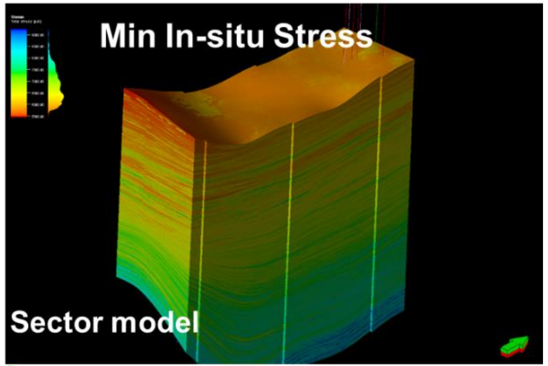


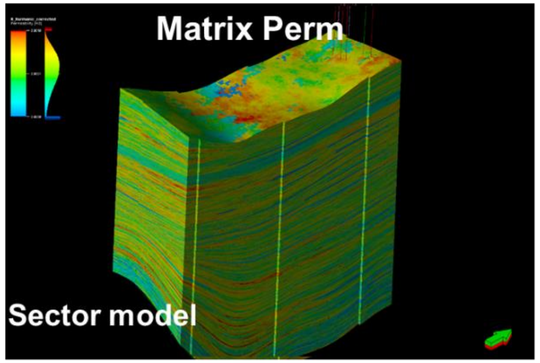


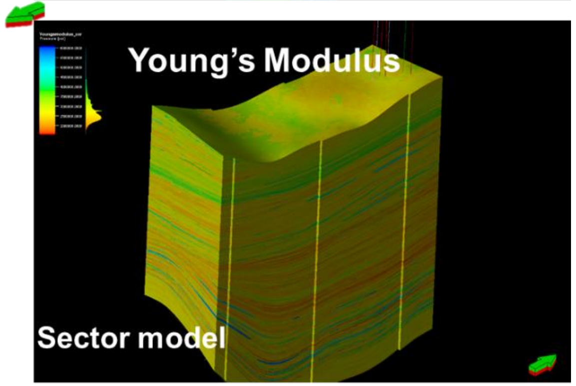
190 Stages
972 clusters

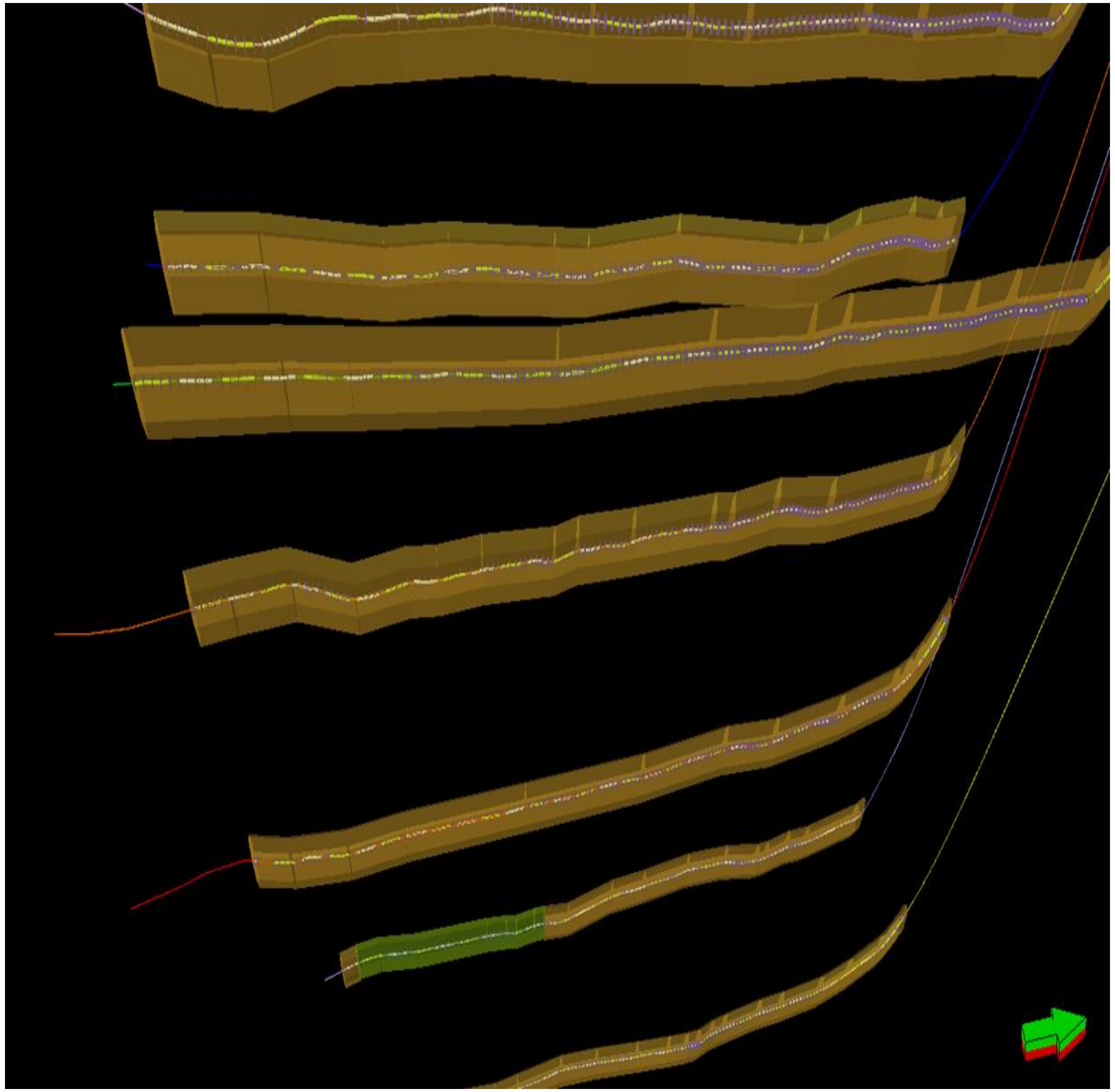
Well Name	4H	5H	6H	9H	7H	1H	2H
Lateral length (ft)	8,222	8,642	8,642	8,642	9,244	8,851	7,922
	29	30	30	30	31	18	22
	138	145	145	145	155	112	132
Cluster Spacing (ft)	60	60	60	60	60	75	60
Fracturing Fluid Type	slick water, x-linked gel						
Proppant Type	30/50 + 20/40	30/50	40/70	40/70	30/50 + 20/40	40/70	30/50 + 20/40
Clean Fluid Amount (bbl/ft)	26	26	27	29	27	40	19
Proppant Amount (lb/ft)	1,060	1,055	1,110	1,100	1,121	1,044	996





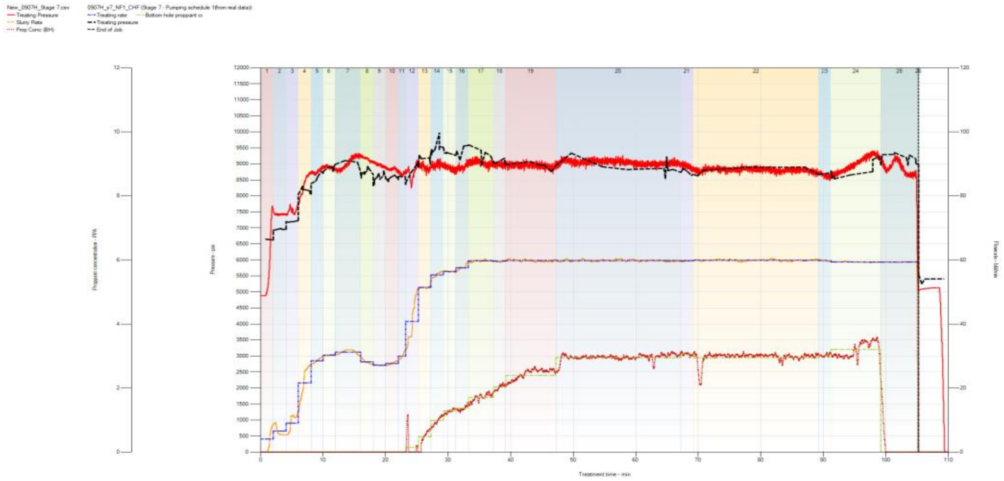


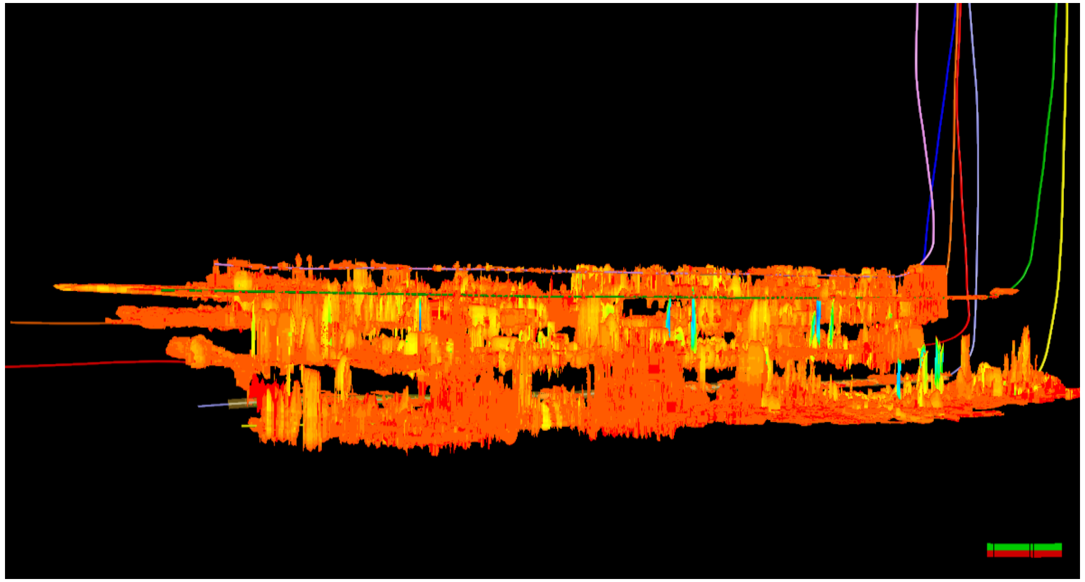


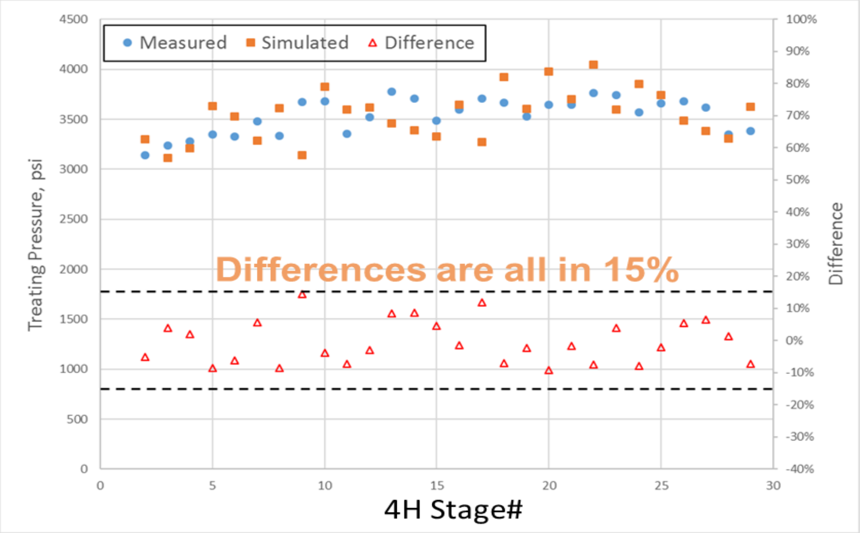


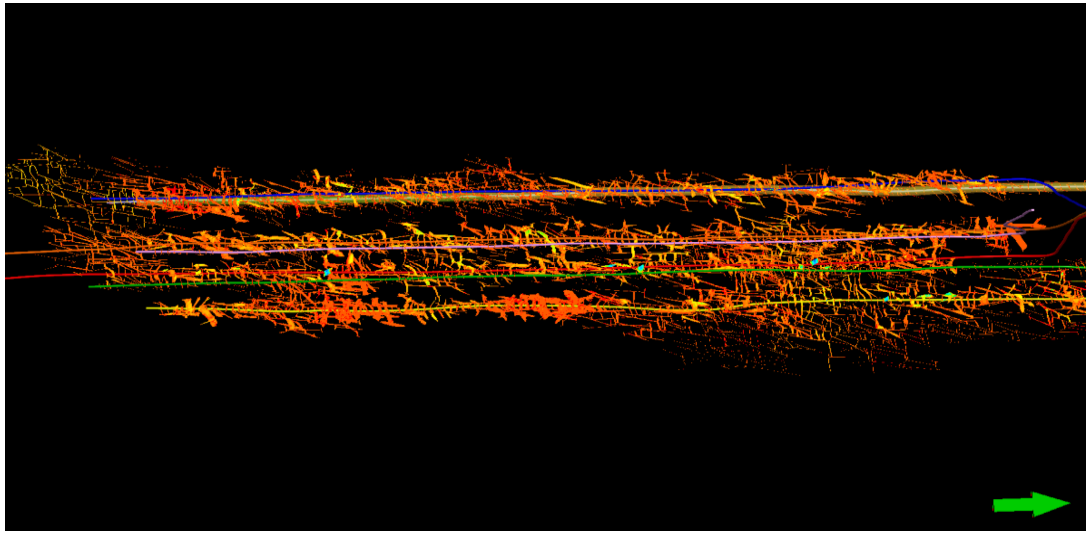
Sector Model Properties		
TVD		7700 -10310 ft
Zone set	Length	12600 ft
	Width	4200 ft
	Height	3000 ft
Shmin		5430 - 9280 psi
Stress Anisotropy		1%
Young's Modulus		1.38-6.12 Mpsi
Poisson's Ratio		0.1-0.43

Example of Pumping History Match

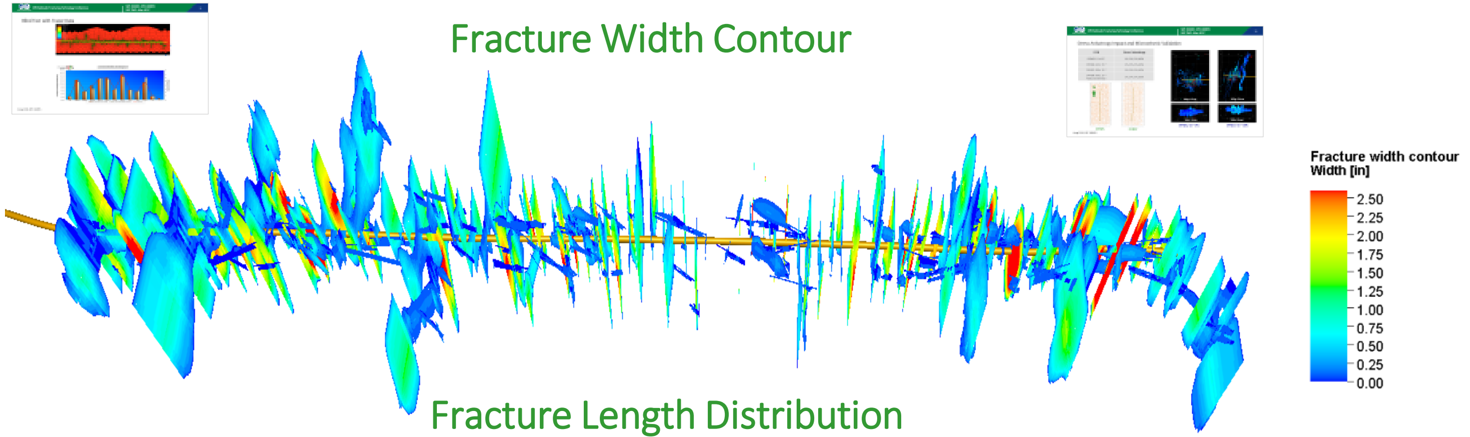


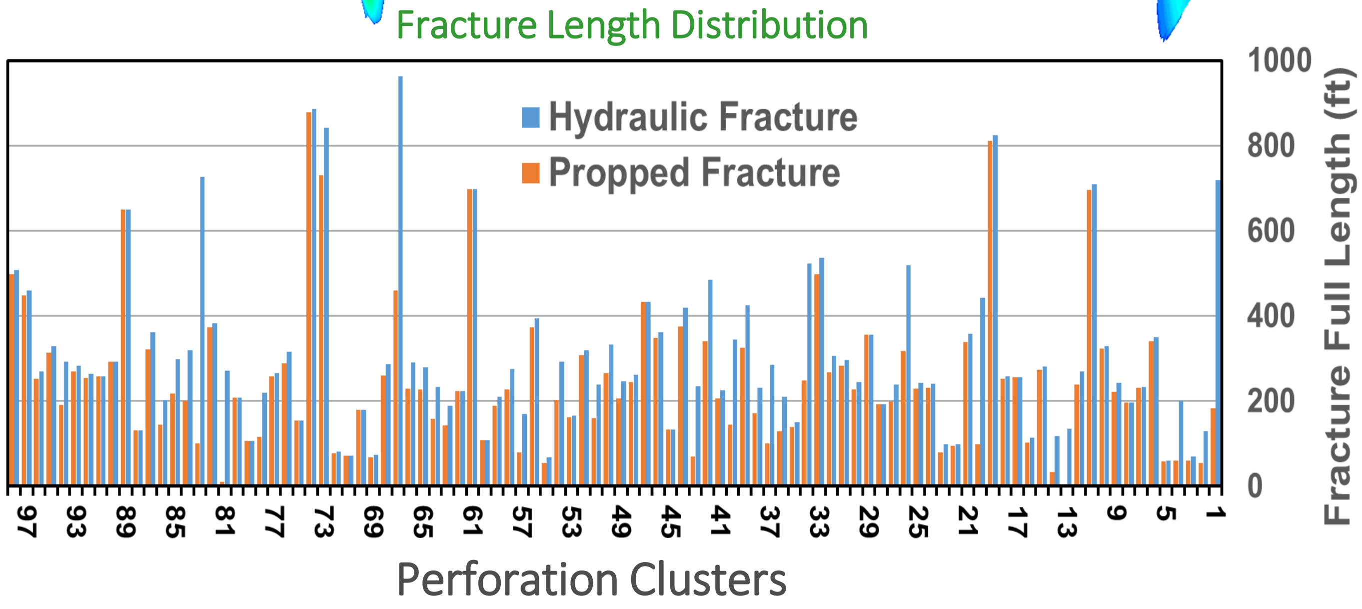




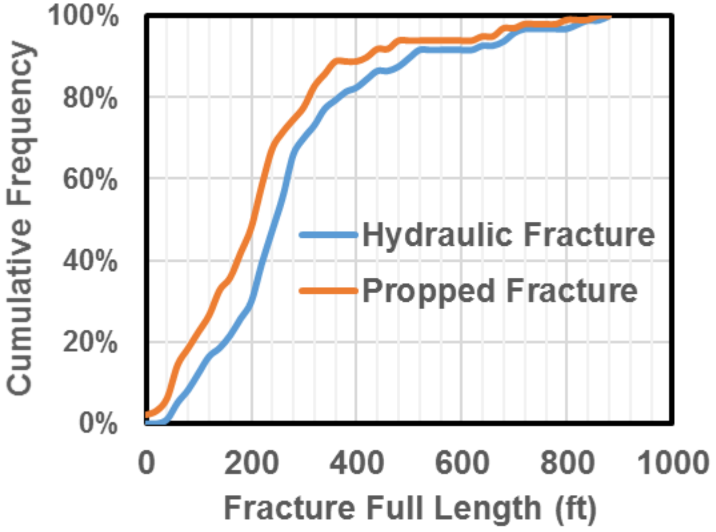


Non-Uniform Fractures Generated From Fracture Modeling (SPE 189855)

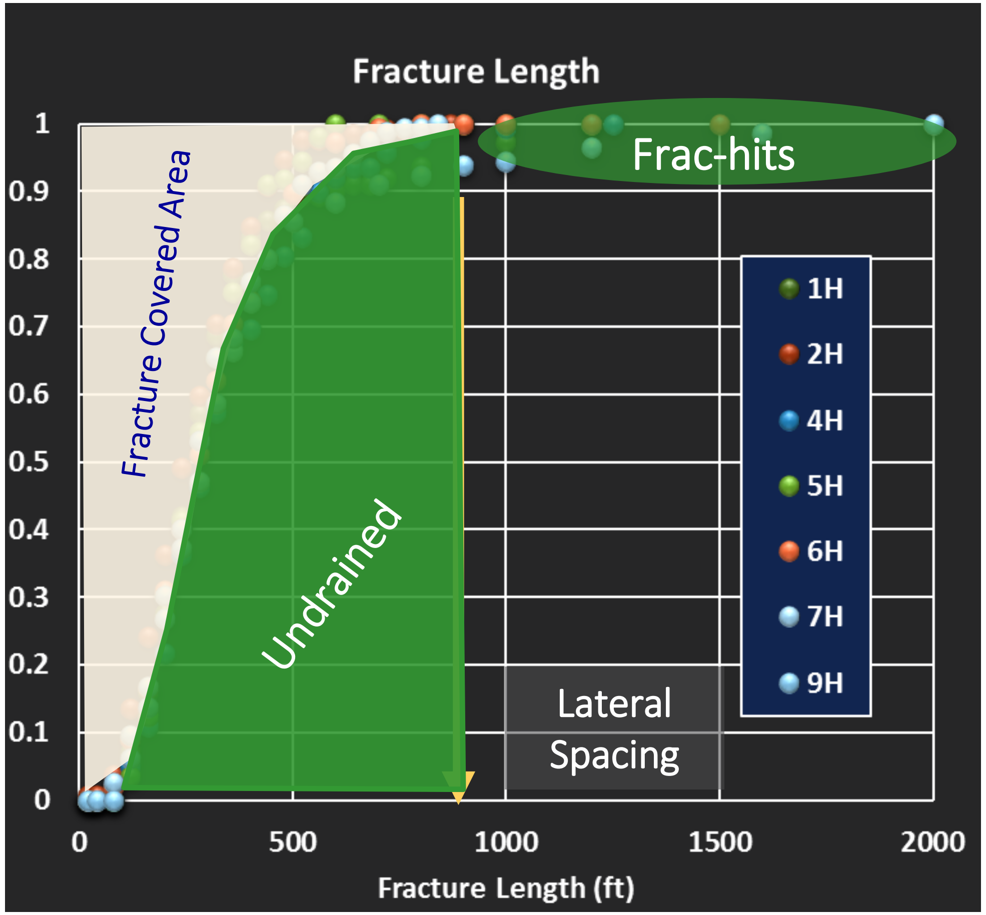


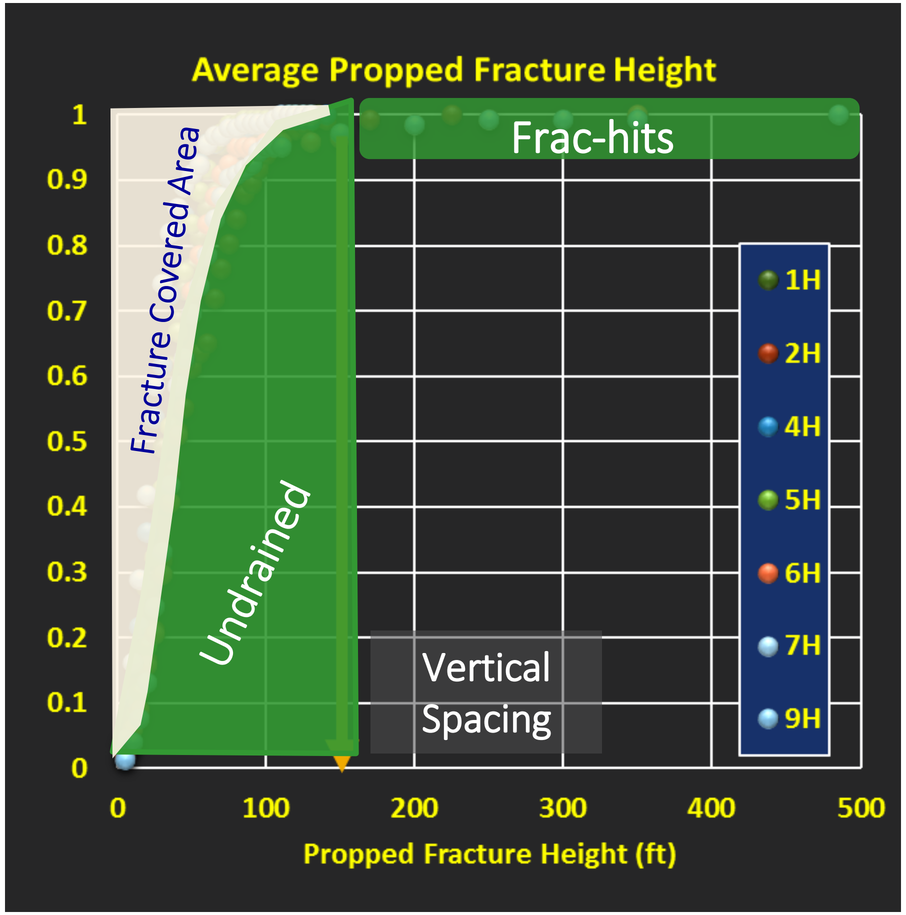


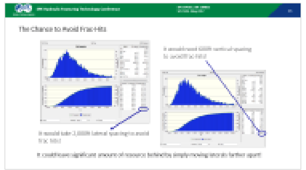
- 3D non-planar fractures with non-uniform length and height.
- P50 for full length of hydraulic and propped fracture: ~250 ft and ~200ft.



The Distributions of Fracture Length and Fracture Height







Completion Design Optimization

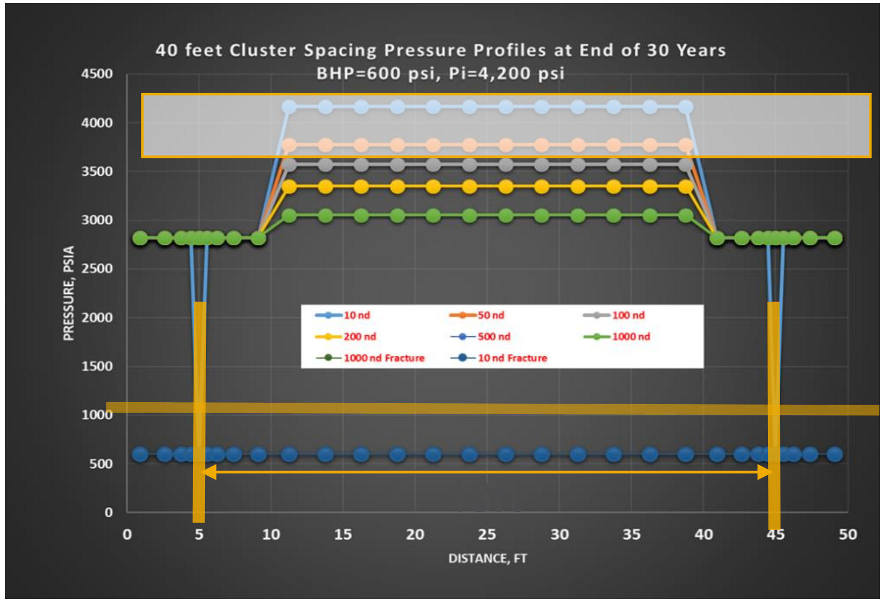
Principle of Optimizing Completion Designs

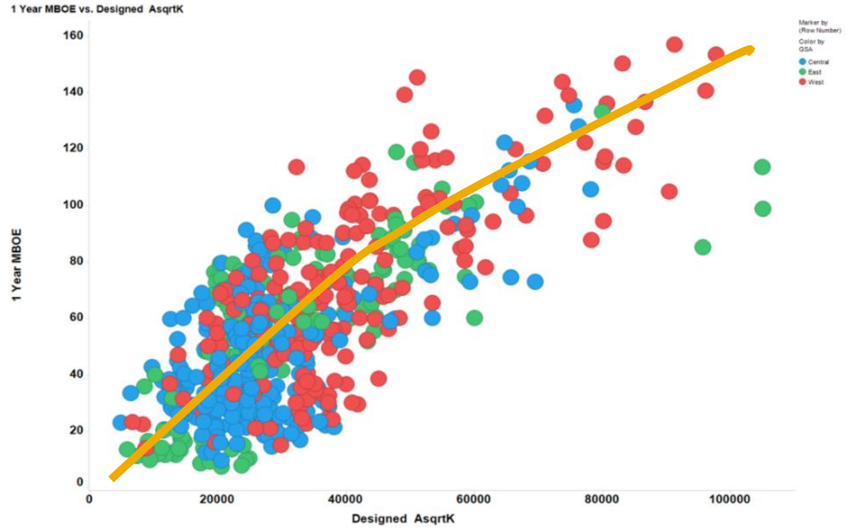
- Production is a function of fracture surface area
- The tighter fracture spacing may result in faster depletion and higher recovery efficiency
- Cost and operation risk impact the cluster spacing decision, and perforation design etc (spending less $ for gained more $$)

Completion

$$q \approx \sqrt{\frac{\emptyset C k_m}{\mu B^2}} * \boxed{A\sqrt{k}} * \Delta p * \frac{1}{\sqrt{t}}$$

$$\text{EUR} = \int f(Rqi, A, k)\Delta p dt$$



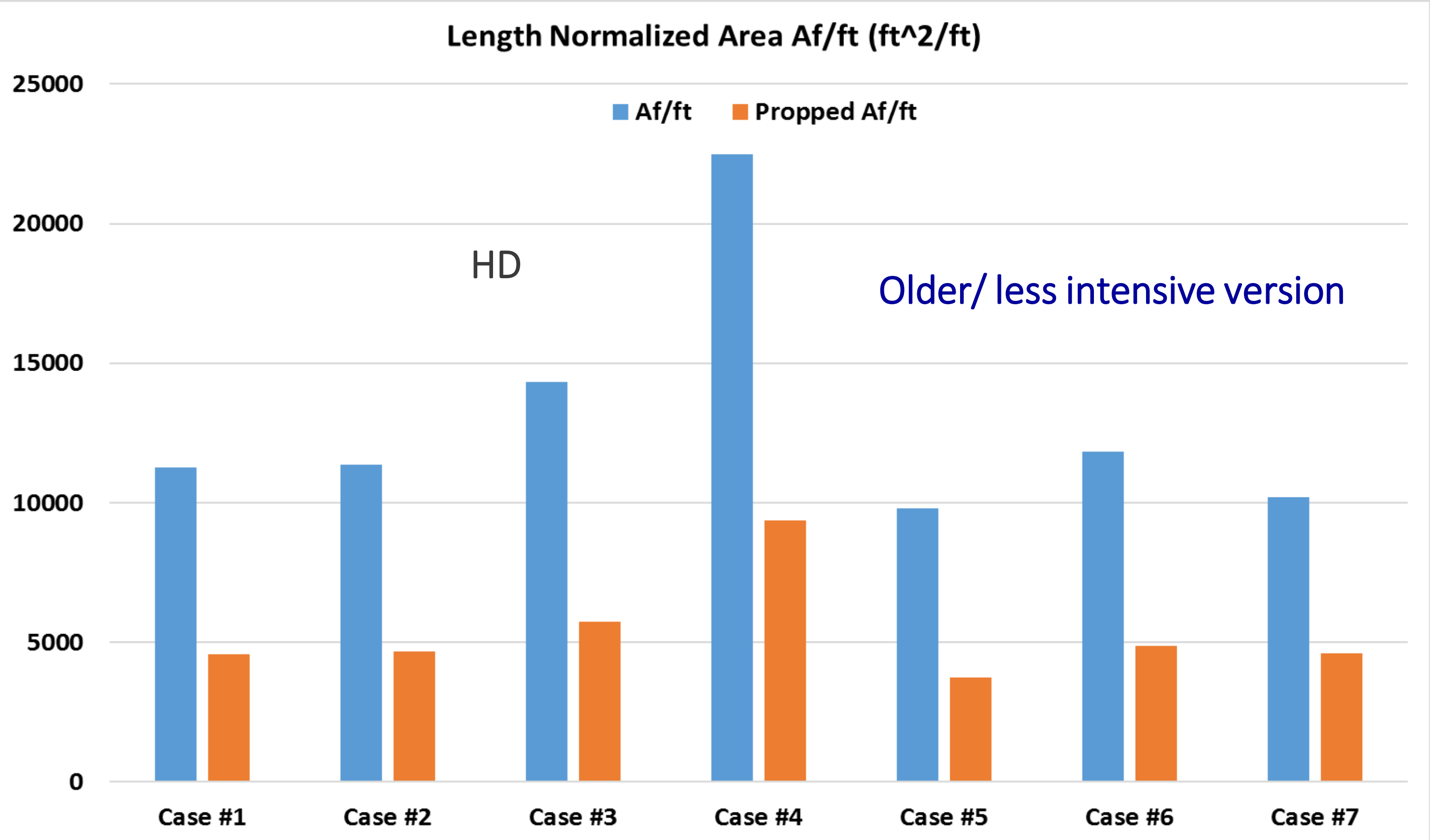


Optimize Completion Designs

Design Parameter	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7
Cluster spacing, ft	10	10	10	10	75	75	30
Clusters/Stage	10	10	5	5	3	3	5
Pumping rate/Cluster, bpm	6	12	12	12	20	20	12
Clean Fluid, bbl/ft	40	40	40	60	40	60	60
Proppant, lbm/ft	2000	2000	2000	3000	2000	3000	3000
Slick Water viscosity, cp	1.5	1.5	1.5	10	1.5	1.5	1.5

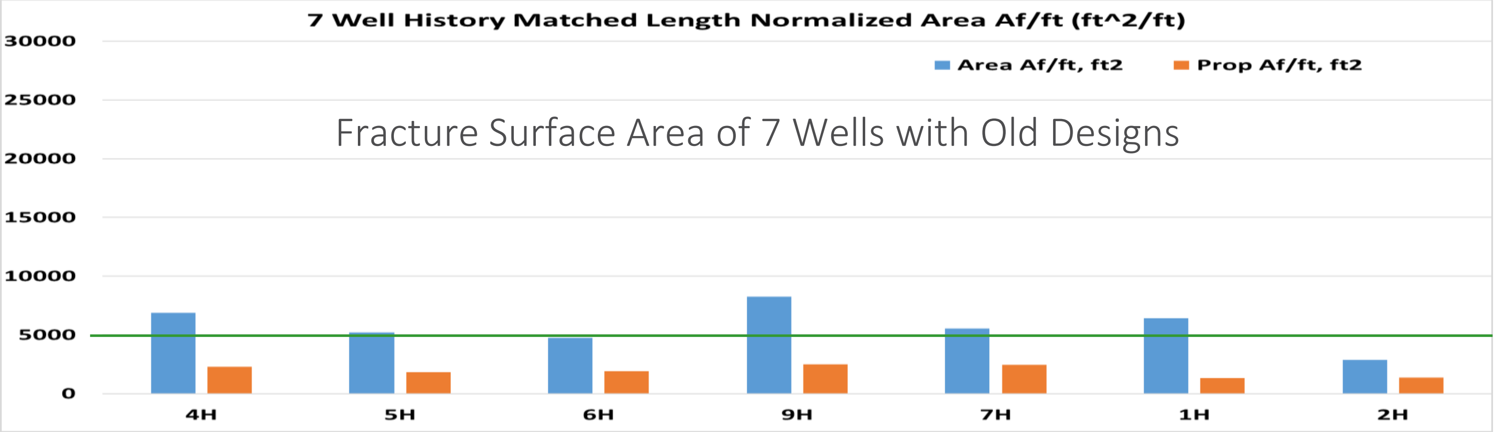
Normalized Fracture Surface Area

$$q \approx \sqrt{\frac{\emptyset C k_m}{\mu B^2}} * \boxed{A\sqrt{k}} * \Delta p * \frac{1}{\sqrt{t}}$$

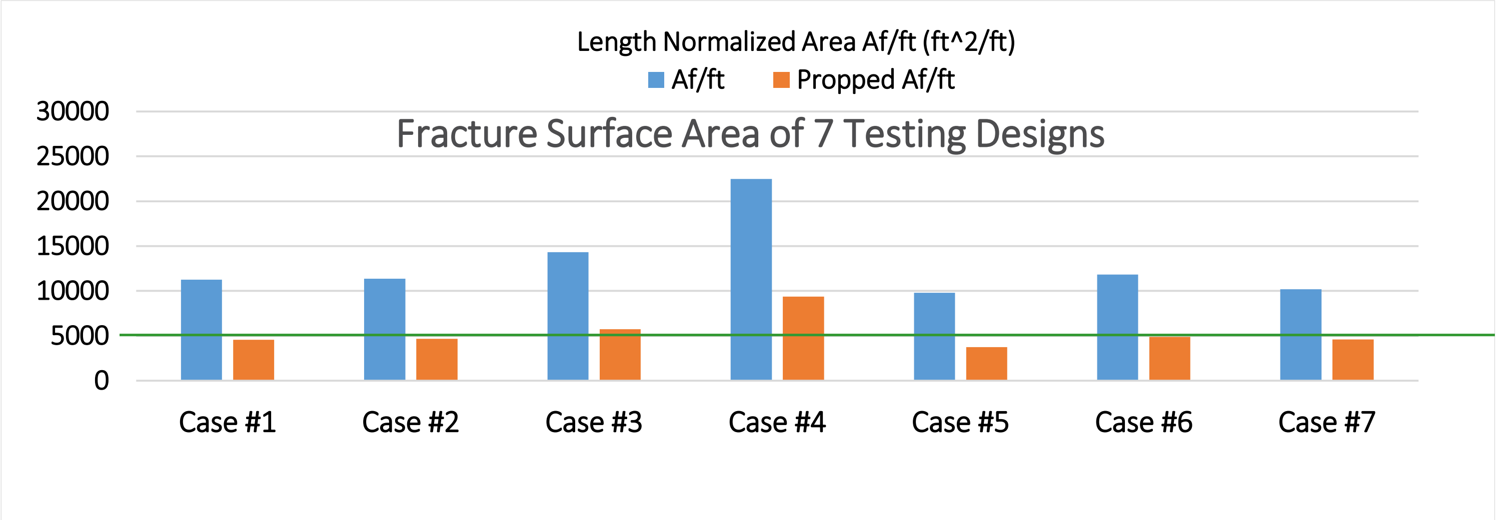


Cluster spacing, ft	10	10	10	10	75	75	30
Clusters/Stage	10	10	5	5	3	3	5
Clean Fluid, bbl/ft	40	40	40	60	40	60	60
Proppant, lbm/ft	2000	2000	2000	3000	2000	3000	3000

Normalized Fracture Surface Area of Those 7 Wells



Fracture Surface Area of 7 Wells with Old Designs



Fracture Surface Area of 7 Testing Designs

Older version of completion designs resulted in very small fracture surface area

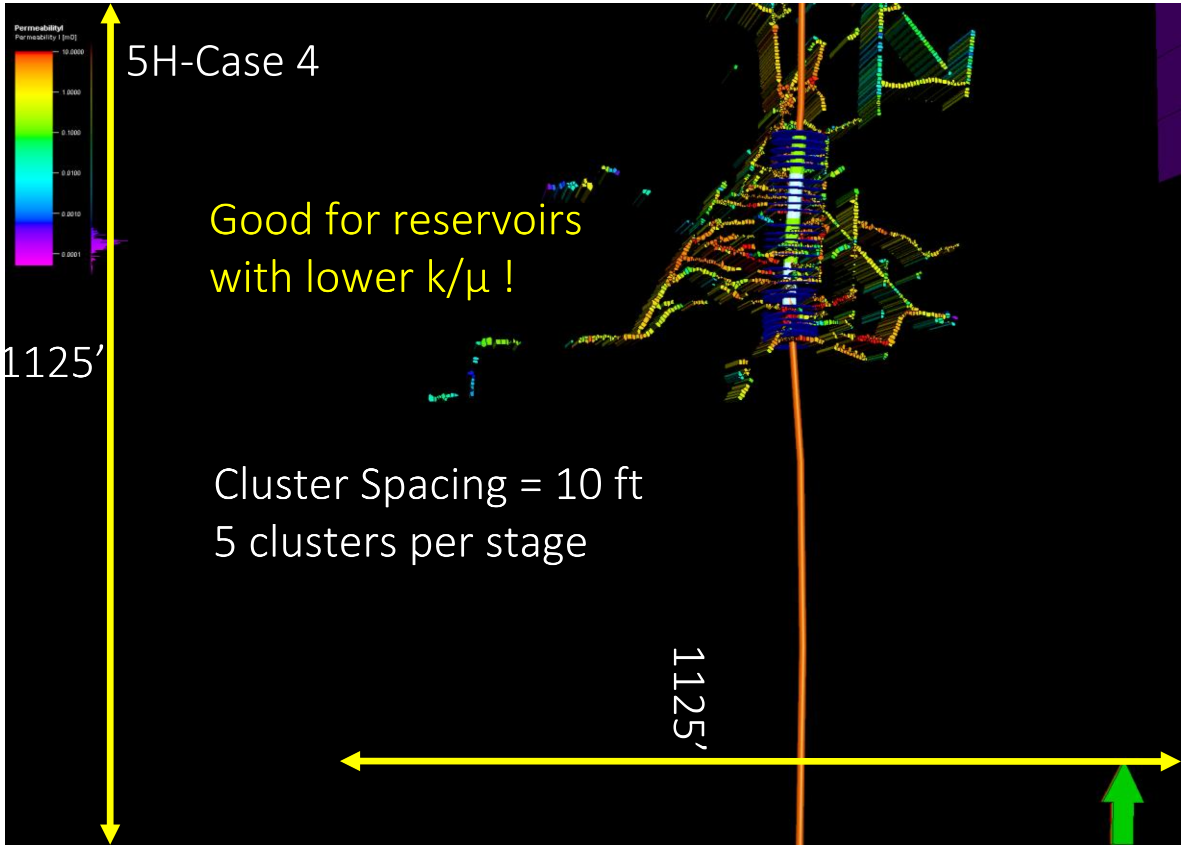
Historical Designs

Well	Cluster Spacing (ft)	Fluid (bbl/ft)	Proppant (lbm/ft)
4H	60	26	1060
5H	60	26	1055
6H	60	27	1110
9H	60	29	1100
7H	60	27	1121
1H	75	40	1044
2H	60	19	996

Testing Designs

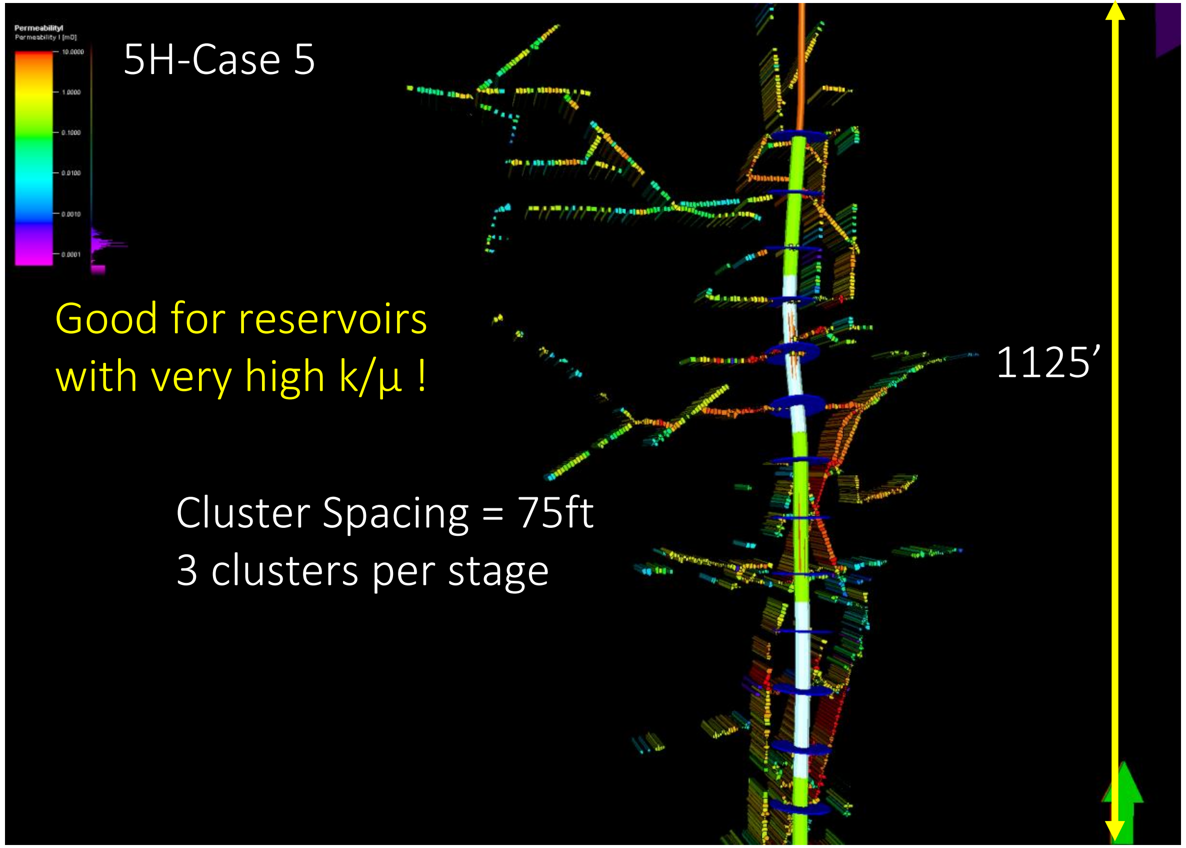
Case	Cluster spacing (ft)	Fluid (bbl/ft)	Proppant (lbm/ft)
1	10	40	2000
2	10	40	2000
3	10	40	2000
4	10	60	3000
5	75	40	2000
6	75	60	3000
7	30	60	3000

HD Completion Enhances Completion Effectiveness *(results from a 5-stage completion example)*



Good for reservoirs with lower k/μ !

Cluster Spacing = 10 ft
5 clusters per stage

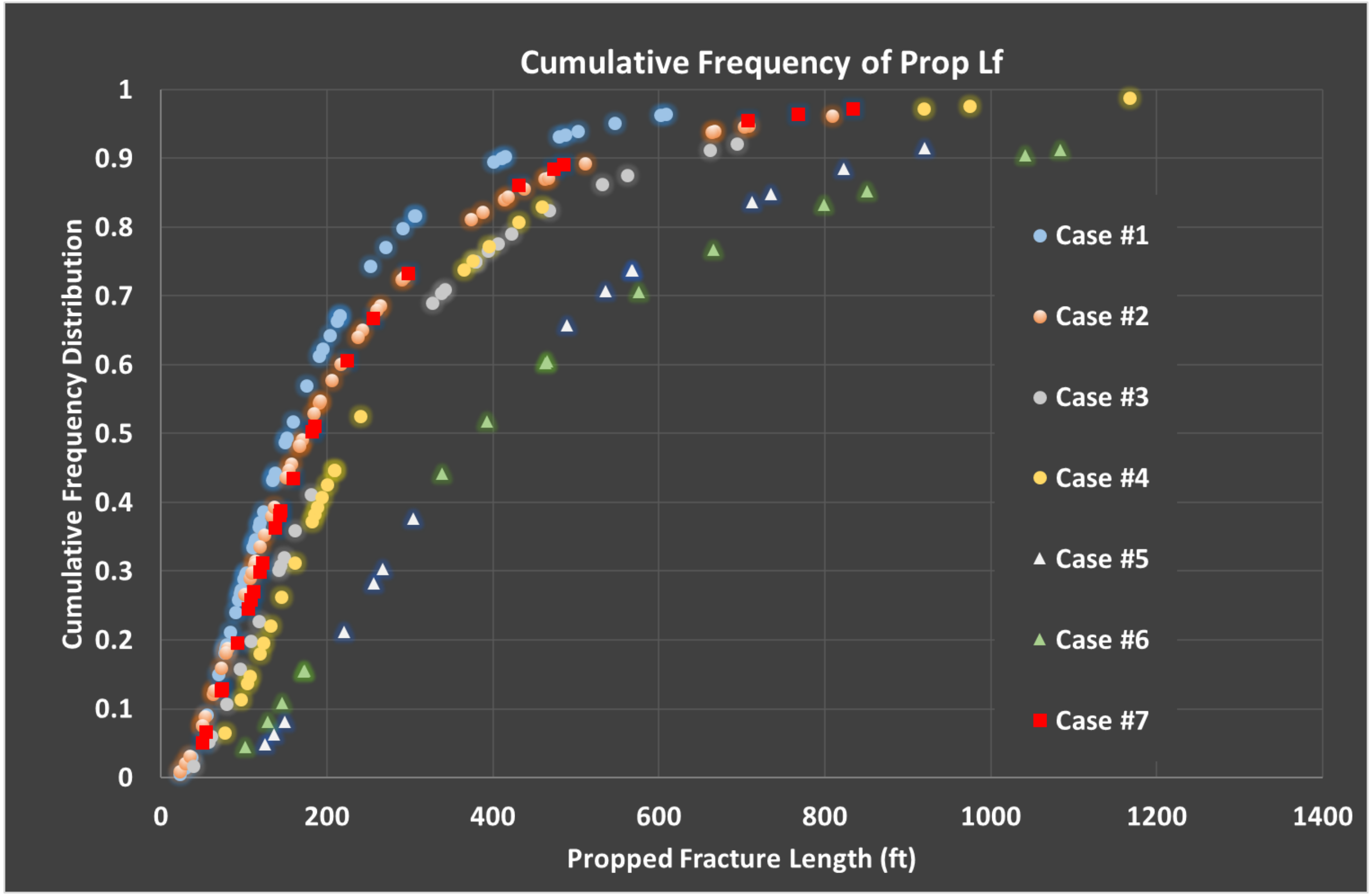


Good for reservoirs with very high k/μ !

Cluster Spacing = 75ft
3 clusters per stage

- The fracture network generated from the wide cluster spacing (75 ft – Case 5) is sparely spread along the wellbore, which results in much less fracture surface area per unit wellbore length
- Comparing to Design Case 5, Design Case 4 would create 2.5 times of more fracture surface area, which would significantly improve produce rate q=f($A\sqrt{k}$)

Fracture Length Distributions of Different Completion Designs



- It seems that the wide cluster spacing (75’ in Cases 5-6) resulted in more heterogeneous fracture dimensions

Case	Cluster Spacing, Ft	Clusters/Stage
1	10	10
2	10	10
3	10	5
4	10	5
5	75	3
6	75	3
7	30	5

Conclusions

- The effective fracture spacing is critical to well performance and full field development economics;
    - Tighter fracture spacing may yield more fracture surface area for higher prod rate
    - Tighter fracture spacing will speed up depletion for faster economic return
- Field data indicate that the wells with tighter cluster spacings outperform the wells with wider cluster spacings;
- Completion designs in the unconventional reservoirs can be optimized by complex fracturing modeling with the calibrated geological models, which is cheaper and faster than the field trials or well pilot tests;
- For the given formation of Wolfcamp in the Southern Midland Basin, tighter cluster spacing with less clusters per stage may create larger fracture surface area with high fluid and proppant intensity, which ought to increase the initial production rate and the ultimate recovery; and
- Frac-hit and some hydraulic communications between horizontal wellbores are expected because of the heterogeneities of formation properties and hydraulic fracturing propagation. Optimizing well completion designs may mitigate the frac-hits.

Q&A

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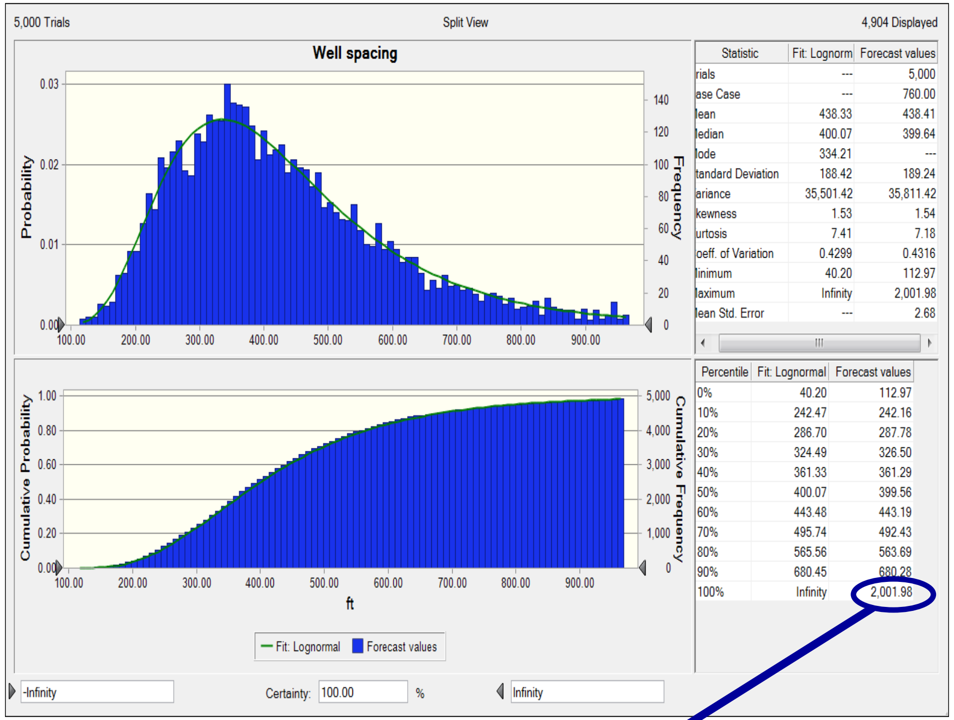
The Chance to Avoid Frac-Hits

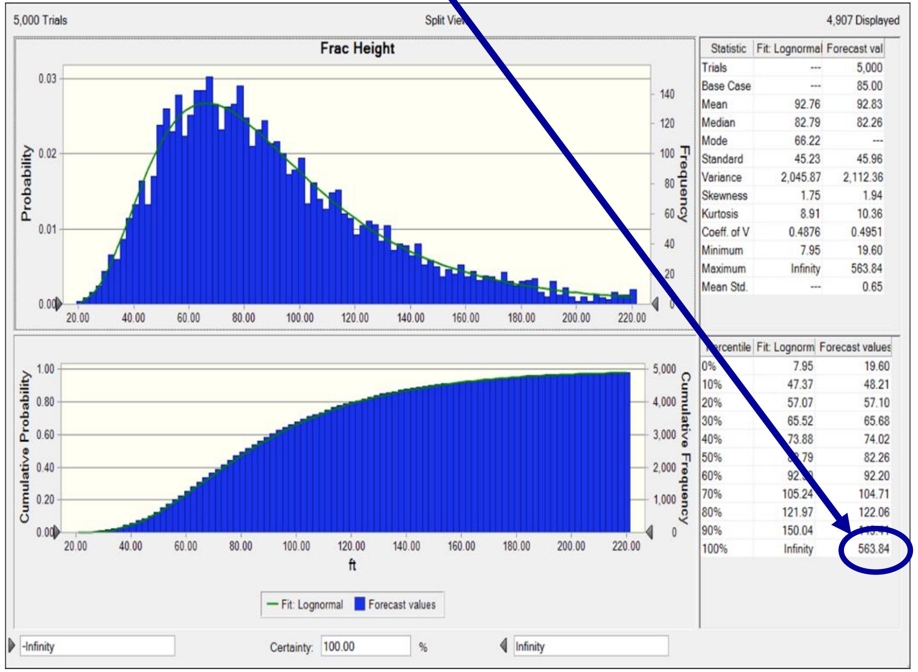


Statistic	Fit: Lognorm	Forecast values
rials	---	5,000
ase Case	---	760.00
lean	438.33	438.41
ledian	400.07	399.64
lode	334.21	---
tandard Deviation	188.42	189.24
ariance	35,501.42	35,811.42
kewness	1.53	1.54
urtosis	7.41	7.18
oeff. of Variation	0.4299	0.4316
linimum	40.20	112.97
laximum	Infinity	2,001.98
lean Std. Error	---	2.68

Percentile	Fit: Lognormal	Forecast values
0%	40.20	112.97
10%	242.47	242.16
20%	286.70	287.78
30%	324.49	326.50
40%	361.33	361.29
50%	400.07	399.56
60%	443.48	443.19
70%	495.74	492.43
80%	565.56	563.69
90%	680.45	680.28
100%	Infinity	2,001.98

It would take 2,000ft lateral spacing to avoid frac hits!

It would need 600ft vertical spacing to avoid frac-hits!

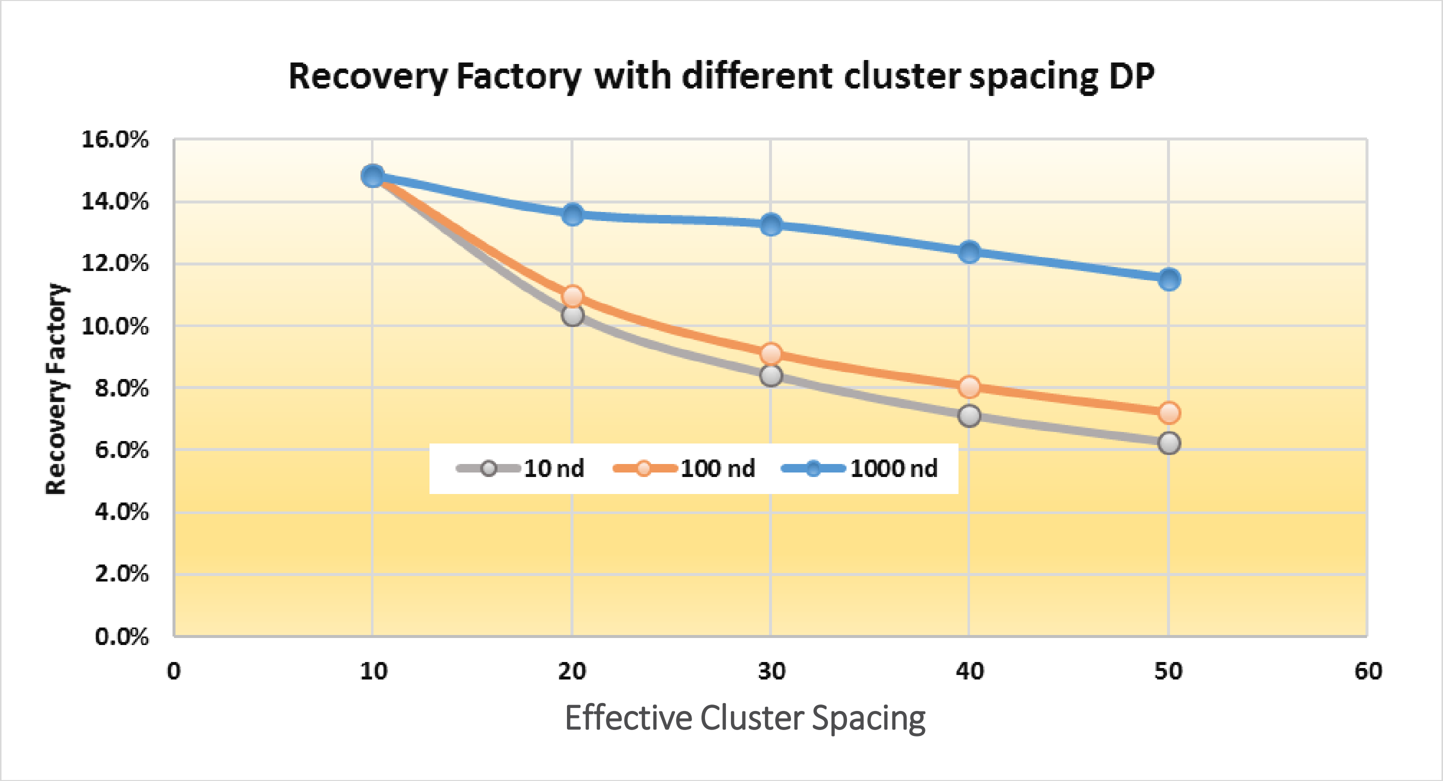


Statistic	Fit: Lognormal	Forecast val
Trials	---	5,000
Base Case	---	85.00
Mean	92.76	92.83
Median	82.79	82.26
Mode	66.22	---
Standard	45.23	45.96
Variance	2,045.87	2,112.36
Skewness	1.75	1.94
Kurtosis	8.91	10.36
Coeff. of V	0.4876	0.4951
Minimum	7.95	19.60
Maximum	Infinity	563.84
Mean Std.	---	0.65

Percentile	Fit: Lognorm	Forecast values
0%	7.95	19.60
10%	47.37	48.21
20%	57.07	57.10
30%	65.52	65.68
40%	73.88	74.02
50%	82.79	82.26
60%	92.[illegible]	92.20
70%	105.24	104.71
80%	121.97	122.06
90%	150.04	[illegible]
100%	Infinity	563.84

It could leave significant amount of resource behind by simply moving laterals farther apart!

Dual Porosity Modeling Indicates Low Recovery Efficiency

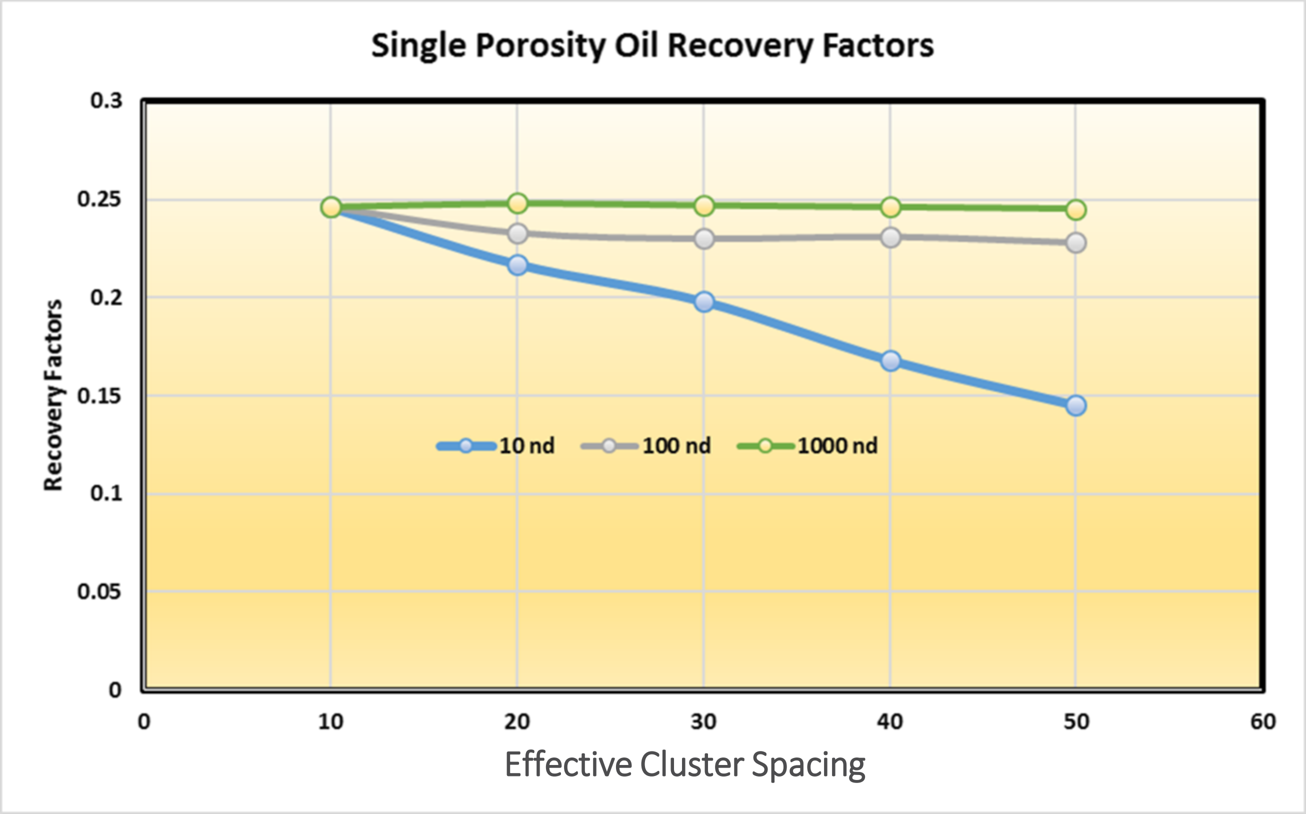


Recovery efficiency depends on the cluster/fracture spacing - tighter effective cluster/fracture spacing increase recovery efficiency!

Cluster Spacing Optimization (Hongjie Xiong)

Xiong 2017, SPE TWA

Single Porosity Modeling Indicates High Recovery Efficiency



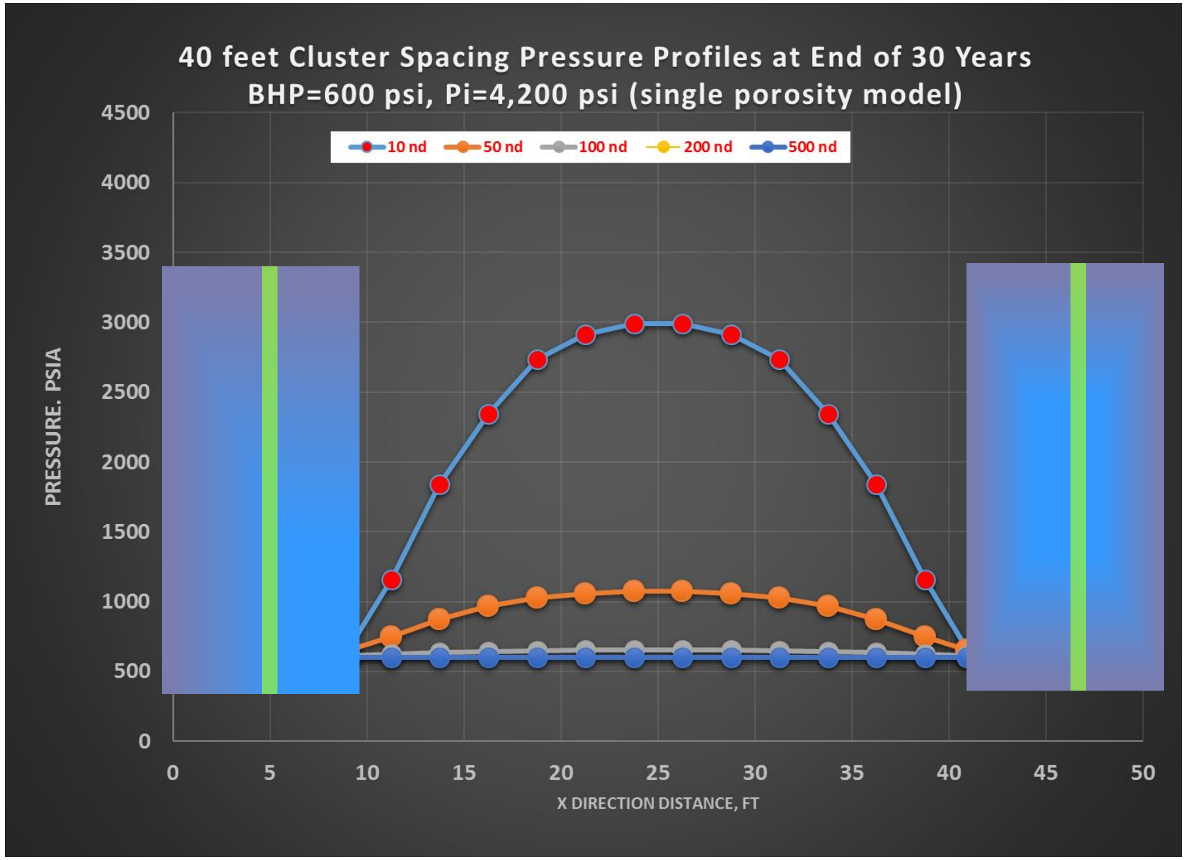
Recovery efficiency depends on the cluster/fracture spacing - tighter effective cluster/fracture spacing increase recovery efficiency!

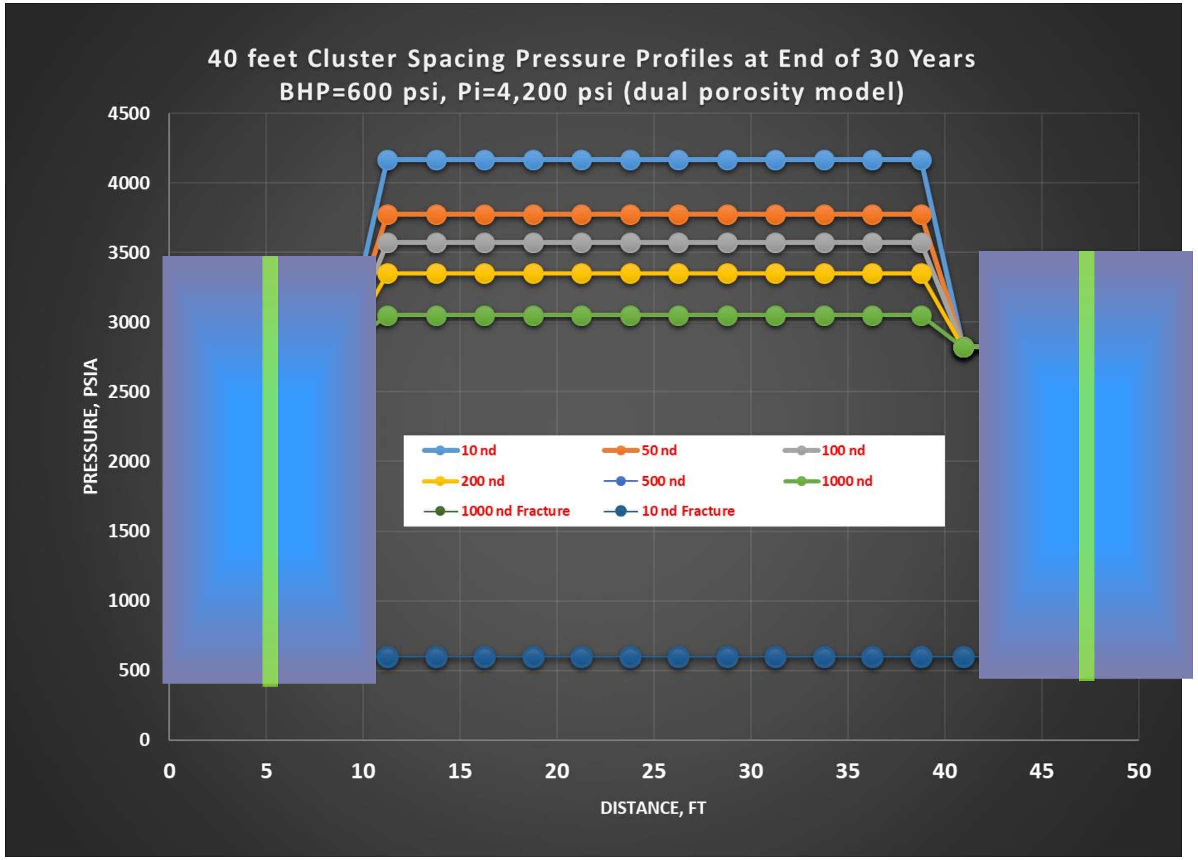
Cluster Spacing Optimization (Hongjie Xiong)

Xiong 2017, SPE TWA

Single Porosity Modeling Indicates Significant Pressure Depletion inside Matrix Blocks, which seems not suitable based upon well performance data

Dual Porosity Modeling Indicates Little Pressure Depletion within Matrix Blocks





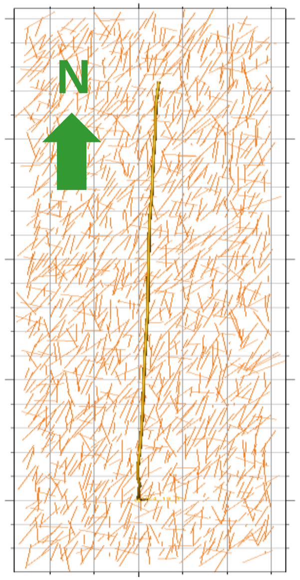
Single Porosity Modeling may probably not be suitable!

Dual Porosity Modeling may be more suitable!

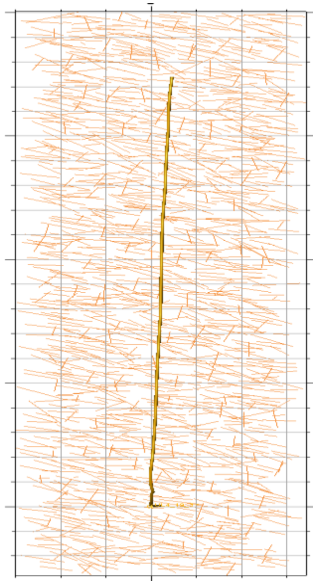
Xiong 2017, SPE TWA

Stress Anisotropy Impact and Microseismic Validation

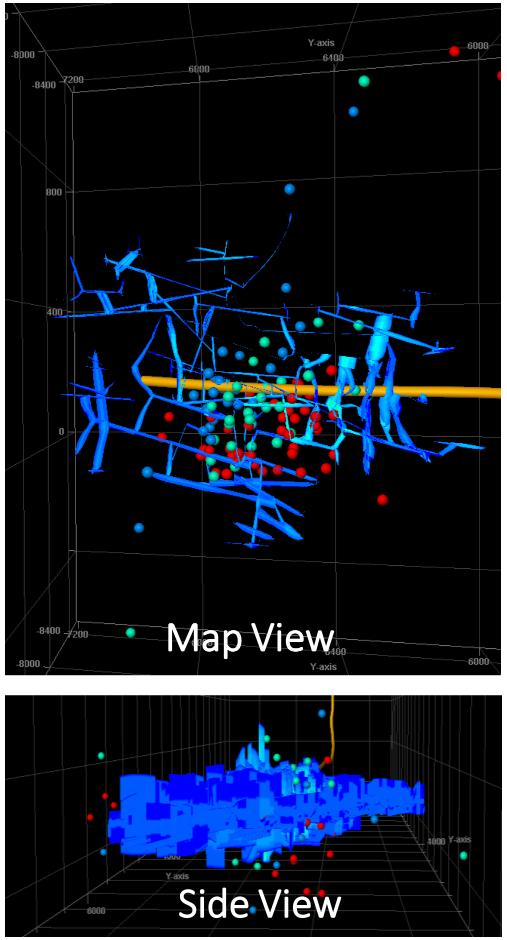
DFN	Stress Anisotropy
DFN05: 0 ± 15 °	1%, 3%, 5%,10%
DFN06: 45 ± 15 °	1%, 3%, 5%,10%
DFN07: 90 ± 15 °	1%, 3%, 5%,10%
DFN08: 90 ± 15 ° Reduced Density	1%, 3%, 5%,10%



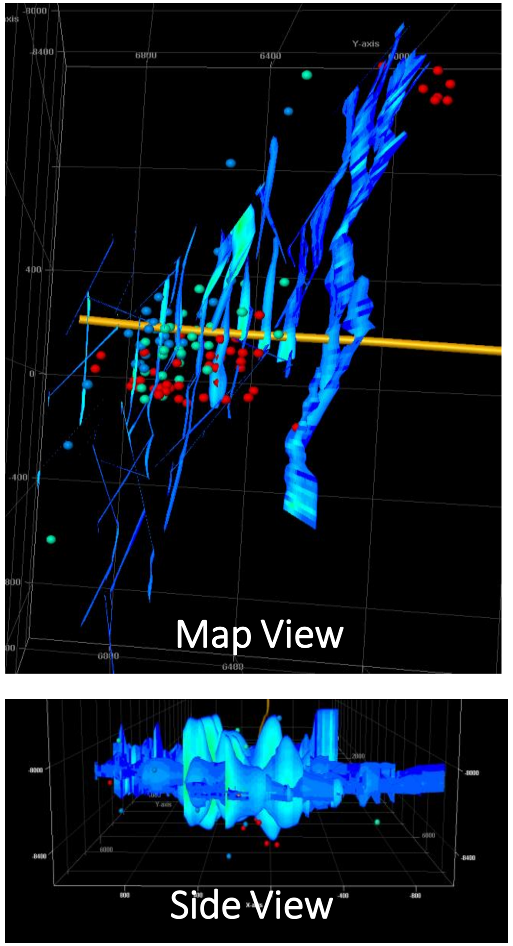
DFN05



DFN07



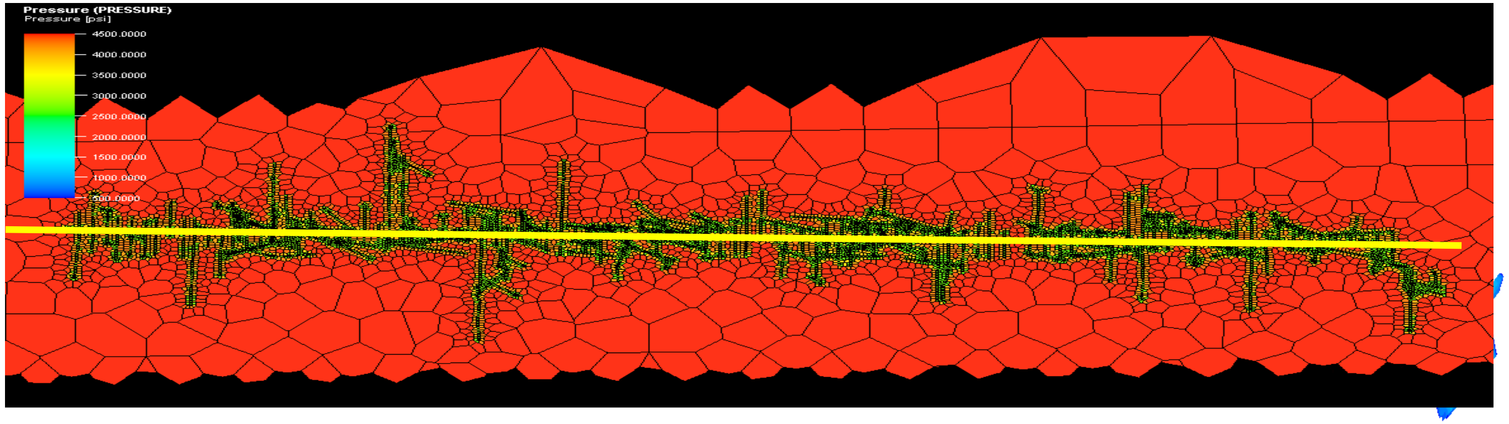
DFN05, SA =1%

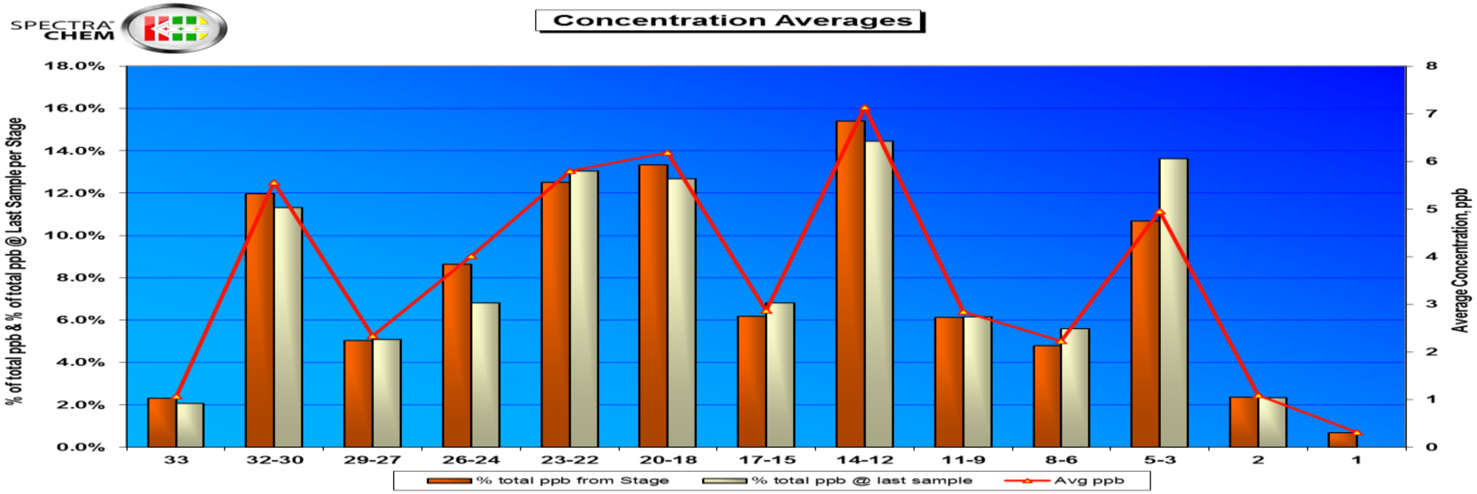


DFN07, SA =10%

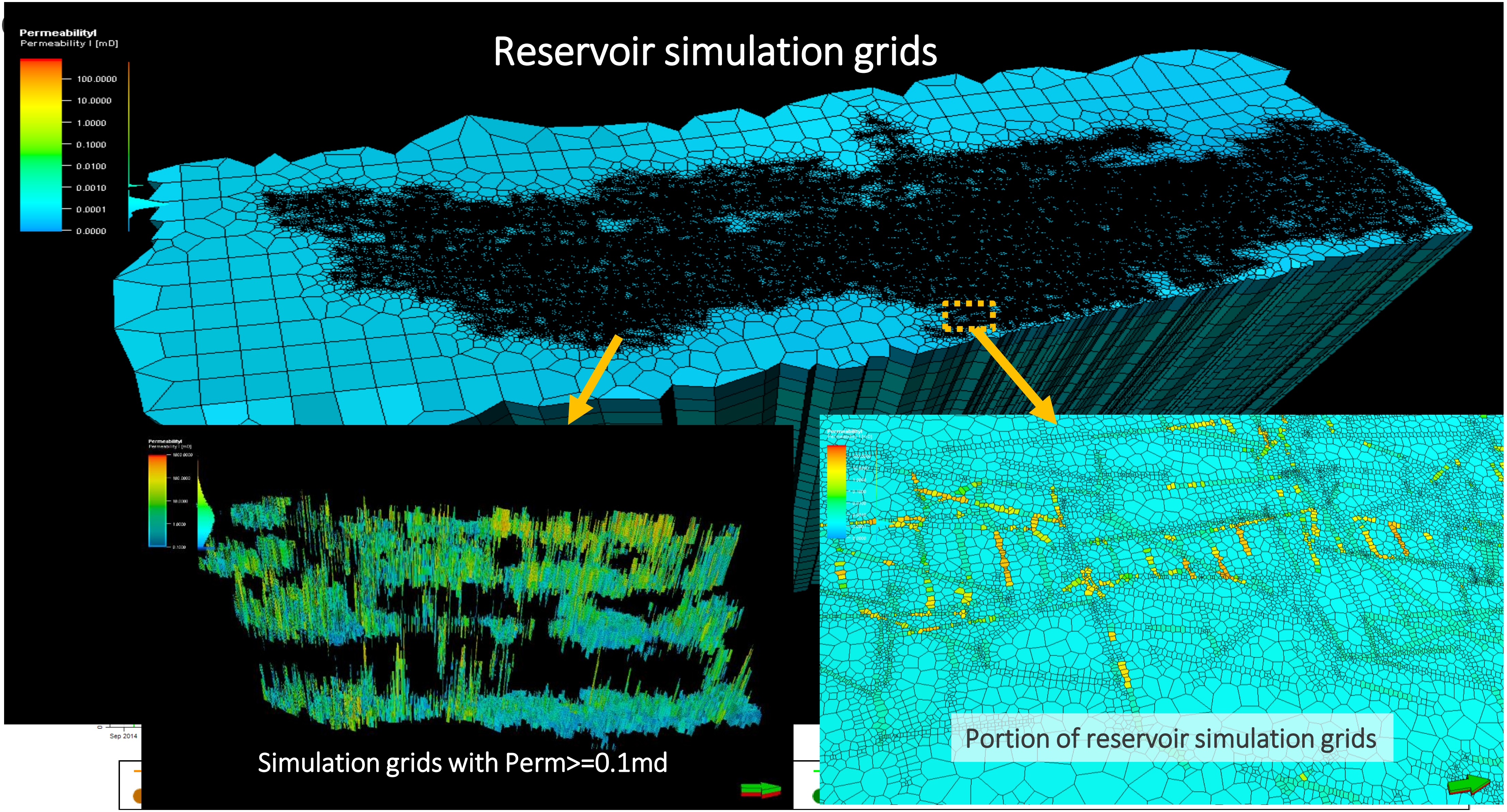
Xiong 2018, SPE 189855

Blind Test with Tracer Data





Xiong 2018, SPE 189855



Reservoir simulation grids

Simulation grids with Perm>=0.1md

Portion of reservoir simulation grids