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Optimizing Well Completion Design and Well Spacing with Integration of Advanced Multi-Stage Fracture Modeling & Reservoir Simulation

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Overview

- Introduction – the status of the art
- Objectives
- Case History 1 – Single Well
  - Workflow
  - Complex fracture network modeling
  - Reservoir performance modeling
  - Blind tests on the calibrated models
  - Optimize well completion design with the calibrated models
  - Determine well spacing with the calibrated models
- Case History 2 – Multiple Wells
  - Workflow and modeling results
- Conclusions

2016-18 TOGI Subsurface Projects

Wellbore Orientation Study
Integration of Geomechanics and Well Performance

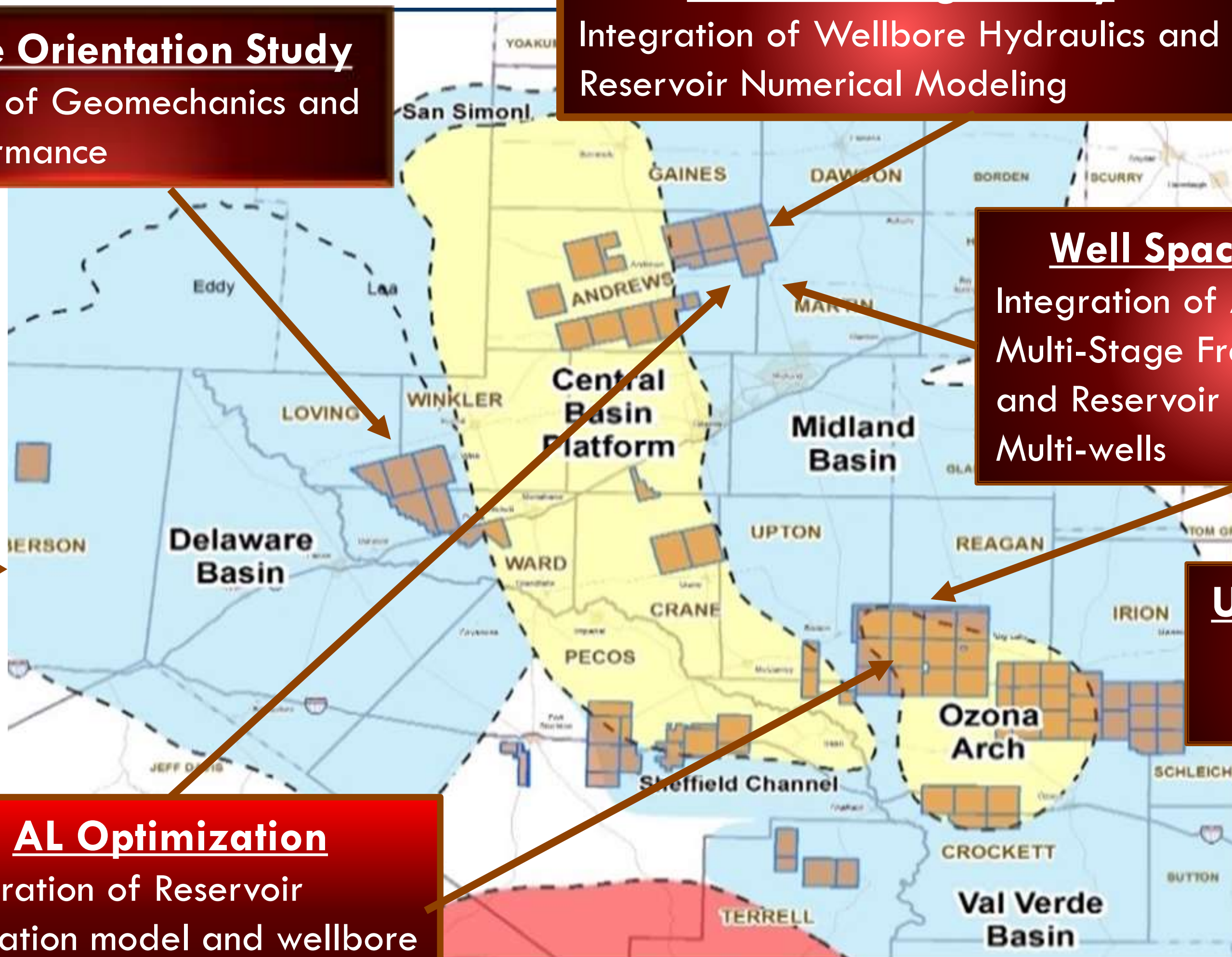
Wellbore Length Study
Integration of Wellbore Hydraulics and Reservoir Numerical Modeling

Well Spacing Studies
Integration of Advanced Multi-Stage Fracture Modeling and Reservoir Simulation of Multi-wells

Geology Study

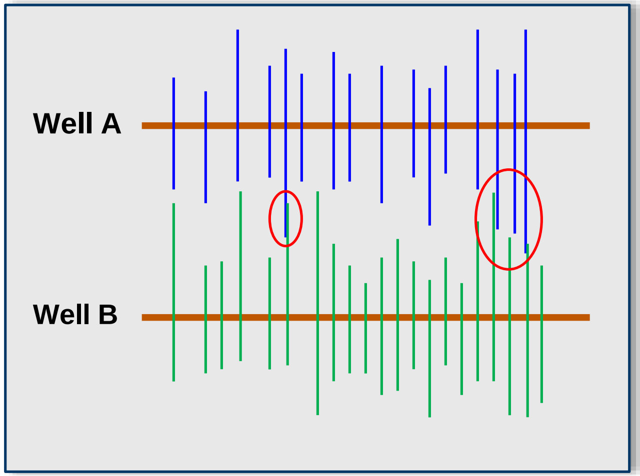
Underperformer Diagnosis

AL Optimization
Integration of Reservoir simulation model and wellbore hydraulics model

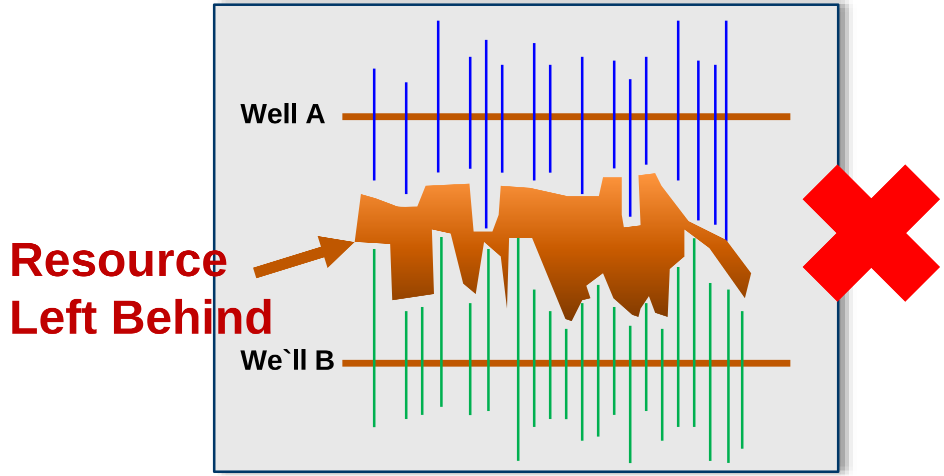


Resource Assessment

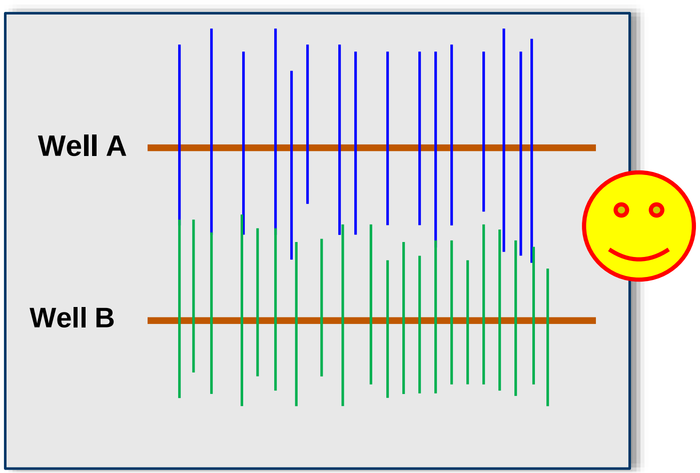
Well Spacing Is Critical in Unconventional Reservoir Development



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



Case B (Wider Spacing – Leave MORE Recourses Behind)



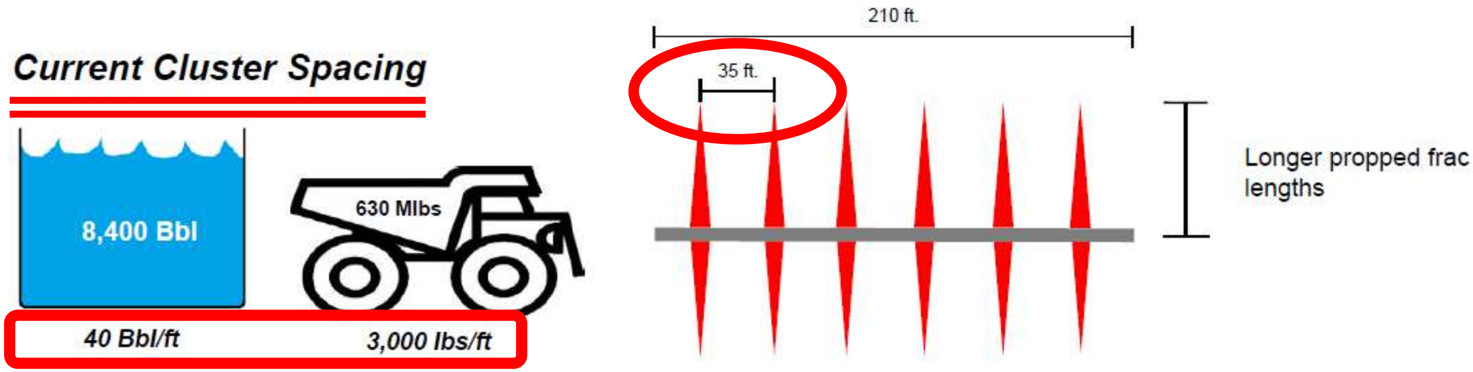
Case C (Optimal Spacing with Optimal Completion)

- Wells do not drain much farther beyond hydraulic fractures. Thus, the fracture length decides the well spacing
- Fracture Spacing/Cluster efficiency is the key to maximize Initial rate and EUR. The industry spends huge resource (time and money) on many pilot tests!

- Fracture geometry is complicated and depends on
  - Pressure conditions
  - Rock mechanical properties
  - DFN
  - Fracturing treatments
  - ….

Completion Optimization Advances with Numerous Times of Trying (version 1, version 2, … version 4.x)

Latest Design Change – Reduction in Perf Cluster Spacing



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

Could complex fracture modeling speed up the well completion optimization ?!

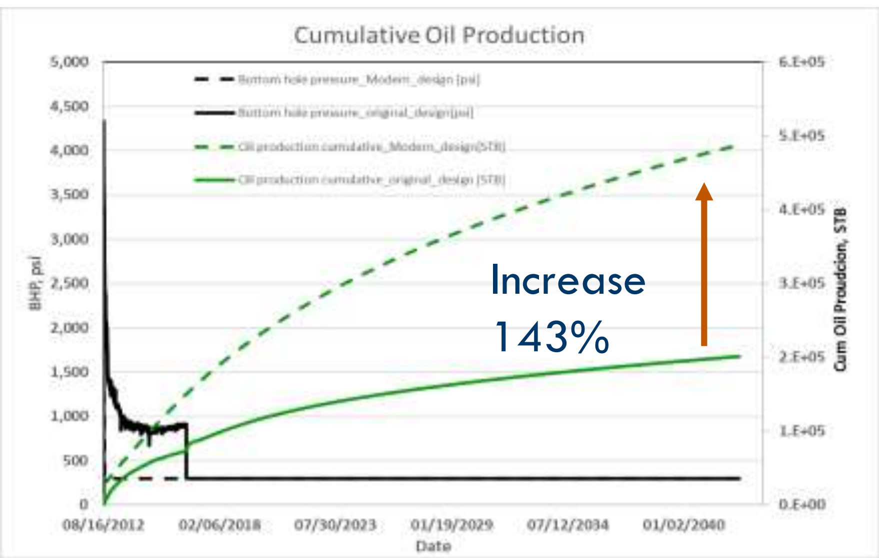
Objectives

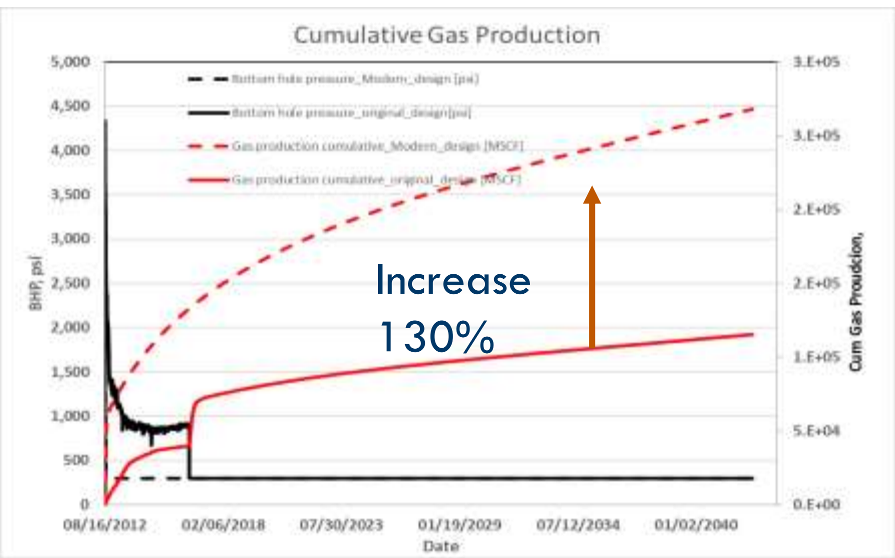
- *Can we use the latest modeling technologies to speedup the process to optimize well completion and well spacing, instead of spending hundreds of millions dollars and waiting for years?*

- Assess and apply the latest multi-stage hydraulic fracturing modeling technologies to
  - Optimize well completion design
  - Investigate well performance
  - Optimize well spacing

Take Away Message: Yes, We Can!

- For the two case studies on those wells located in the Permian Basin, we built and calibrated complex fracturing models with its pumping history data, and reservoir performance models with the production history;
- Blind tests indicate that the models are robust; and
- The models can be used to optimize well completion design and well spacing

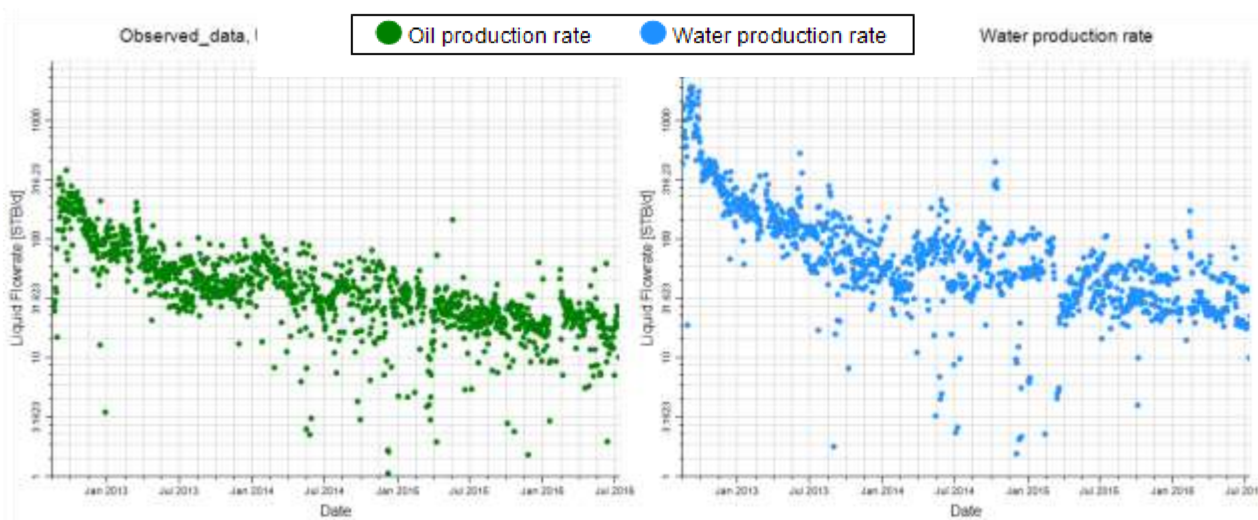




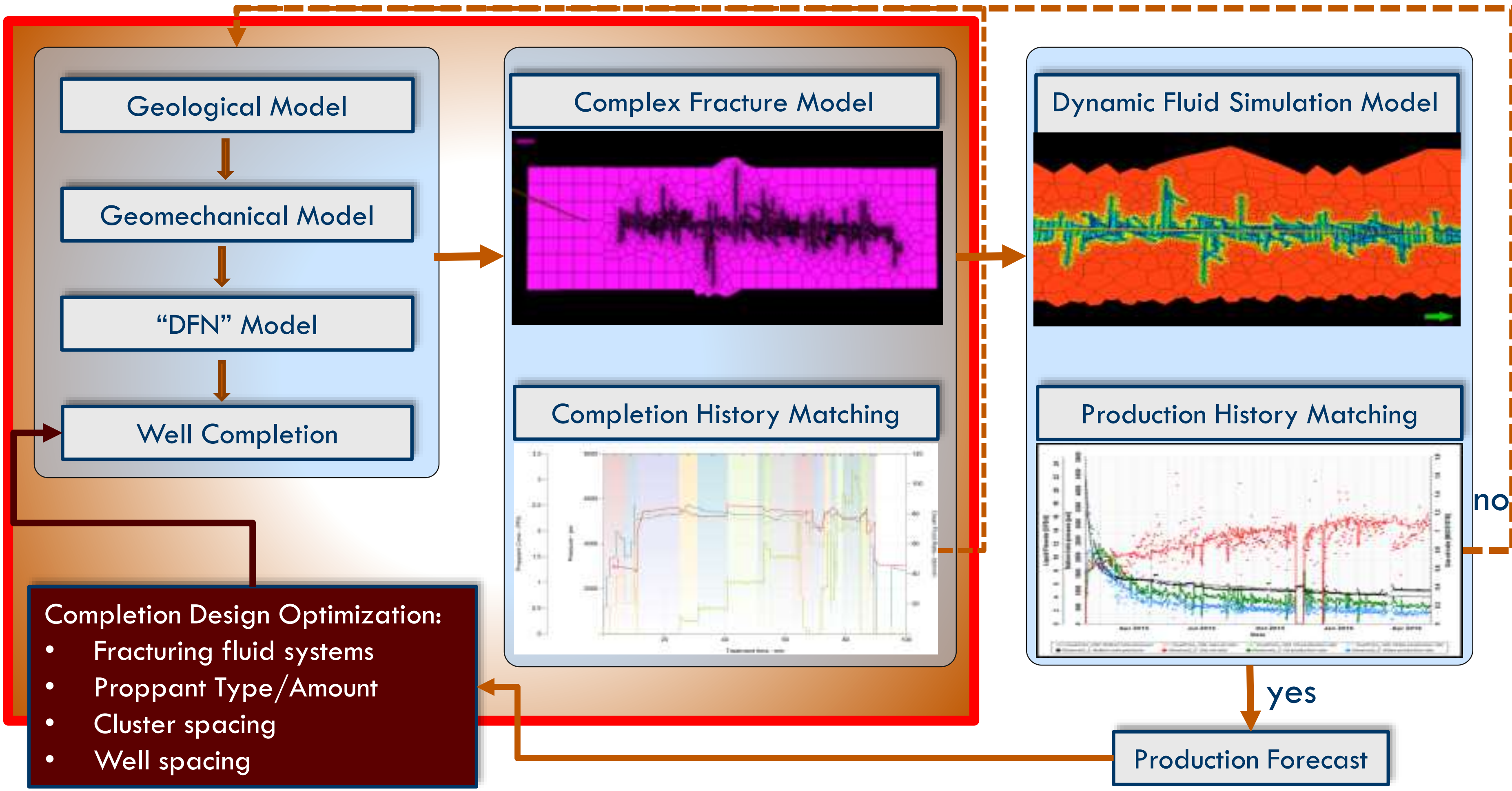
Case History 1 - Single Well Study

- HZ Well completed in WC, Upton county
- Completed and started producing in 2012
- Oil production from 200 ~ 300 bbl/day → 20 ~ 40 bbl/day

Completions	
Lateral length	About 6,000 ft
Number of Stages	33
Number of Clusters	98 clusters, 3/stage
Cluster Spacing	60 ft
Perforations/cluster	13/cluster
Proppant Type	RCS Brown 30/50
Fracturing Fluids	linear gel, crosslinked gel
Clean Fluid Amount	32.5 bbl/ft
Proppant Amount	1150 lb/ft



Integration of Multi-stage Fracturing and Well Performance Simulation - Workflow



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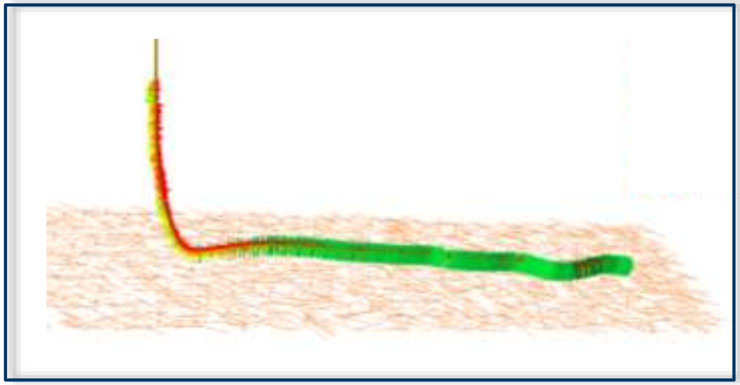
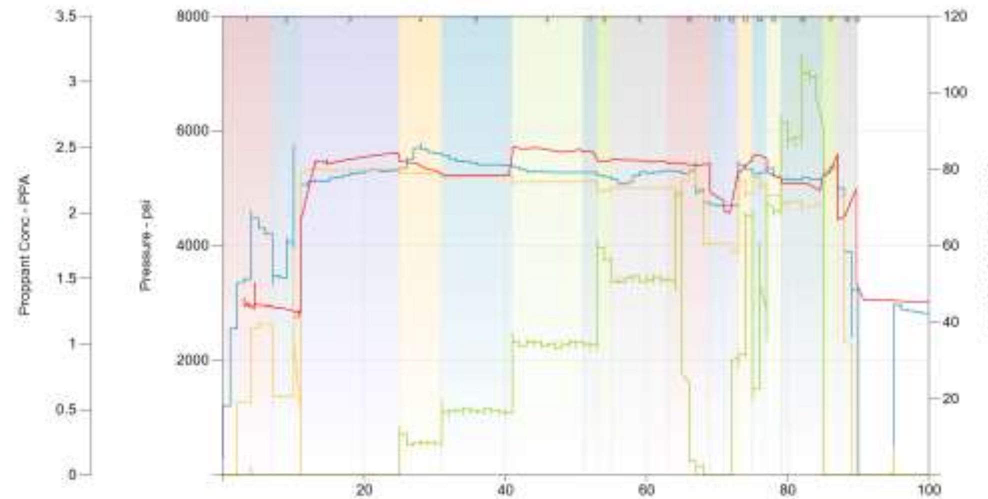
Calibrate Fracturing Models with Treating Pressure and Pumping History

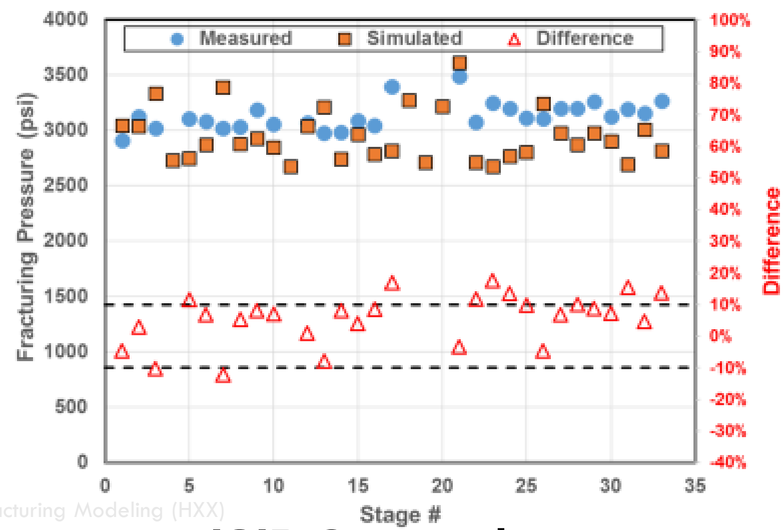


Geomodel with the wellbore



Fracturing Pumping HM Example

- History match treating pressure for each stage
- Simulated and measured pressure are within ± 10% for most stages.



ISIP Comparison

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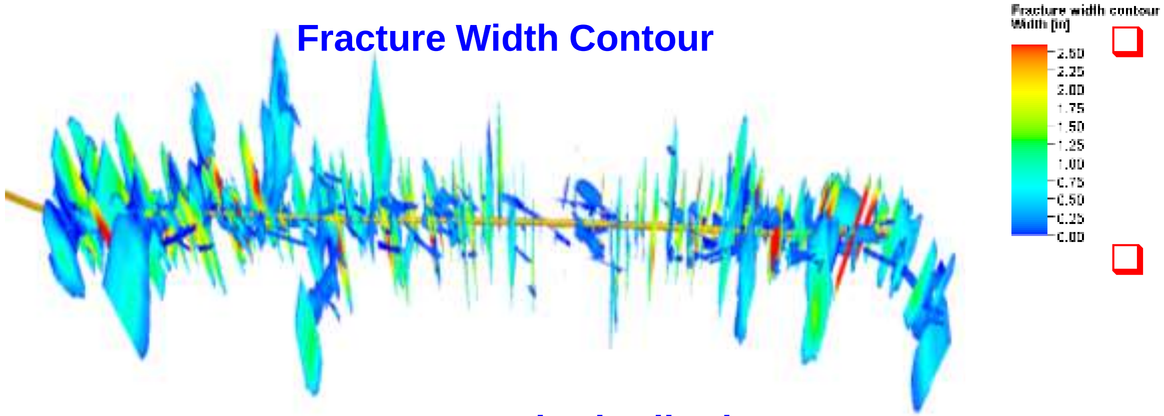
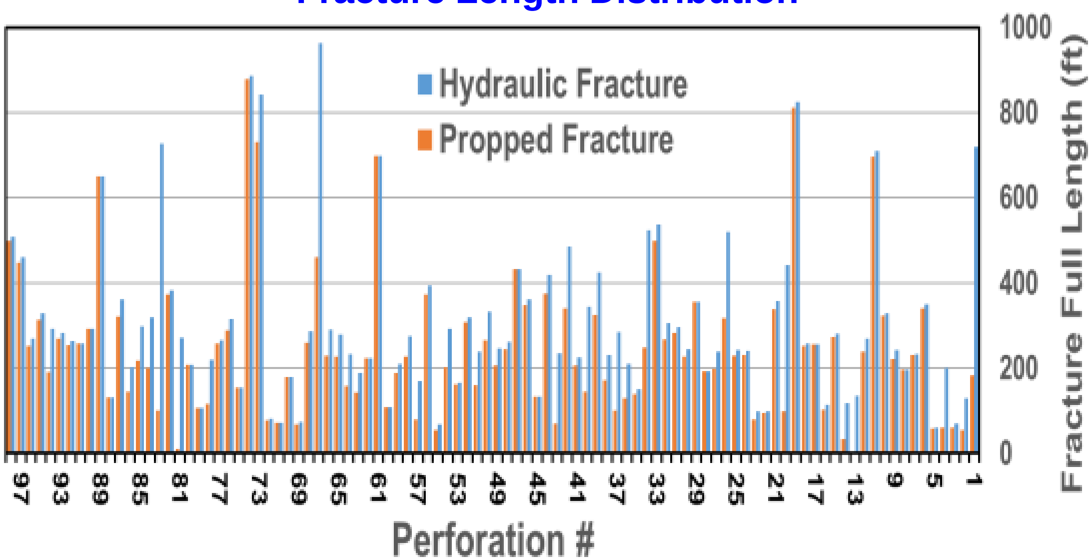
Non-Uniform Fractures Generated From Fracture Modeling

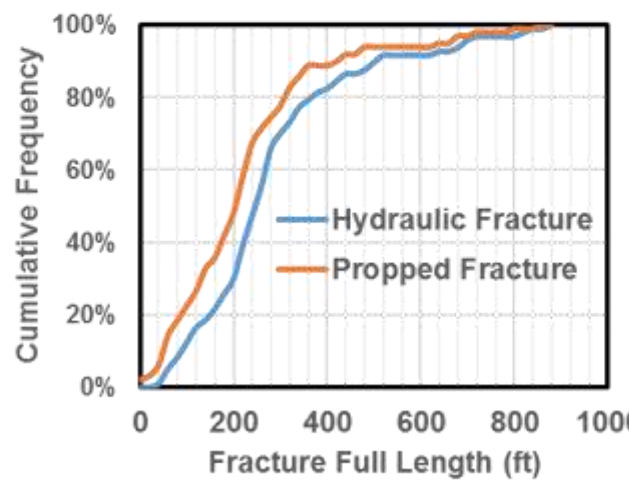
Fracture Width Contour



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

Fracture Length Distribution





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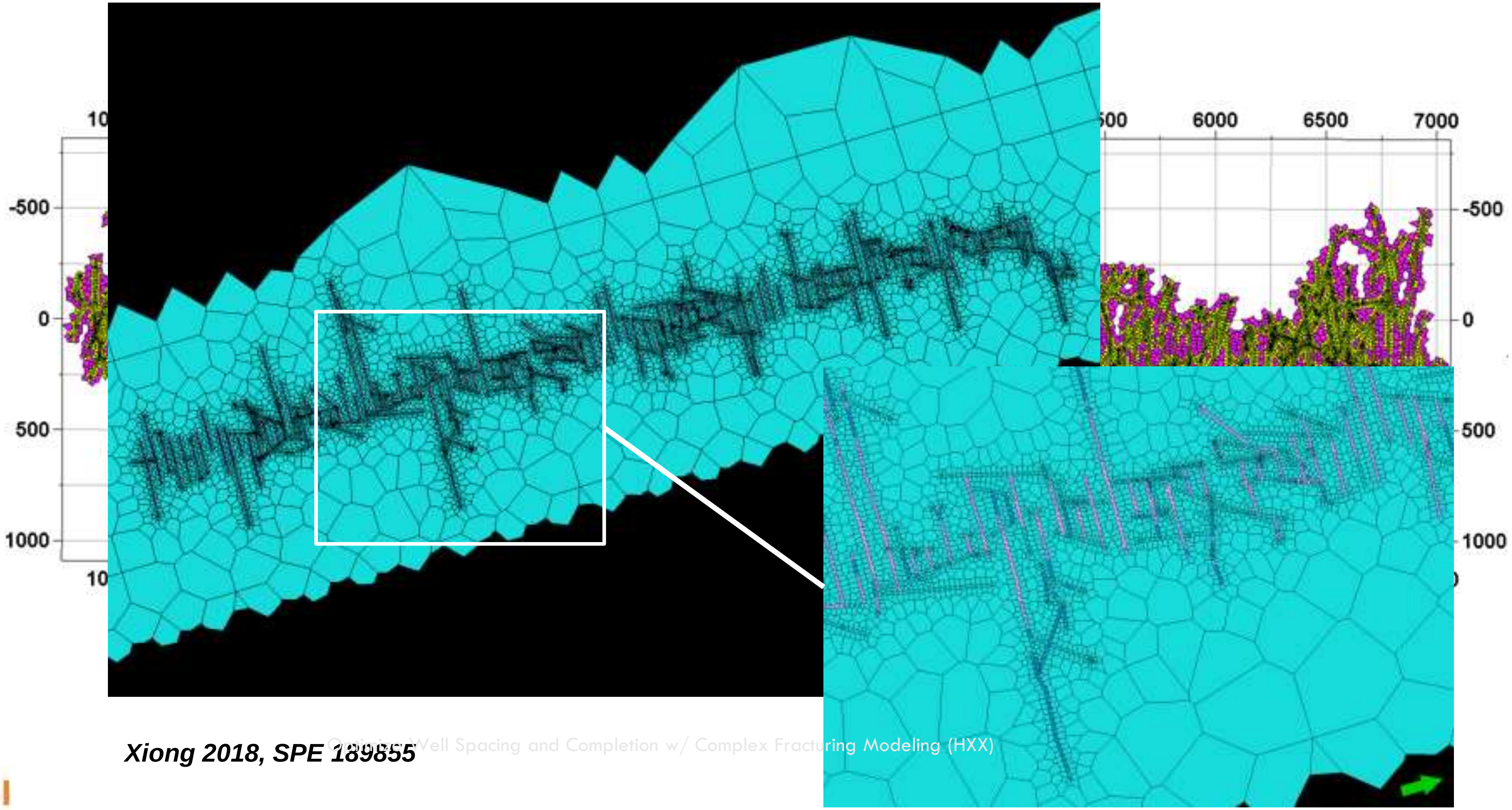
Convert Fracture Model into Reservoir Flow Simulation Model

- The use of unstructured grids maintains the fidelity between the complicated fracture model and reservoir simulation.



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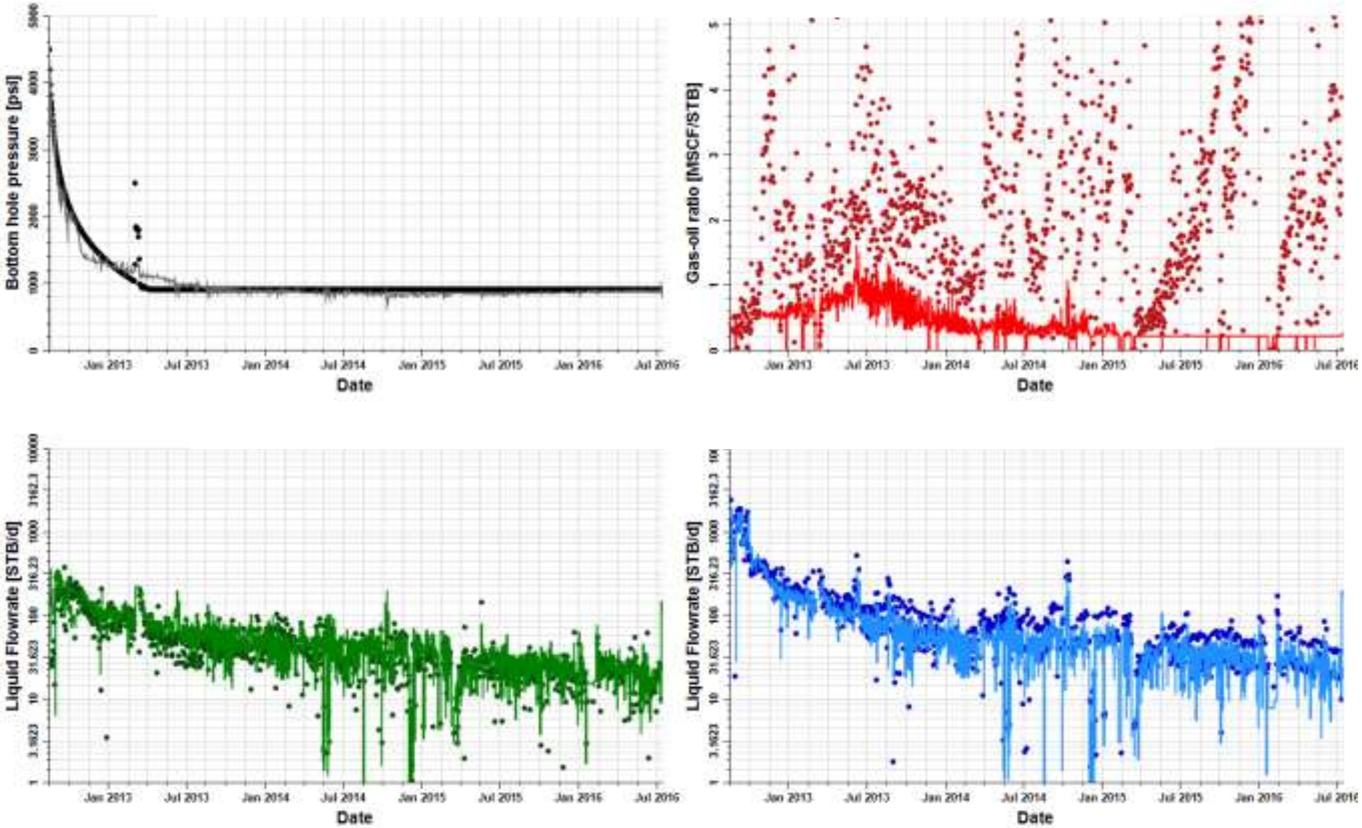
Production Data History Match

- Decent history match of the actual production history was achieved for the original case.



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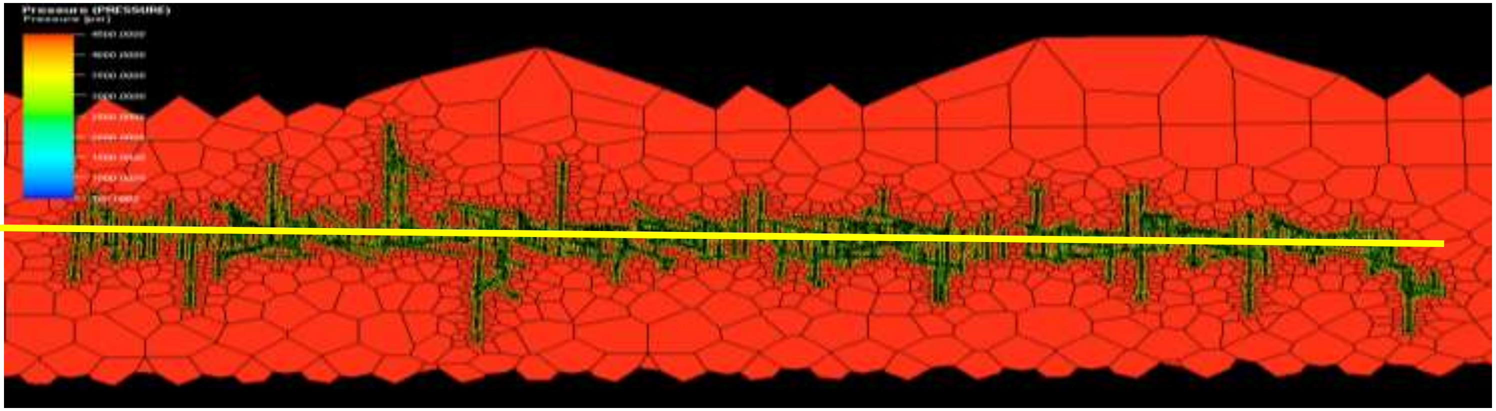
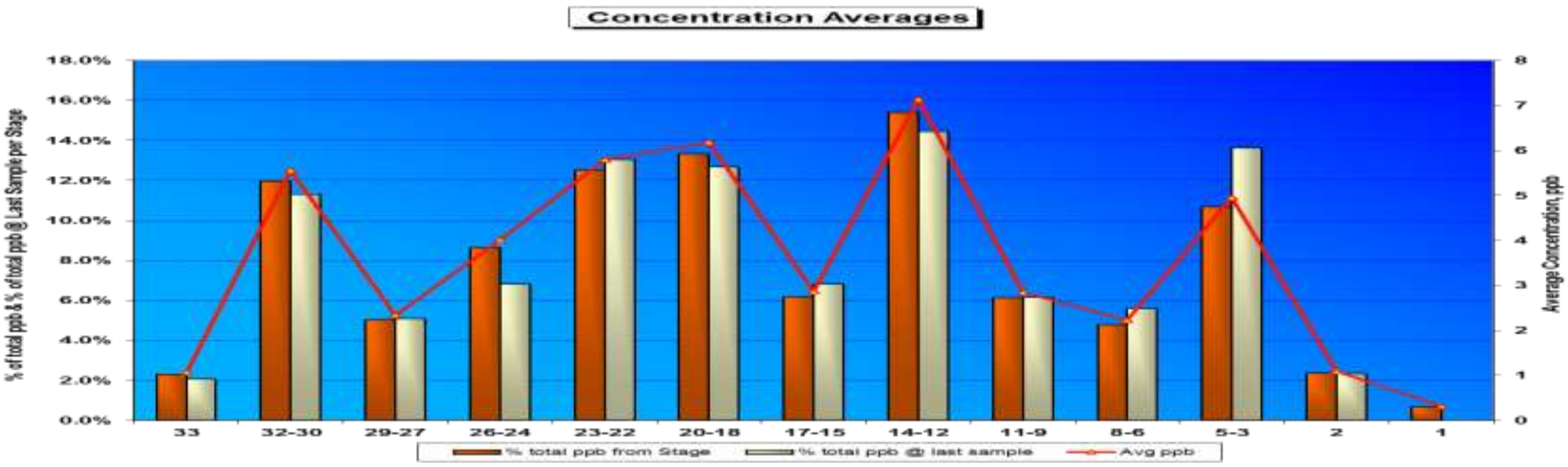
Blind Test 1 - Between Tracer and Propped Fracture Modeling Results

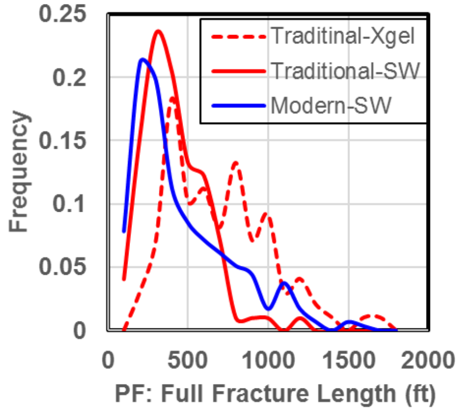


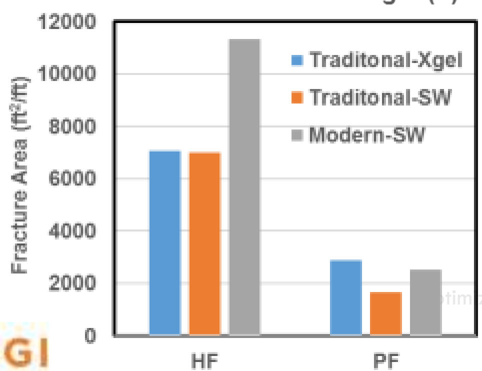


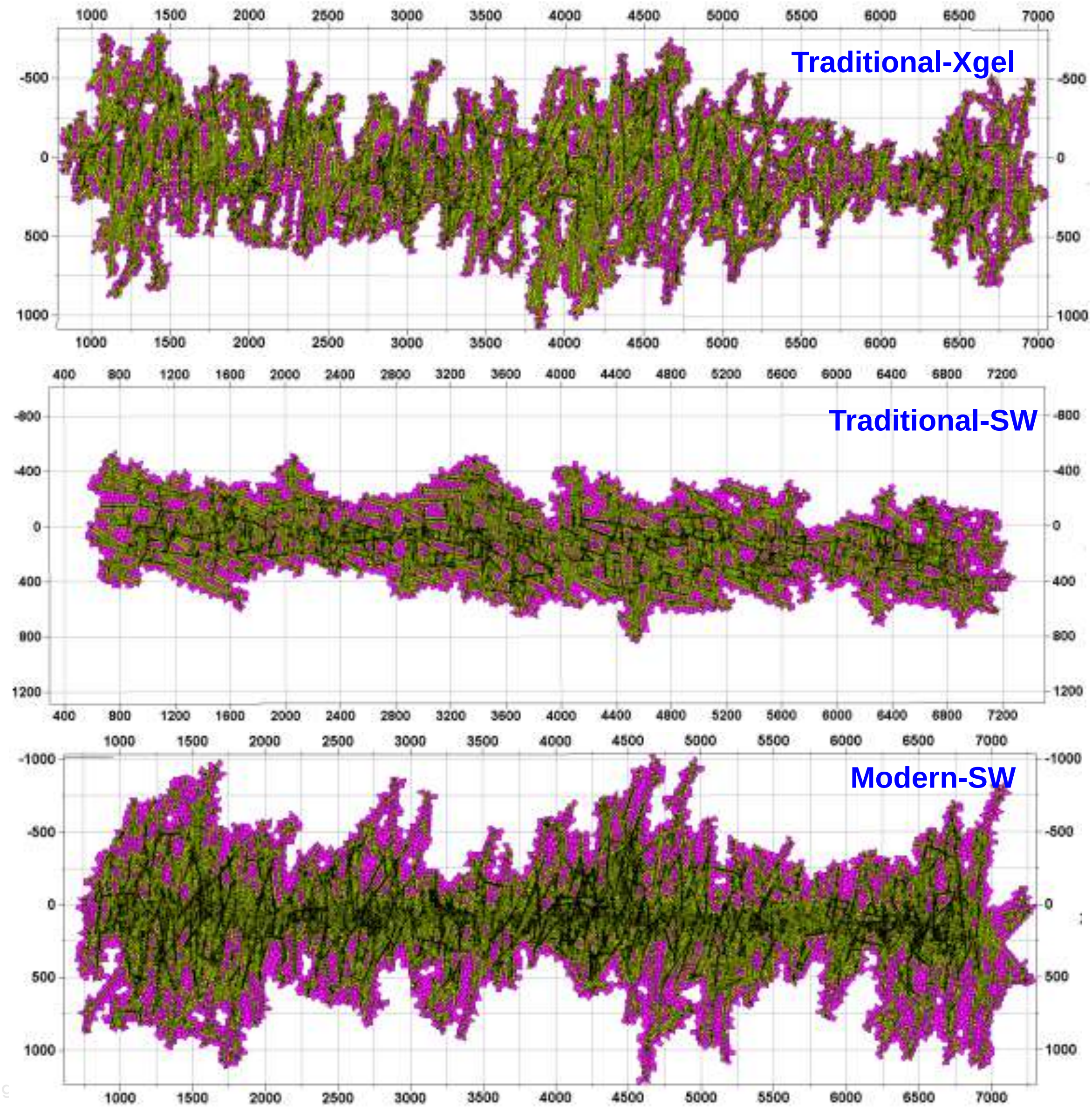
Complex fracturing modeling results can explain tracer logging results

Modern Fracturing Design with Reduced Cluster Spacing Increases Completion Effectiveness

Completion			
Design	Trad' - Xgel	Trad'-SW	**Modern**
Stages #	33	33	**98**
CS, ft	60	60	**20**
Clusters/ Stg	3	3	3
Prop. Loading, lb/ft	1200	1200	**3000**
Fluid	Xgel	SW	SW







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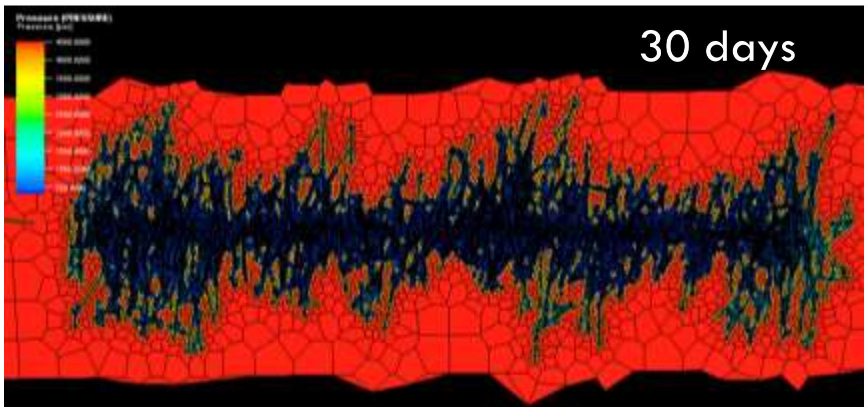
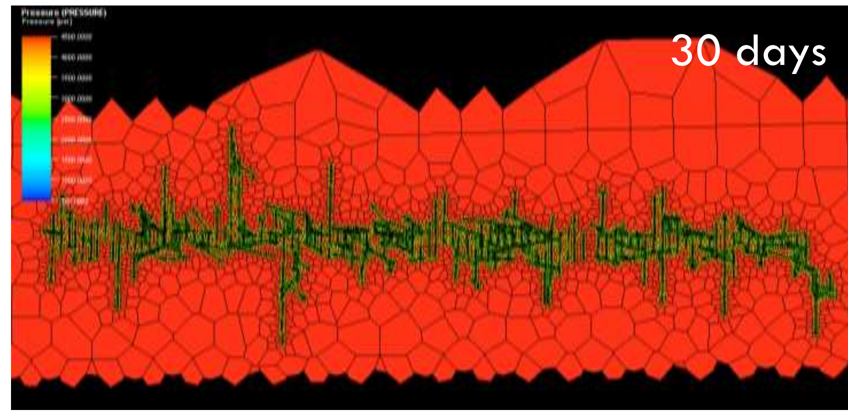
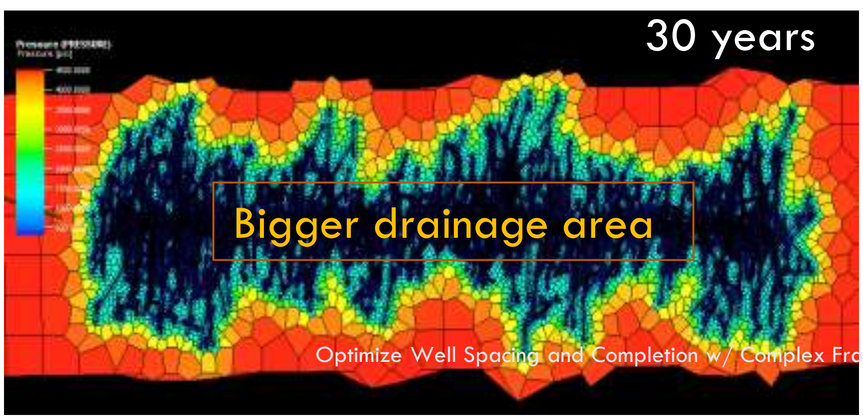
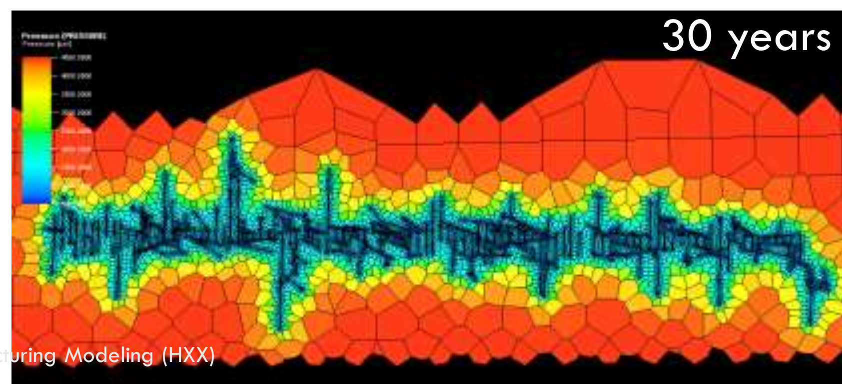
Pressure Depletion Comparison with Modern Completion Design

- Modern design:
  number of clusters = 294, slick water
- Original design:
  number of clusters = 98, crosslinked-gel



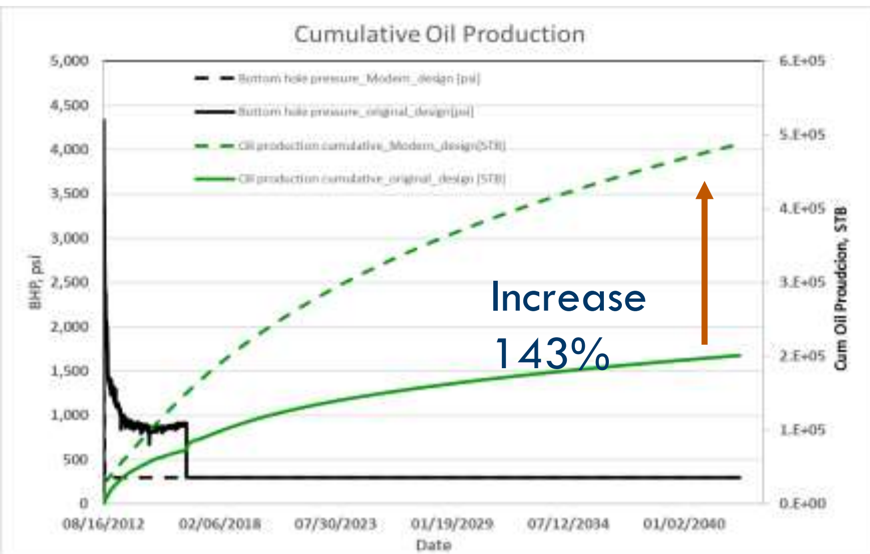


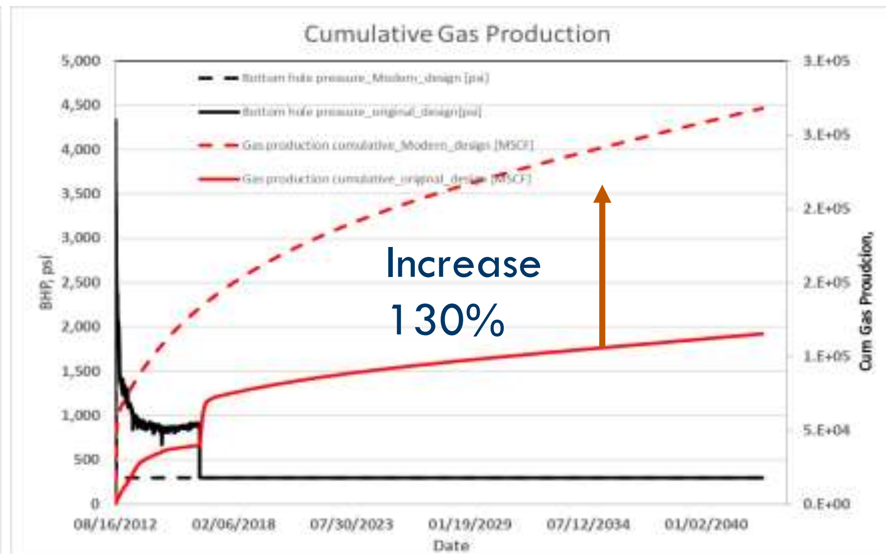




Production Forecast Comparison

- The impact of cluster spacing and fracture complexity on well performance was evaluated by comparing the production forecasts for modern fracture design and the original fracture design.





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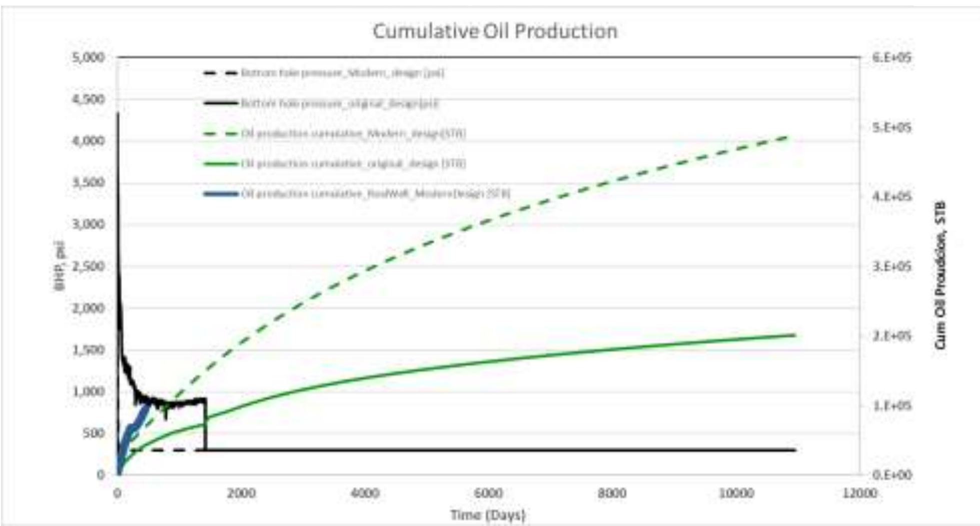
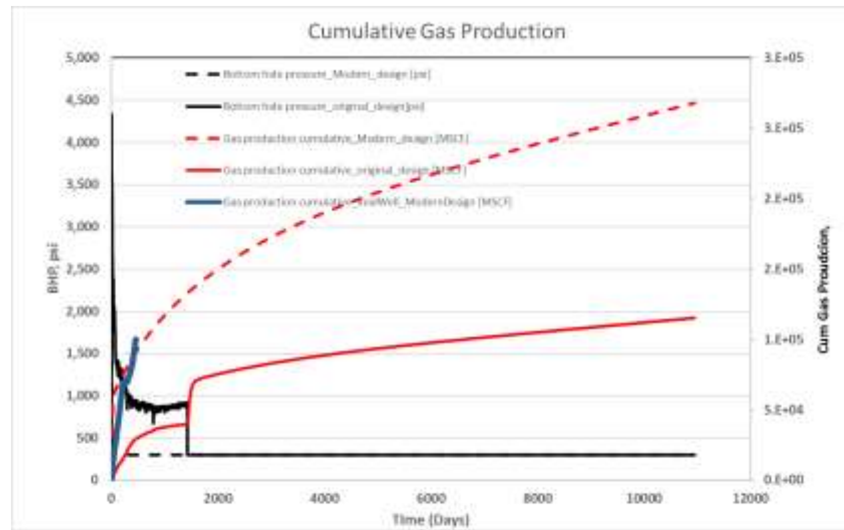
Blind Test 2 - Comparing Production from a Random Well Completed with Similar (modern) Completion Design

Oil Production Comparison



Gas Production Comparison



It indicates that the calibrated model is robust by comparing forecasting results with the production data from a randomly selected well with similar completion design.

Using the Calibrated Models to Optimize Well Completion Designs

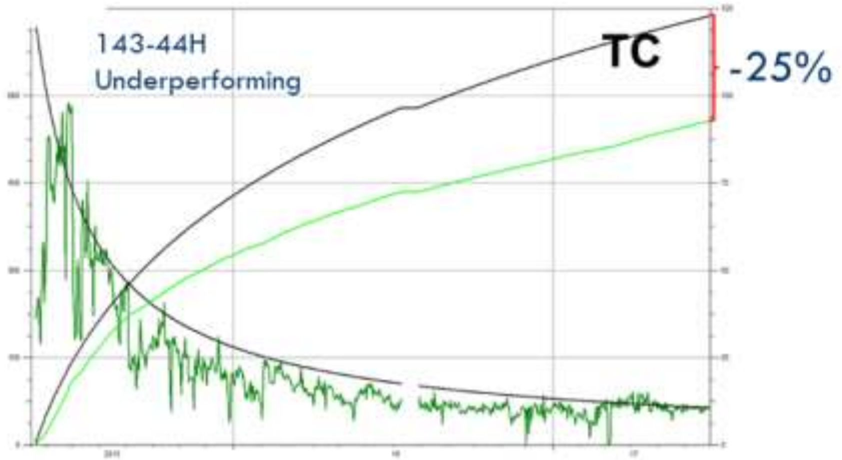
- Scenario 1: The impact of number of clusters per stage
- *Scenario 2: The impact of X-linked gel vs slickwater*
- *Scenario 3: The impact of pumping rate*
- *Scenario 4: The impact of cluster spacing*

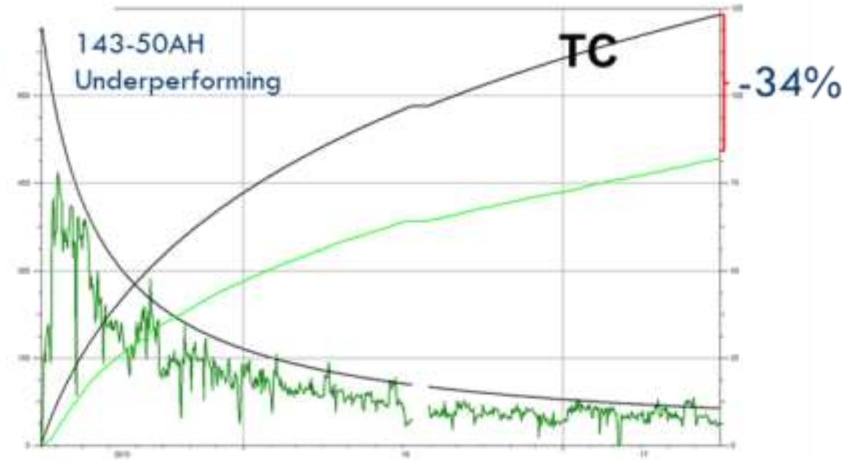
Scenario 1 - Completion Comparison: More Clusters/Stage for Underperforming Wells, X-Linked Made Worse

Performance	Underperforming		Outperforming	
Well Number	143-44H	143-50H	193-33H	193-38H
Completion Date	5/17/2015	5/12/2015	6/15/2015	6/7/2015
Proppant Type	Brown Sand	Brown Sand	Brown Sand	Brown Sand
Proppant Size	40/70	40/70	40/70	40/70
Proppant (lb/ft)	986	1107	988	765
Fluid Type	7.5% HCl (0.19%) Slickwater (89.09%) 10# Linear Gel (10.72%) (22 stages info)	7.5% HCl (0.20%) Slickwater (34.69%) 15# Linear Gel (1.95%) 15# X-L Borate (63.17%) (15 stages info)	7.5% HCl (0.31%) Slickwater (99.69%) (13 stages info)	7.5% HCl (0.33%) Slickwater (73.09%) 10# Linear Gel (26.58%) (11 stages info)
Fluid (bbl/ft)	38	37	40	33
Cluster Spacing (ft)	60	60	61	60
Total Stage	26	26	41	41
Failure Stage*	0	0	0	8
Number of Clusters in Each Stage	5 (1-5 stage) 6 (6-26 stage)	5 (1-10 stage) 6 (11-26 stage)	3 (1-9 stage) 4 (10-41 stage)	3 (1-9 stage) 4 (10-41 stage)
Total Clusters	151	146	155	155 (123)

TOGI * Low percent of proppant placed in formation

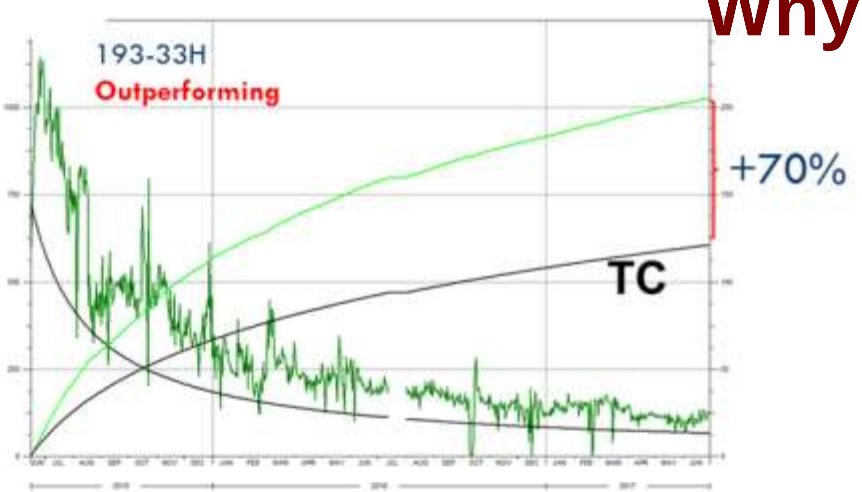
Scenario 1 - Completion Comparison: More Clusters/Stage for Underperforming Wells, X-Linked Made Worse





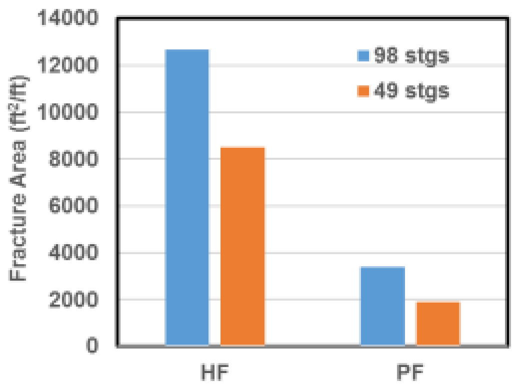
193-33H > 193-38H > 143-44H >143-50H

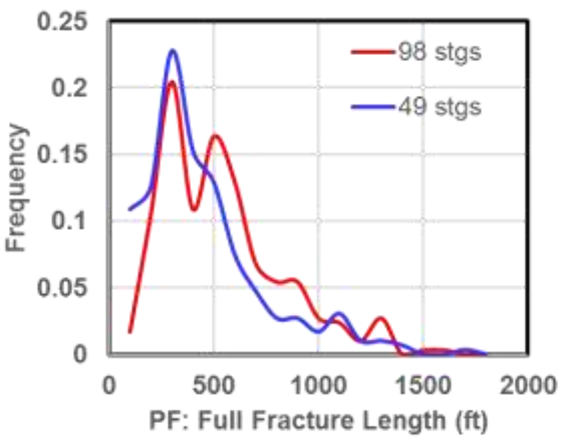
Why ?



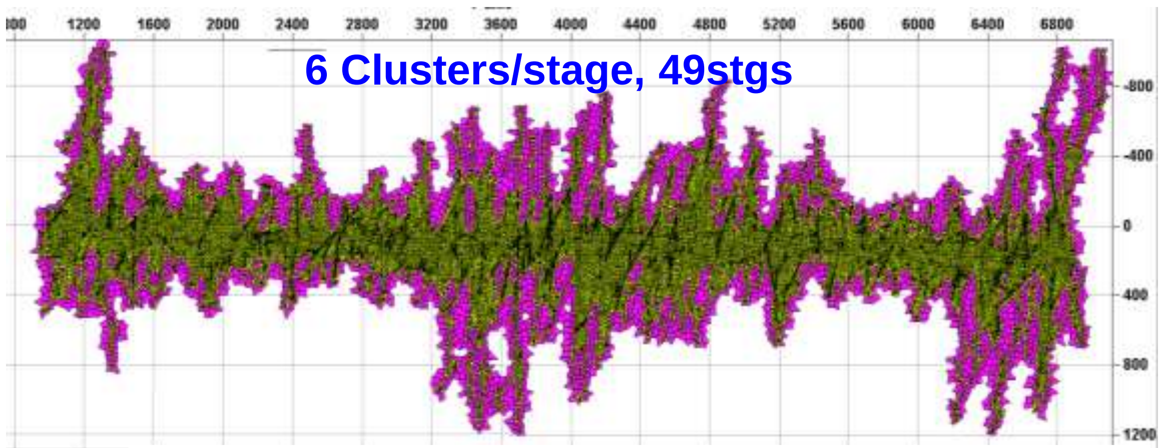
Scenario 1 - Complex Fracturing Results May Explain Why Those Wells Production Performance Behaviors

Completion		
Stages #	98	49
CS, ft	20	20
Clusters/ Stg	3	6
Prop. Loading, lb/ft	3000	3000
Fluid	SW	SW

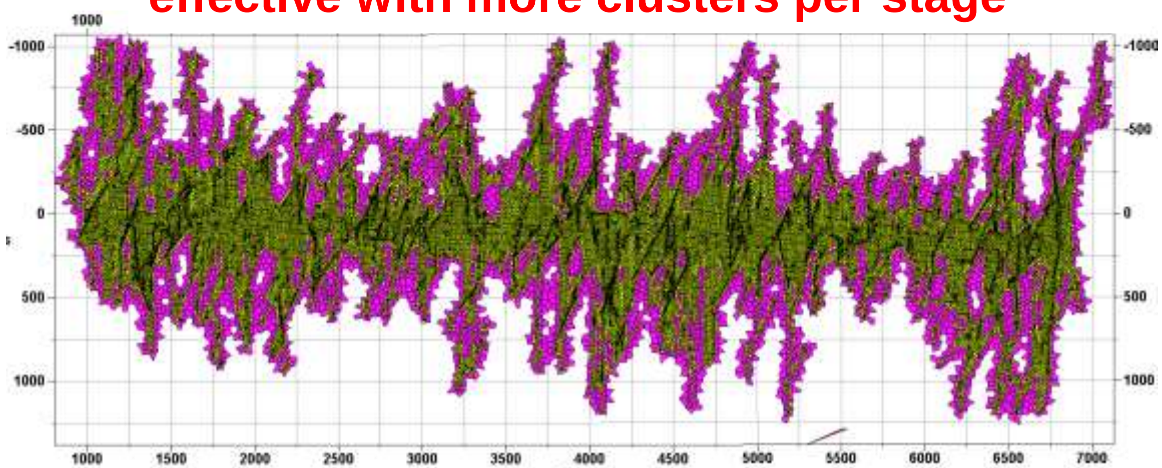




Less clusters per stage increases completion effectiveness



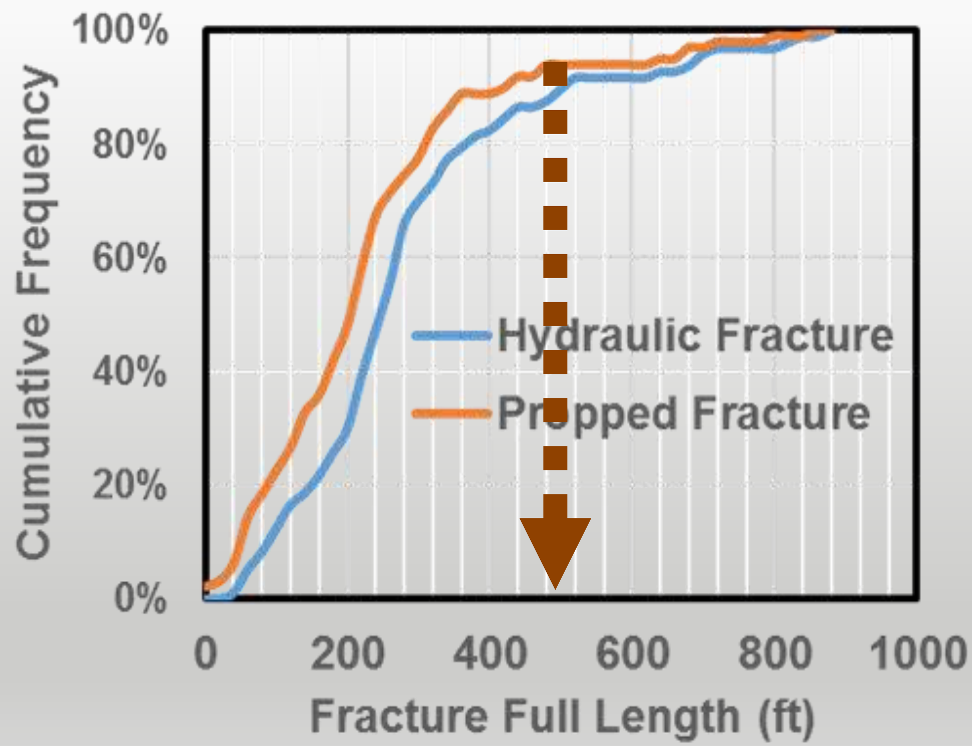
It seems that the completion is less effective with more clusters per stage

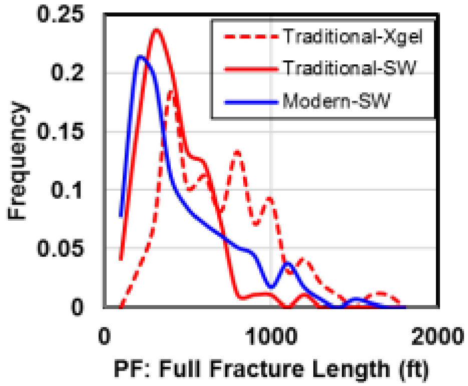


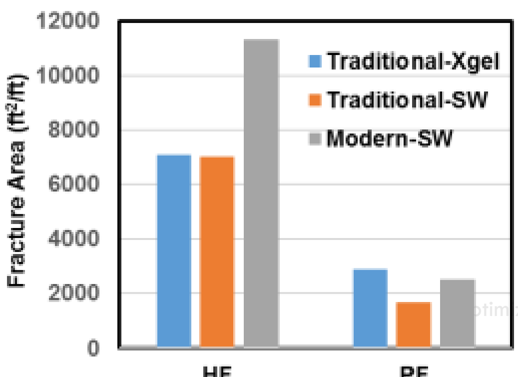
3 Clusters/stage, 98stgs

Well Spacing Determination with Modern Fracturing Modeling

Completion			
Design	Trad' - Xgel	Trad'-SW	Modern
Stages #	33	33	**98**
CS, ft	60	60	**20**
Clusters/ Stg	3	3	3
Prop. Loading, lb/ft	1200	1200	**3000**
Fluid	Xgel	SW	SW







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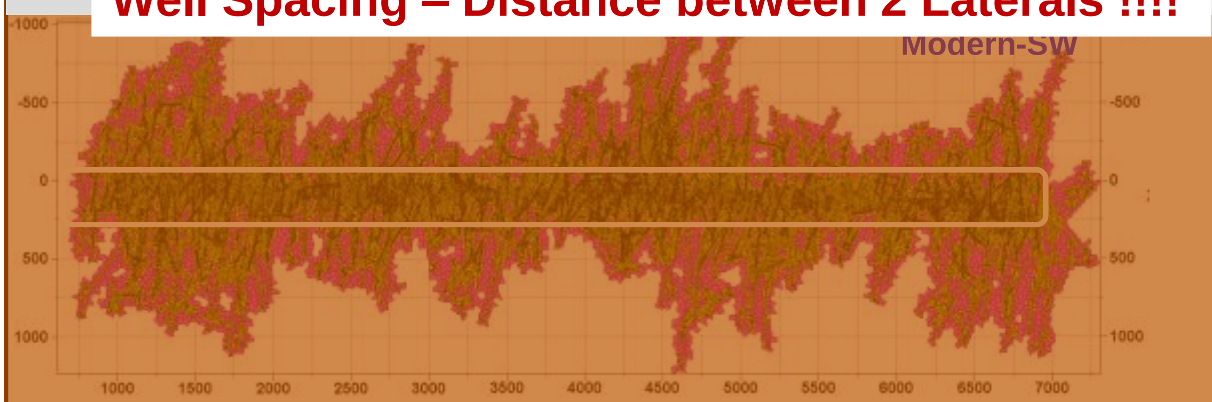
Well Spacing – Distance between 2 Laterals !!!!



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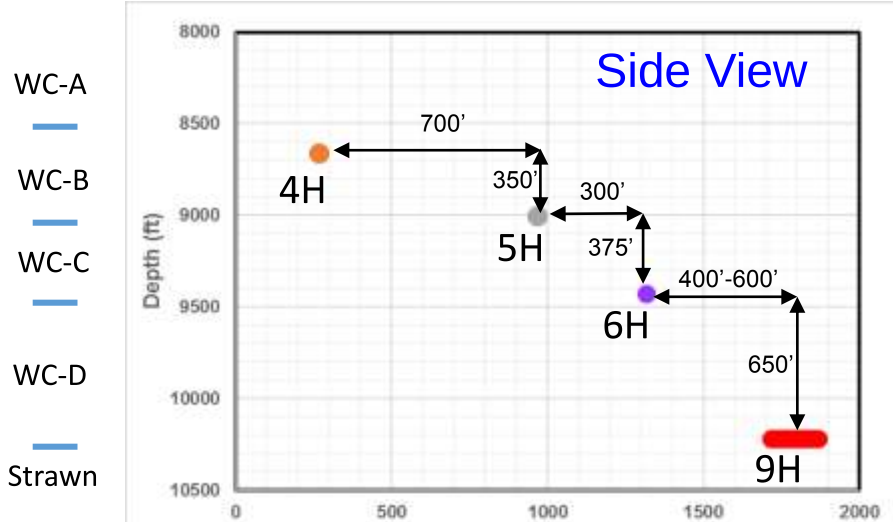
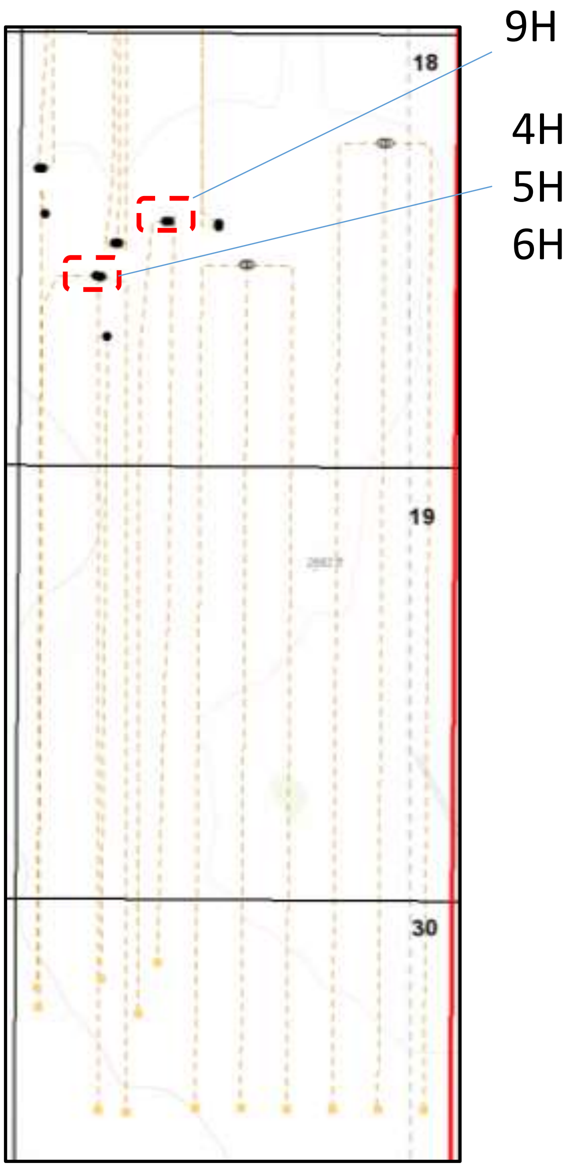
Case History 2 – Multi-Well Study (Basic Info)

- HZ Wells completed in WC, Upton county
- Completed and started producing in 2014

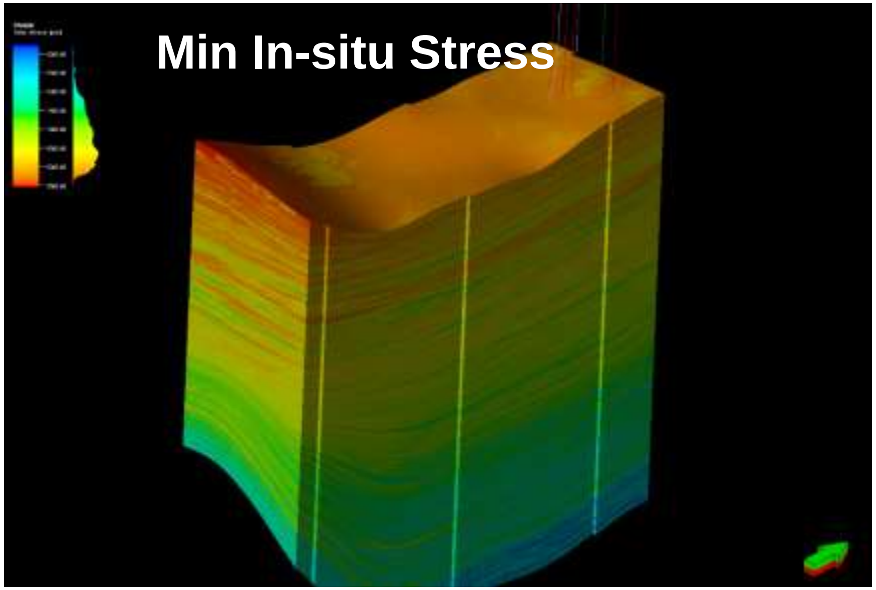


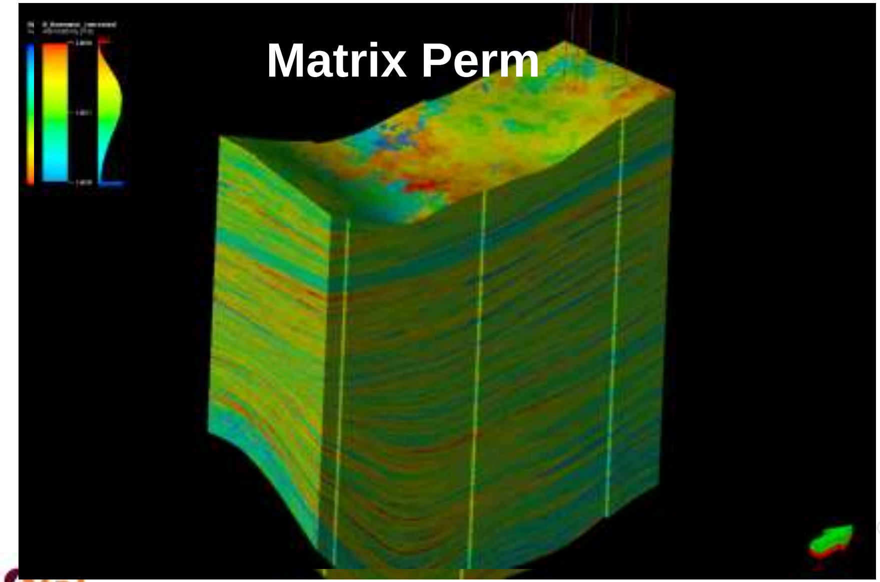
Well Name	4H	5H	6H	9H
Lateral length, ft	8222	8642		
Stages	29	30		
Clusters	138	145		
Cluster Spacing, ft	60			
Perforations/Cluster	8			
Fracturing Fluids	slick water, x-linked gel			
Proppant Size	30/50 + 20/40	30/50	40/70	40/70
Clean Fluid Amount, bbl/ft	26	26	27	29
Proppant Amount, lbm/ft	1060	1055	1110	1100

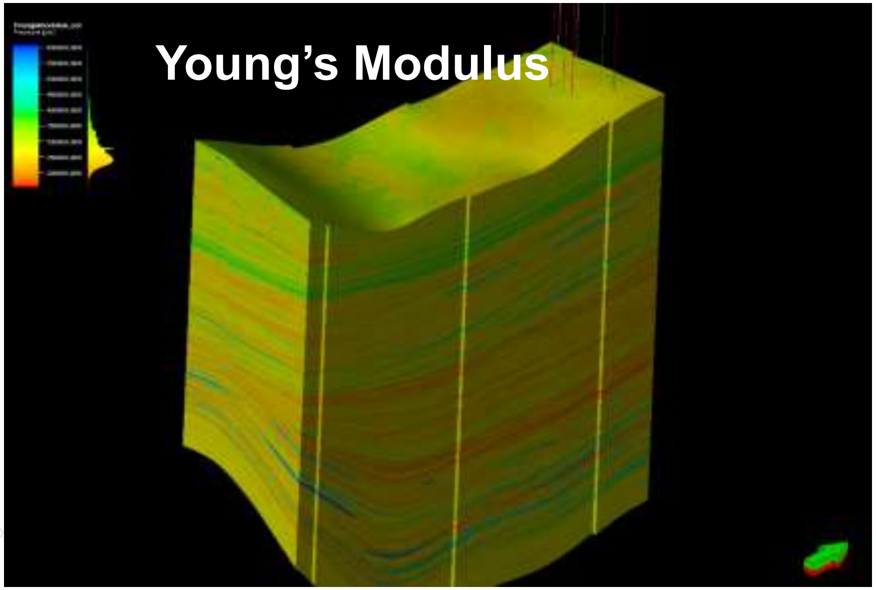


Fully 3D Geological Model

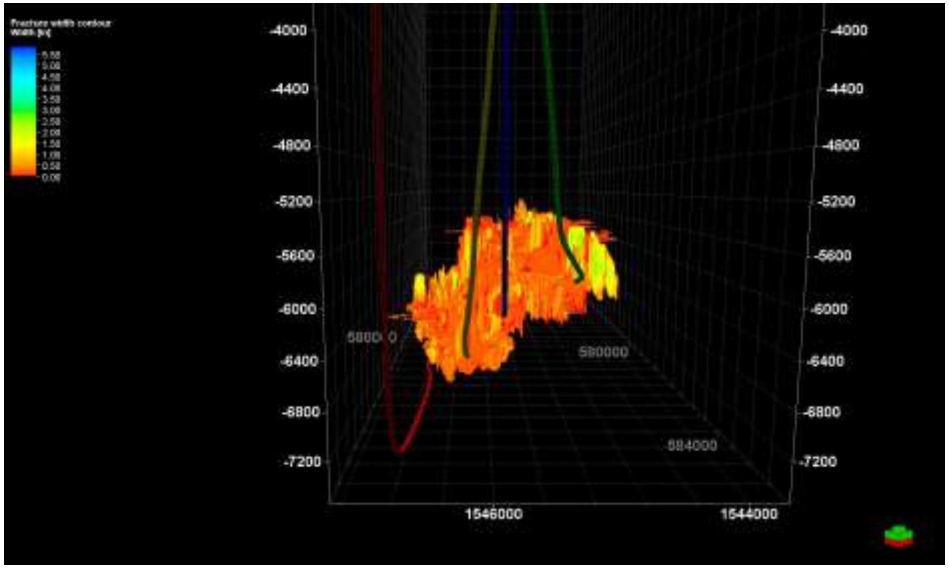
Sector Model Properties		
TVD		7700 -10310 ft
Zone set	Length	12600 ft
	Width	4200 ft
	Height	2600 ft
Shmin		5430 - 9280 psi
Stress Anisotropy		1%
Young's Modulus		1.3-6.1 MMpsi
Poisson's Ratio		0.1-0.43



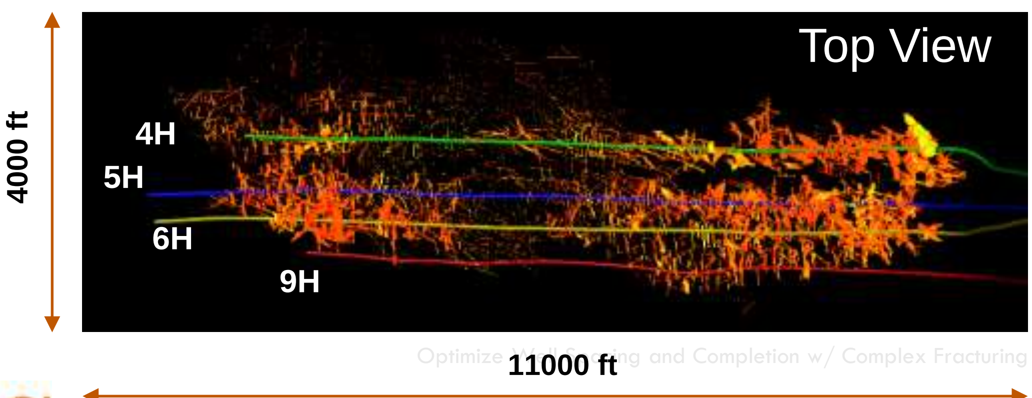


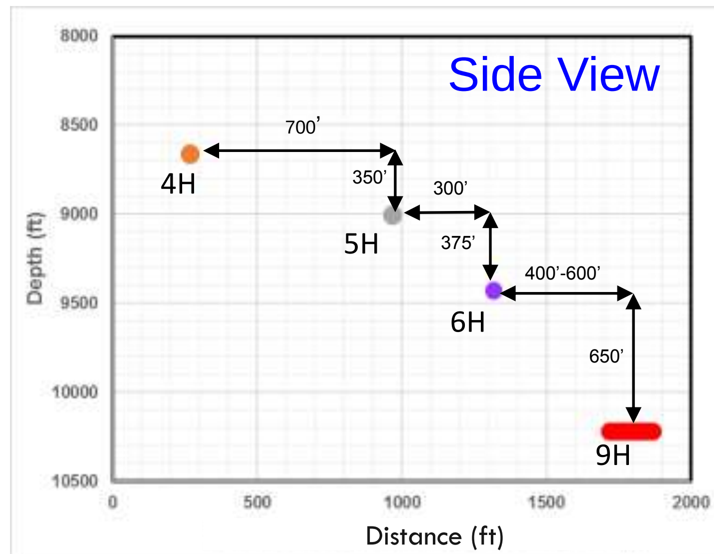


Multi-well Complex Modeling Results – Provide the Insightful Info on Well Spacing

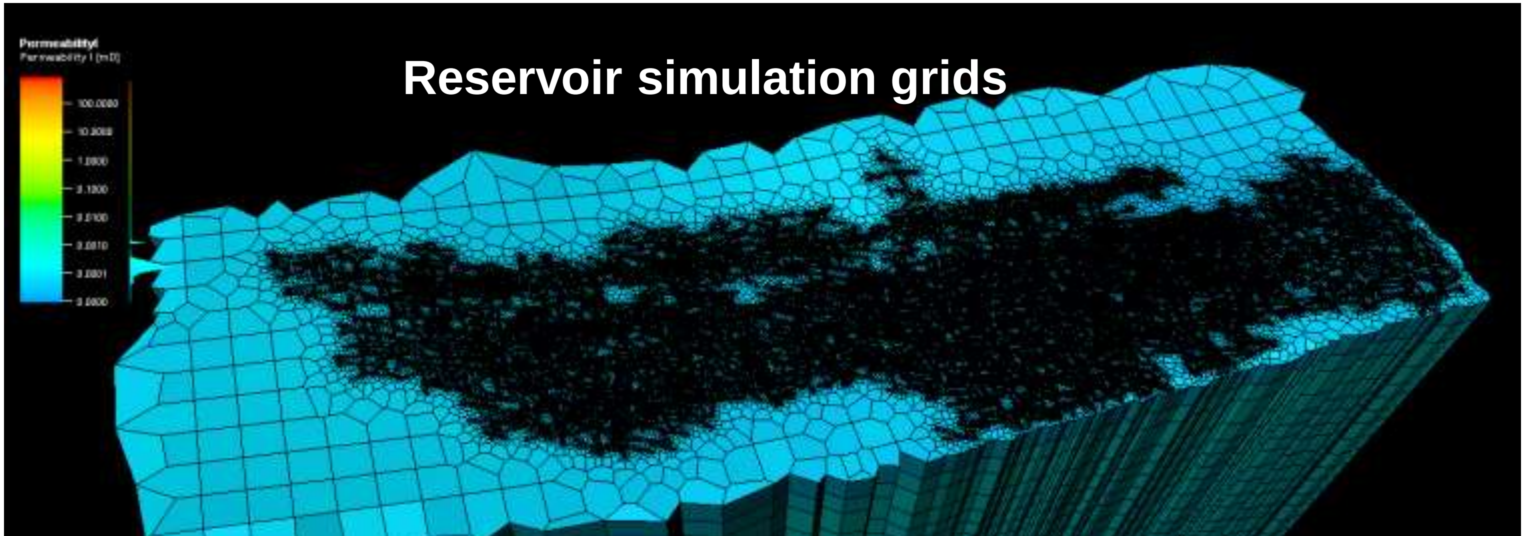


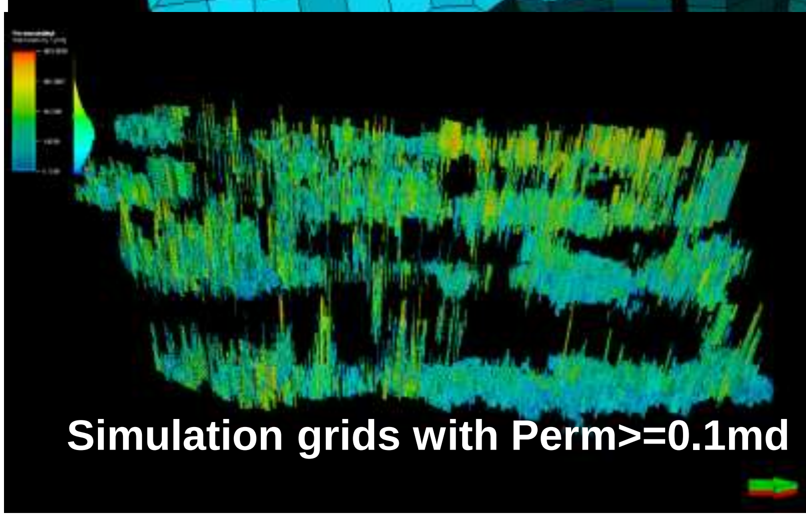
- **Complex fracture network generation due to the interaction between hydraulic fracture and natural fracture**
- **Fracture intersection between wells is observed**

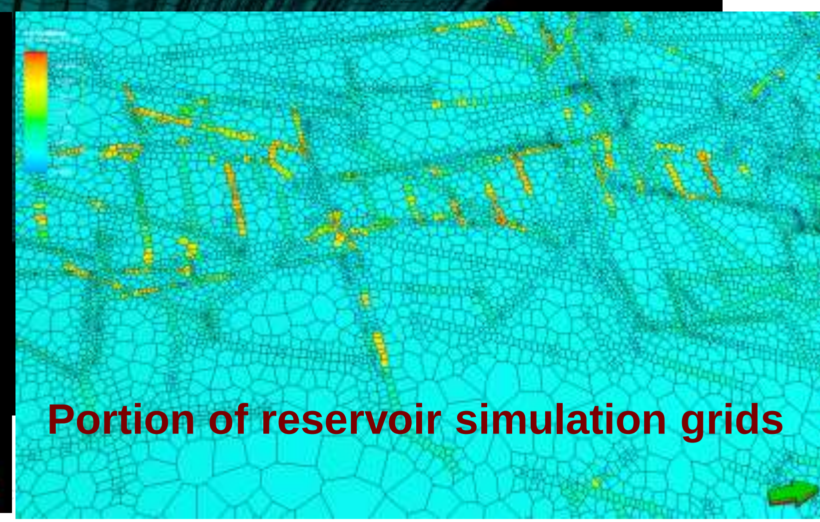




Convert Complex Fracture Model to Reservoir Simulation Model to Study Well Spacing







Conclusions

- Two case studies have proved that we can take advantage of the latest modeling technologies to speed up the well spacing decision and corresponding optimal completion designs, which may save significant amount of money and time for operators

- Smart well spacing with corresponding smart well completion design should be the way to maximize the resource recovery

- Established a workflow integrating and calibrating both multi-stage complex fracture models and reservoir performance models with the latest modeling technologies. Multiple completion scenario modeling results have demonstrated that those models are robust and can be used to optimize well spacing and corresponding completion designs.

- Reservoir characterization is very critical to well completion design and well spacing optimization.

- Backup

Self-Introduction

- Current Position: the Director of Production Enhancement, Texas Oil and Gas Institute.

- Prior to joining TOGI/UL, Dr. Xiong was the Global Reservoir Engineering Advisor for ConocoPhillips, where his main responsibilities were to evaluate company-wide exploration and field development projects, and to appraise and develop unconventional resources plays, including Bakken, Eagle Ford, Horn River, Montney, Niobrara, and Permian Basin.

- Prior positions include the manager of production optimization group for Schlumberger, an engineering advisor for Burlington Resources, and a petroleum engineer for S.A. Holditch & Associates Inc. Hongjie holds a Ph.D. in Petroleum Engineering from Texas A&M University.

- Dr. Xiong has published more than 50 technical papers and he is also an adjunct professor of Petroleum Engineering Dept., Texas A&M University, College Station.
  - One of recent publications : Overview – Optimization of Cluster Spacing or Fracture Spacing