# Mamm Creek Field Reservoir Simulation

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The authors acknowledge RPSEA (Research Partnership to Secure Energy for America) for financial support, and the Bill Barrett Corporation for providing much of the data that underlie this study.

# Engineering and Simulation

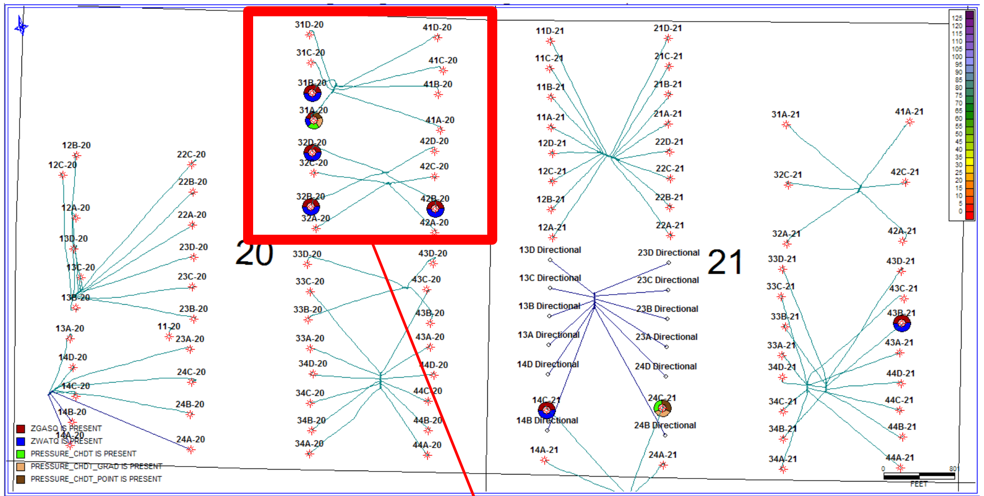
Objective

- Use integrated approach to create a 3D dynamic simulation model based on detailed static geologic and petrophysical models.
- Incorporate and calibrate hydraulic fracture properties at each well to approximate initial productivity.
- Simulate long-term dynamic flow to investigate volume influence of wells and the impact of geologic uncertainty on early and long-time performance.

# Simulation Workflow

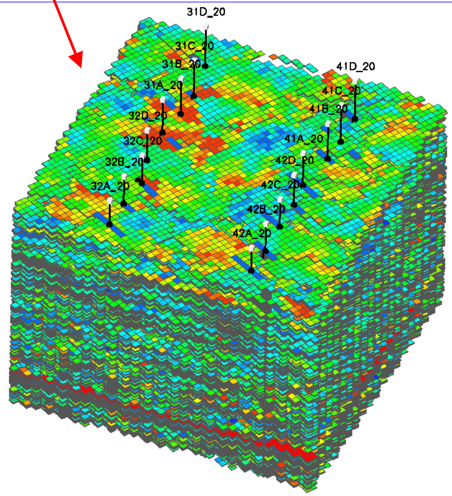
- Geologic Model Choices
  - Distribution methods, (e.g. Objects), seismic constraints
- Petrophysical Constraints
  - net pay, BVW, permeability, overburden impacts
- Initial Pressure Distribution
  - representation of overpressure
- Hydraulic Fracture Representation
  - Propped length, height, orientation and conductivity
- Dynamic Model Calibration
- Forecasts of Long-Term Performance
- Other Considerations / Uncertainty
  - Natural fractures, directional permeability, water production

# Model Area and Grid Size

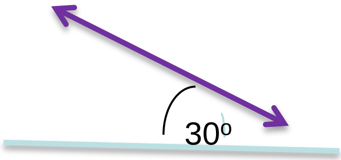


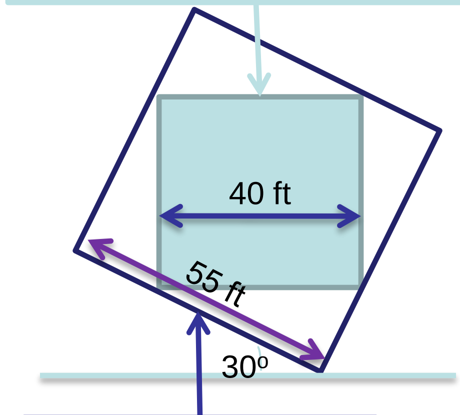

- 71 x 72 x 722 (761,222 active cells)
- DX = DY = 55’ or 0.069 acre/cell
- Avg. DZ = 2.8 ft
- Model area: ~190 acres

  (~2800 ft * 2960 ft)




**Simulation Grid Rotation for Hydraulic fracture representation**

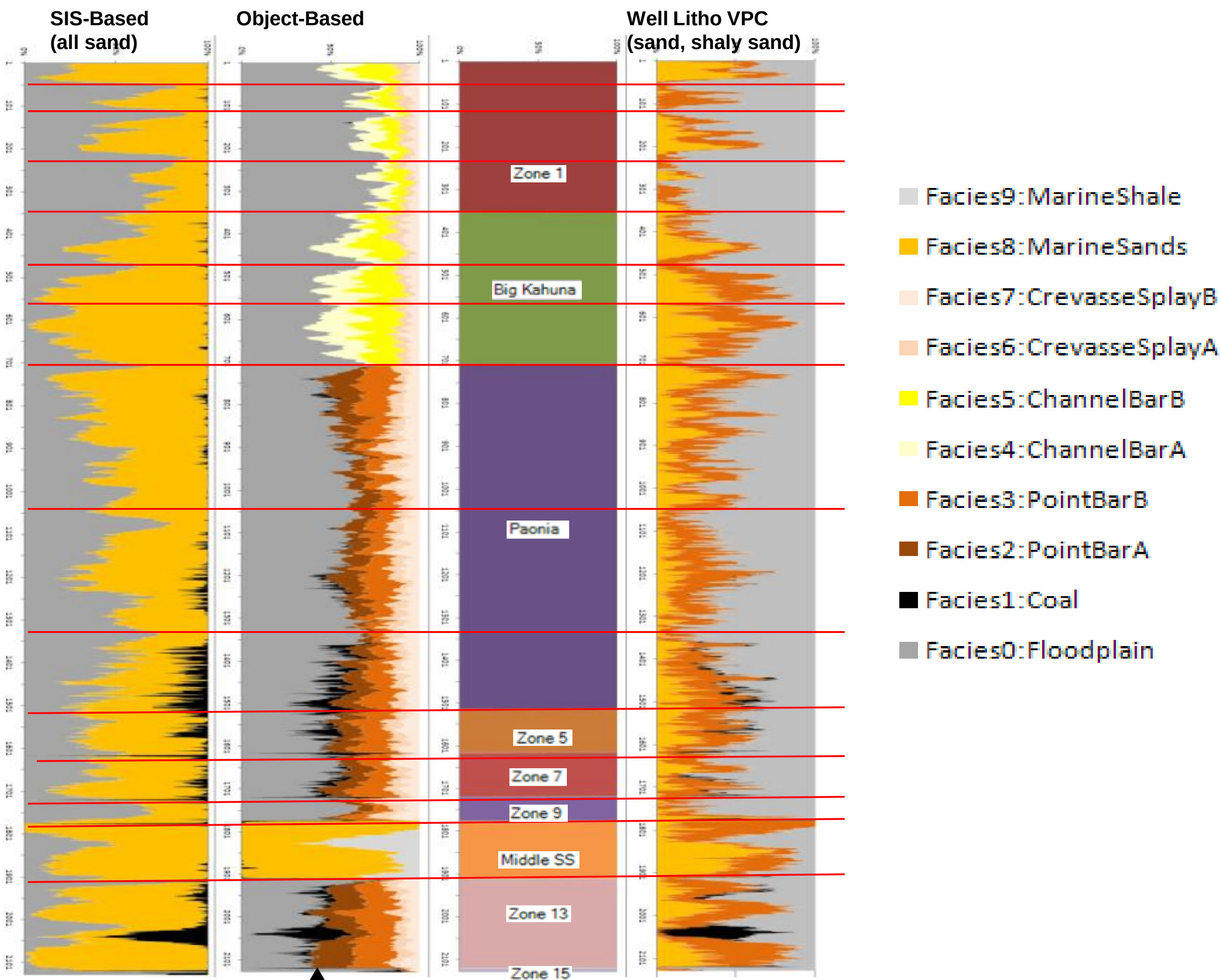



Orientation is N60W. Data from other areas would suggest N45W.

# 1) Geologic Model Choices

Facies Proportion Curves

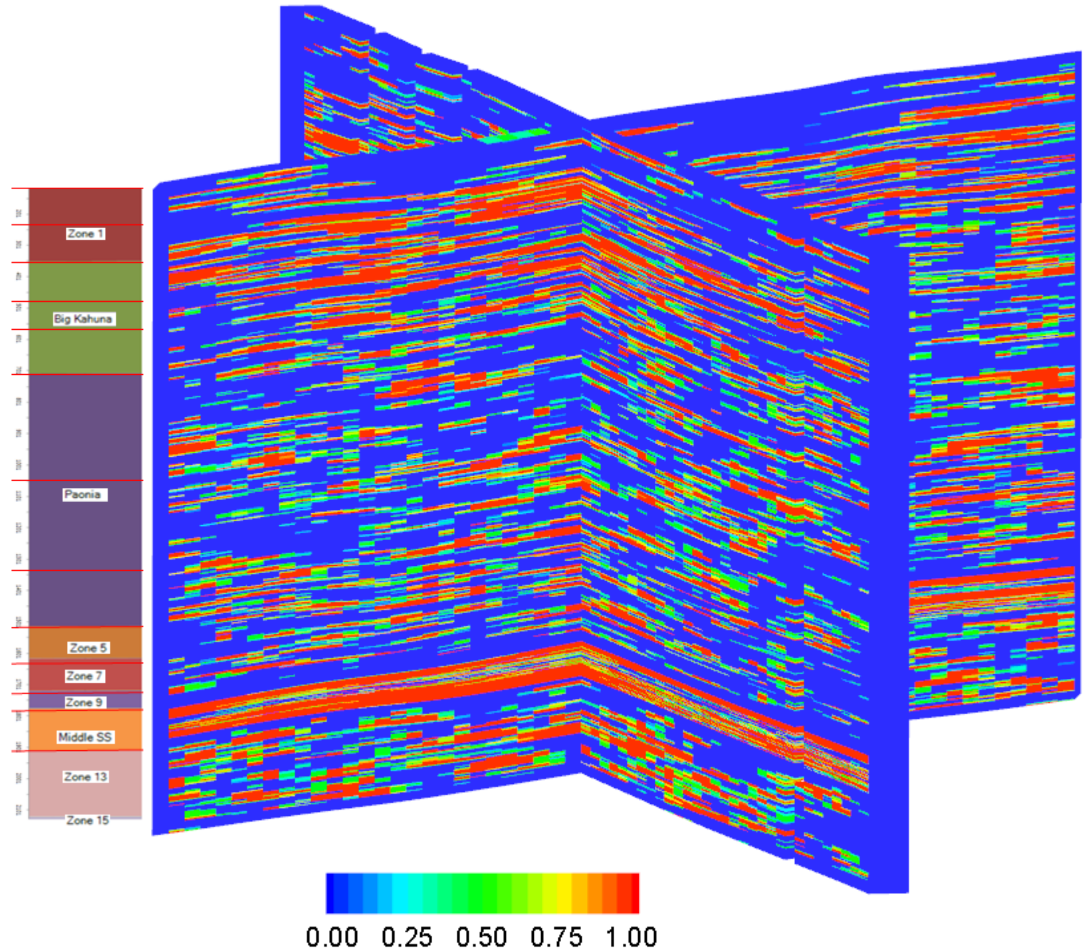



Current base model for simulation

# 2) Petrophysical Constraints

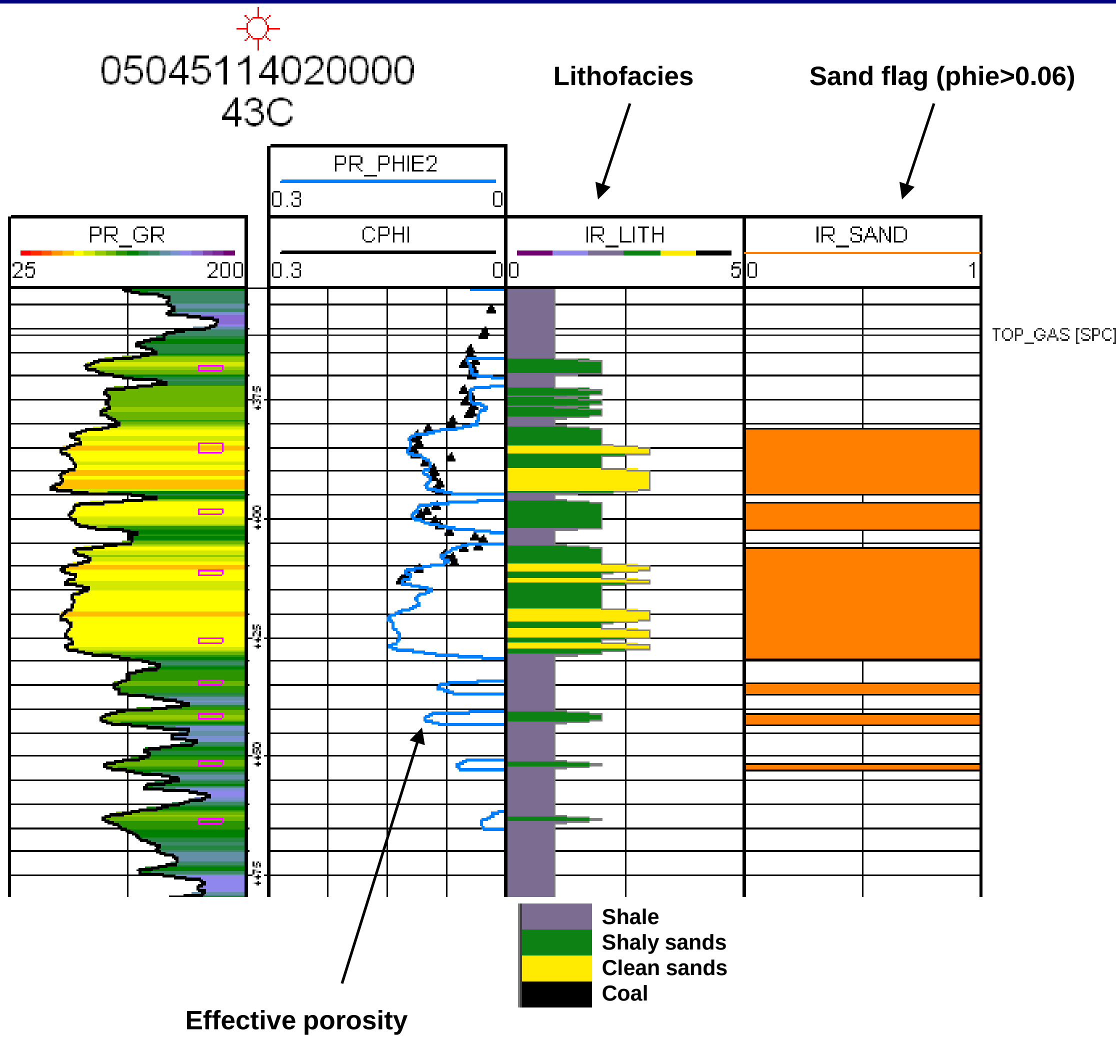
Geomodel Provides:

- Porosity
- Permeability (air)
- Facies Indicators
- Stratigraphic Regions
- NTG (after upscaling)
    - only channel bars, point bars and marine sand considered as pay in this illustration

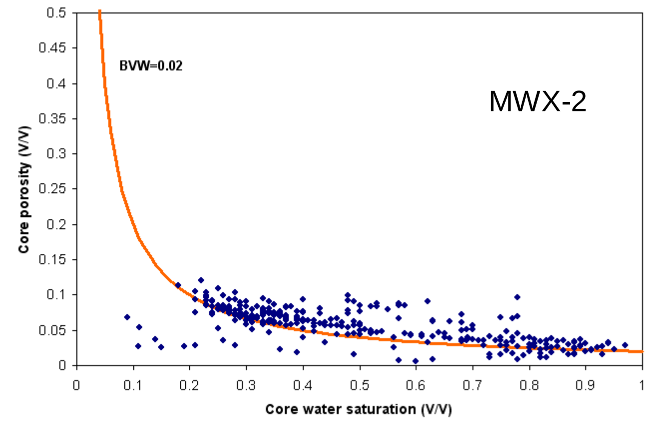



Example NTG

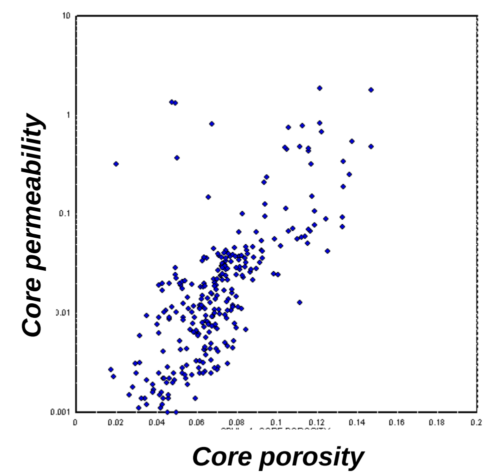
# Petrophysical Calibration




## Irreducible water saturation estimation using Bulk Volume Water (BVW)




## Permeability distribution using Phi-K cloud transform (or other)

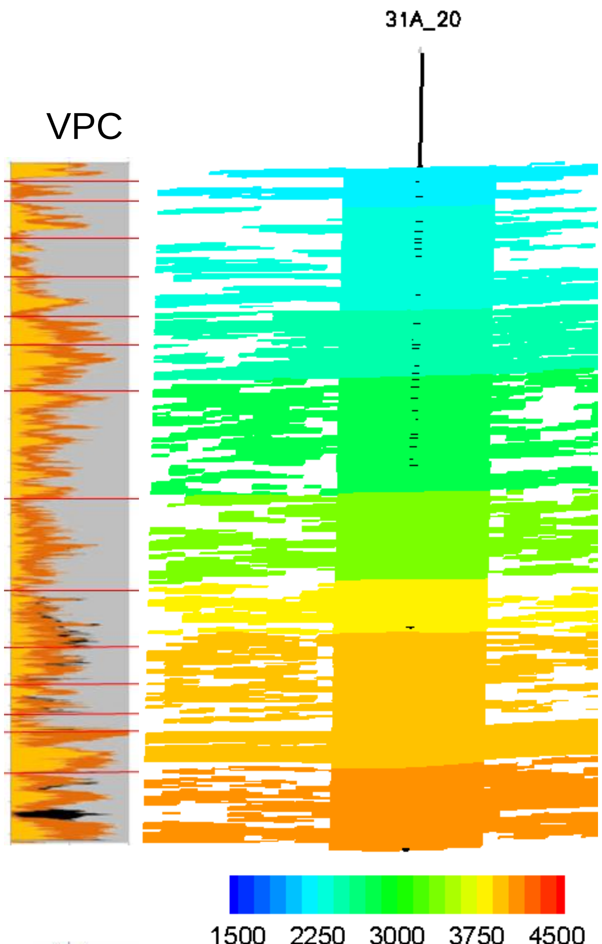



**Facies distributed in the geomodel:**

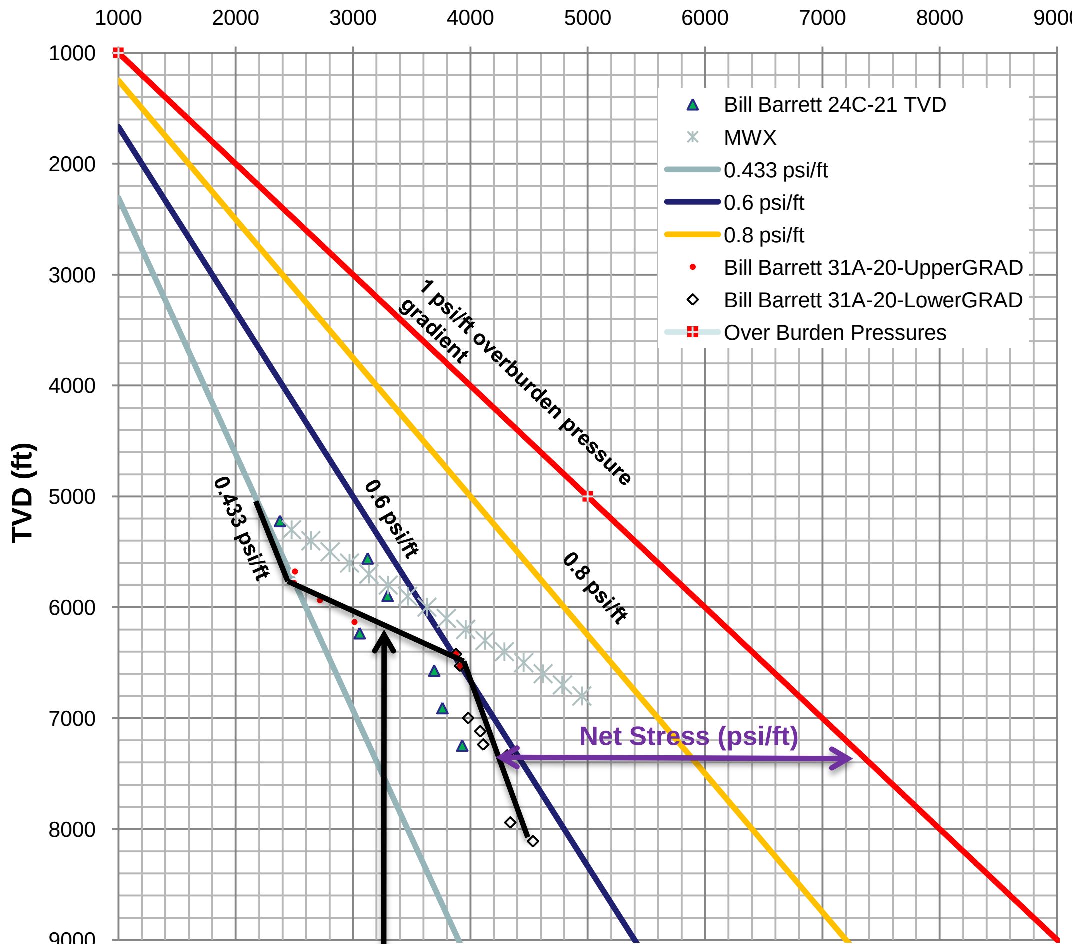
- Shaly sands
- Clean sands

# 3) Pressure Initialization

## Pressure Cross-Section

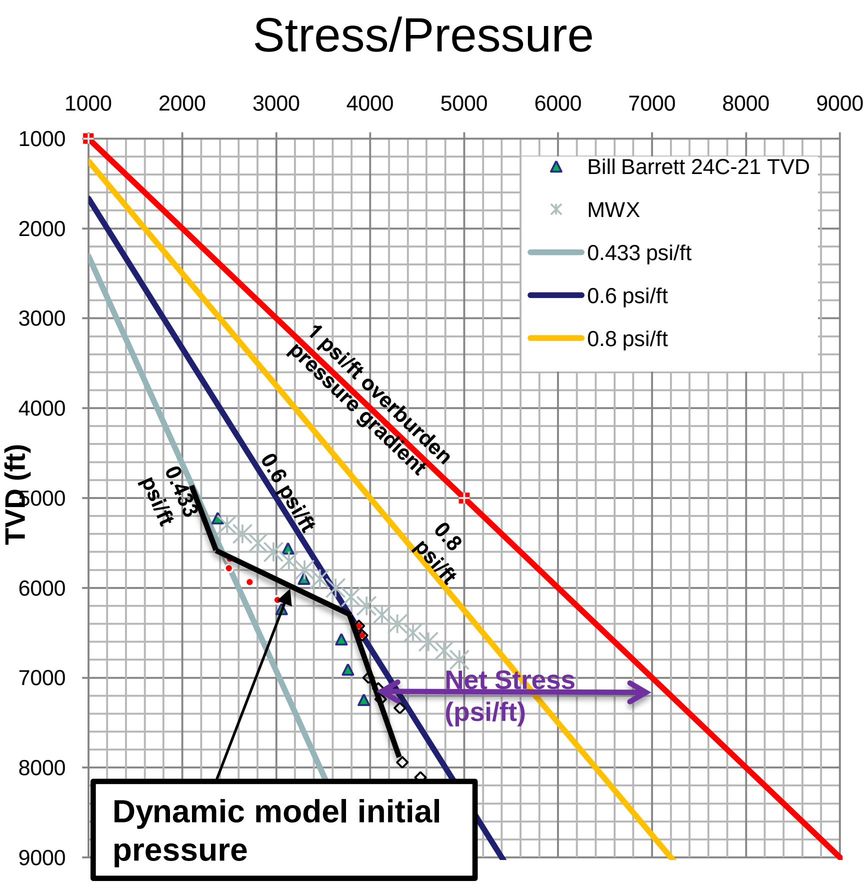



## Initial Pressure (all Cells)

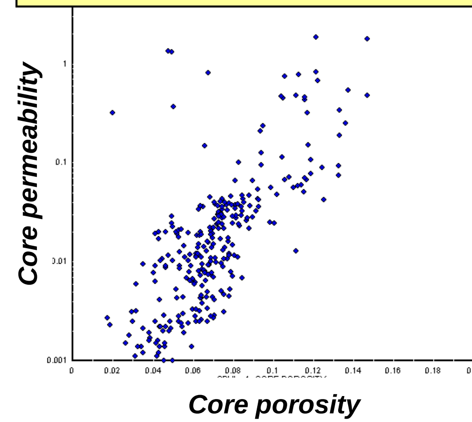



**Dynamic model was initialized along the black line**

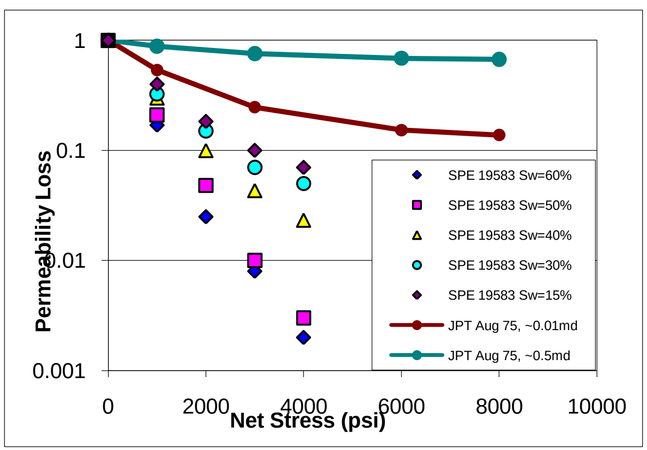
# Initial Pressure, Overburden and Permeability Correction




Phi-k from Core. Permeability distributed in geomodel is air perm at low NCS. Need to correct for reservoir initial conditions. (Net Stress, water presence, Klinkenberg k)



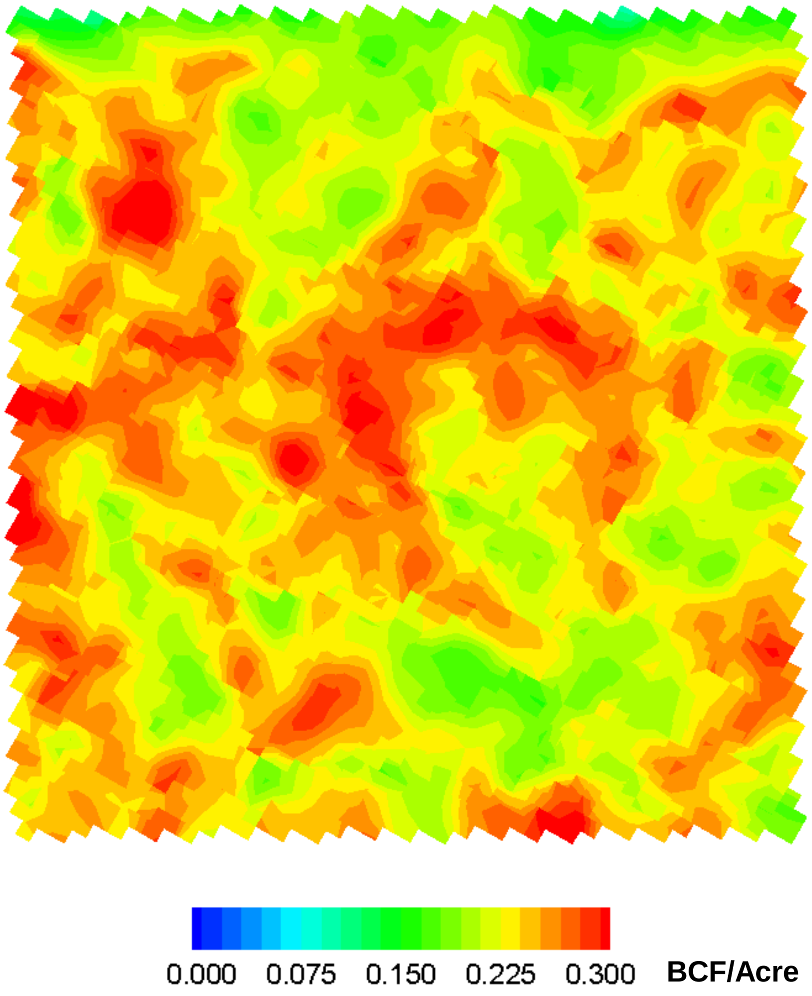

$$\phi, k_g = f(\text{Net Stress})$$




SPE 19583, The Effects of Depositional Environment on Petrophysical Properties of Mesaverde Reservoirs, Northwestern Colorado by Lorenz, Sattler, and Stein

# Initial Gas-In-Place, MSCF/Acre

| | |
|---|---|
| Area, acres | 183 |
| Net Pay Thickness, ft | 570 |
| Avg. Sg*Poro, % | 4.97% |
| Net-Phih*Sg, ft | 28.31 |
| Avg. kx(air), md | 0.0101 |
| Avg. kx(mod), md | 0.0011 |
| Avg BG, RB/MSCF | 0.9475 |
| GIP, BCF | 42 |
| BCF/640 acres | 148 |

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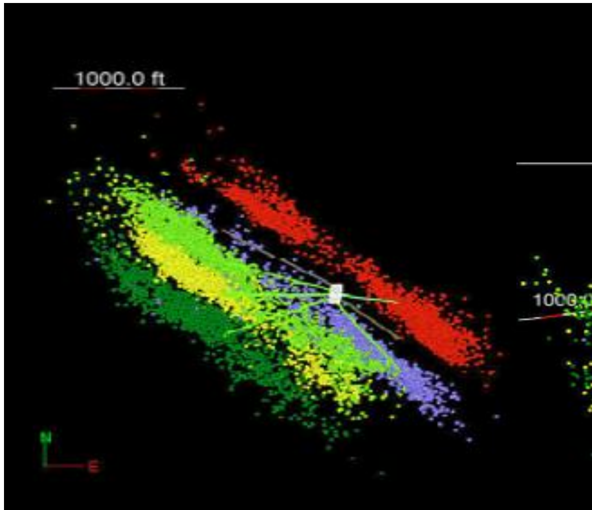
# 4) Hydraulic Fracture Representation

- Propped Length and Height
- Conductivity
- Orientation

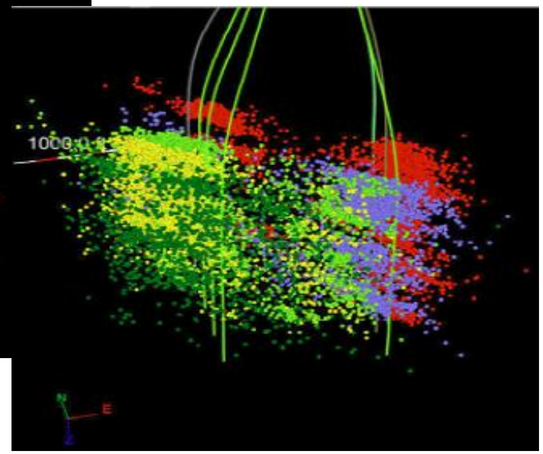
An "Ideal" Frac?

1,500,000 lbs of sands→
~15,000 $ft^3$ →
Height=2000ft
Length=400ft
Width=0.225inches

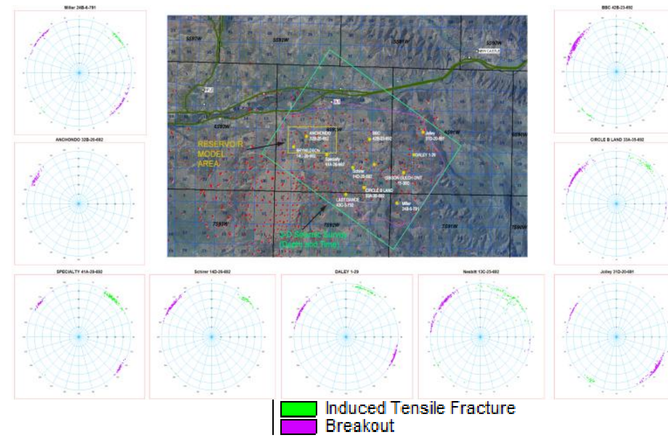
# Piceance Microseismic Example




Gibson Gulch areal view
of microseimic events



Gibson Gulch cross view
of microseimic events




Mamm Creek breakout orientation approximately N60W
Courtesy Sait Baytok

**L. Weijers, Y. Kama, J. Shemeta, and S. Cumella:**
**"Bigger is Better – Hydraulic Fracturing in the Williams Fork Formation in the Piceance Basin" Search and Discovery Article #110092, July 25, 2009, Adapted from extended abstract prepared for oral presentation at the AAPG Annual Convention, Denver, CO June 7-10, 2009**

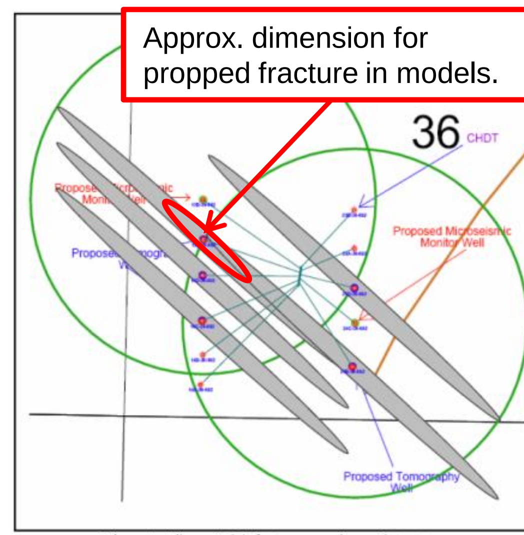
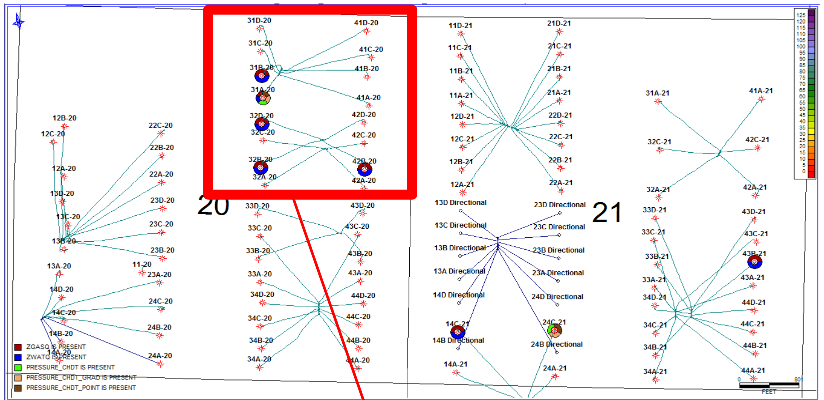



Figure 1. Gibson Gulch fracture mapping project setup.

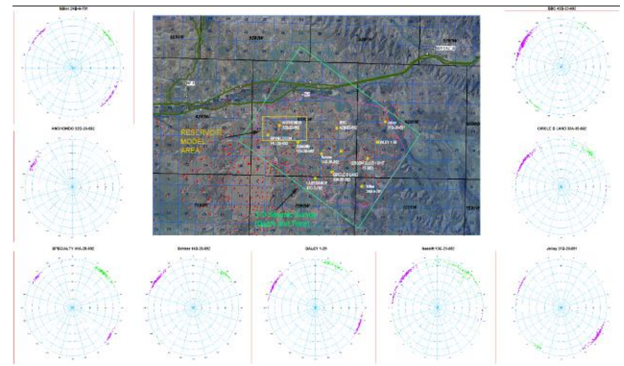
SPE 116304: "Effective propped half-lengths are significantly shorter than measured hydraulic half-lengths."

Note this data shows approximate N45W orientation.

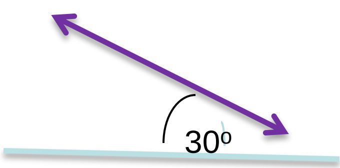
# Model Area and Hydraulic Fracture Representation

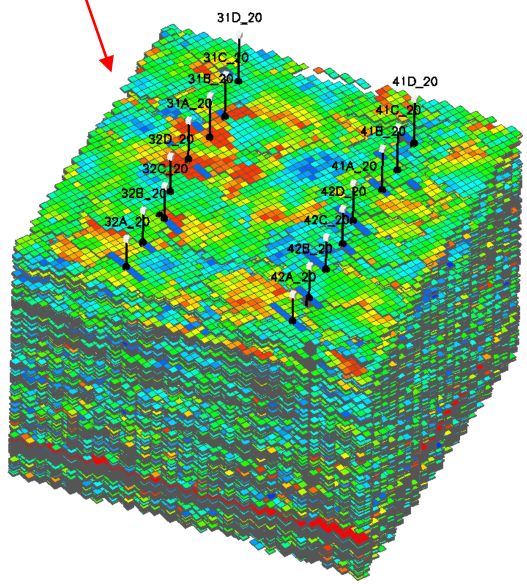



Area Borehole Breakout (Sait Baytok)

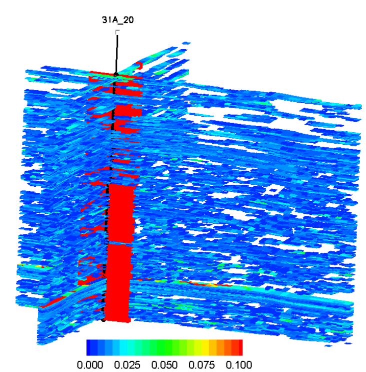


Simulation Grid Rotation for Hydraulic fracture representation

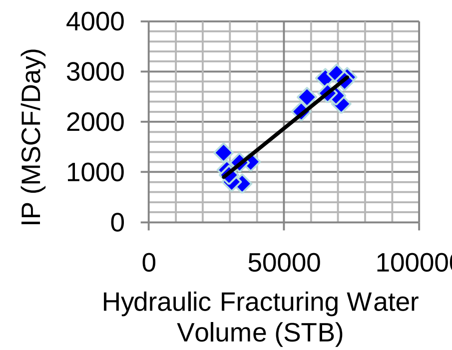



Simulated Hydraulic Fracture (Red = hydraulic fracture)




Model area IPs




- Near well perm boost for hydraulic fracture conductivity. Initial fracture conductivity 0.5-75 md-ft, xf 138-248ft

# 5) Calibration of Dynamic Model

- Well performance comparison
  - Model controlled by gas rate
  - Modeled pressures are compared with measurements
  - Two well groups based on hydraulic fracturing performance
  - The hydraulic fractures properties were independently adjusted for history matching
  - For five deeper wells in the model (deeper than modeled area) assume 10% gas came from the deeper zone
  - No “clean-up” / workover time is simulated
  - Water remains immobile

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# Calibrating to Rate Performance

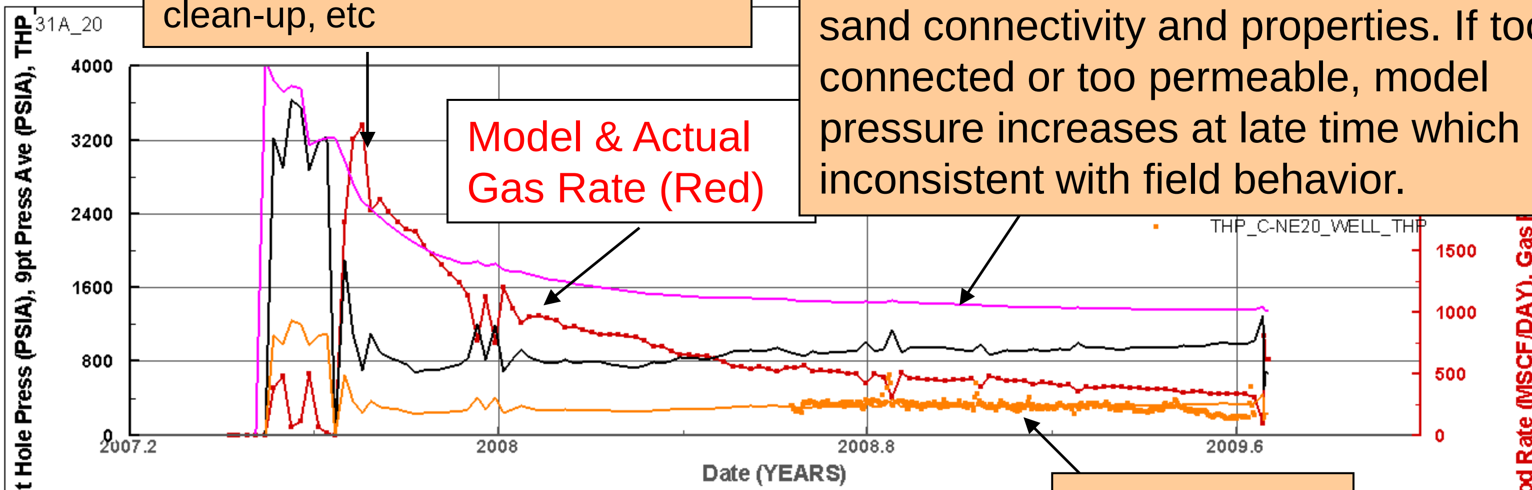
Early time behavior is dominated by hydraulic fracture properties, clean-up, etc

Model & Actual Gas Rate (Red)

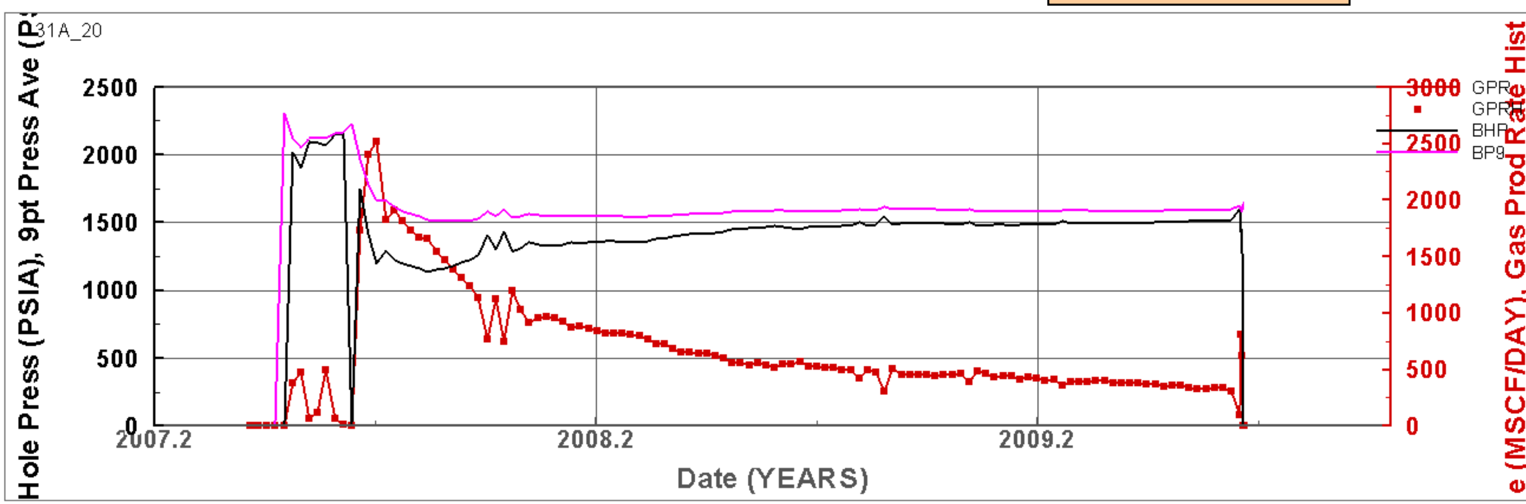
Late time near-well pressure affected by sand connectivity and properties. If too connected or too permeable, model pressure increases at late time which is inconsistent with field behavior.

Matched THP

Good Match




Over Predicted Permeabilities

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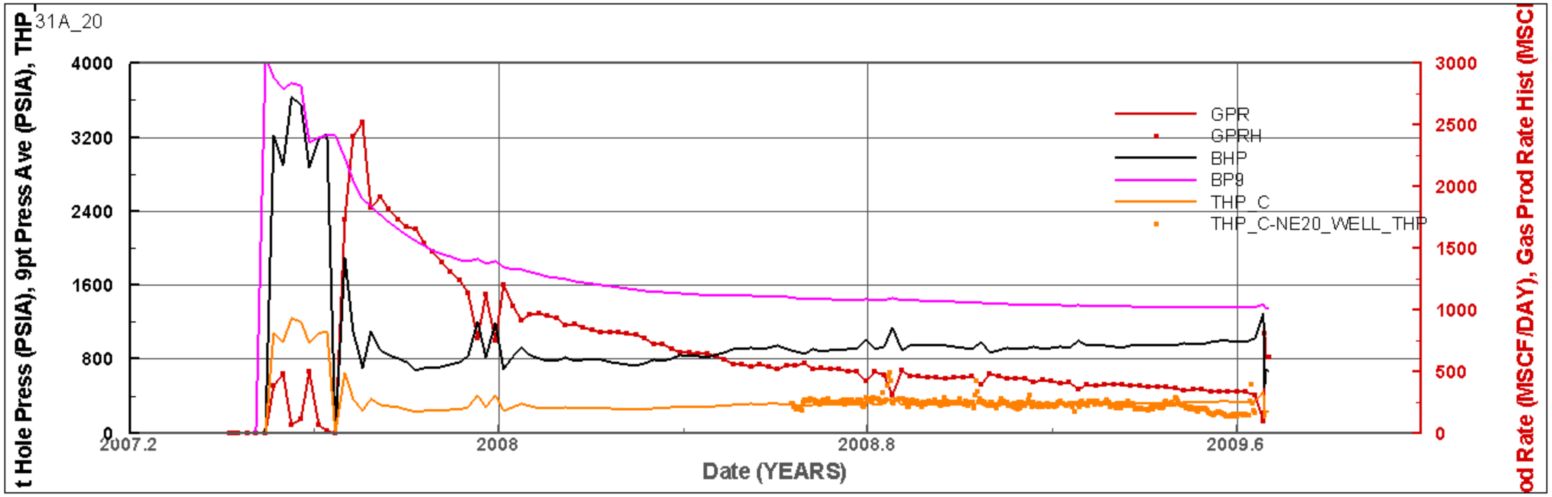
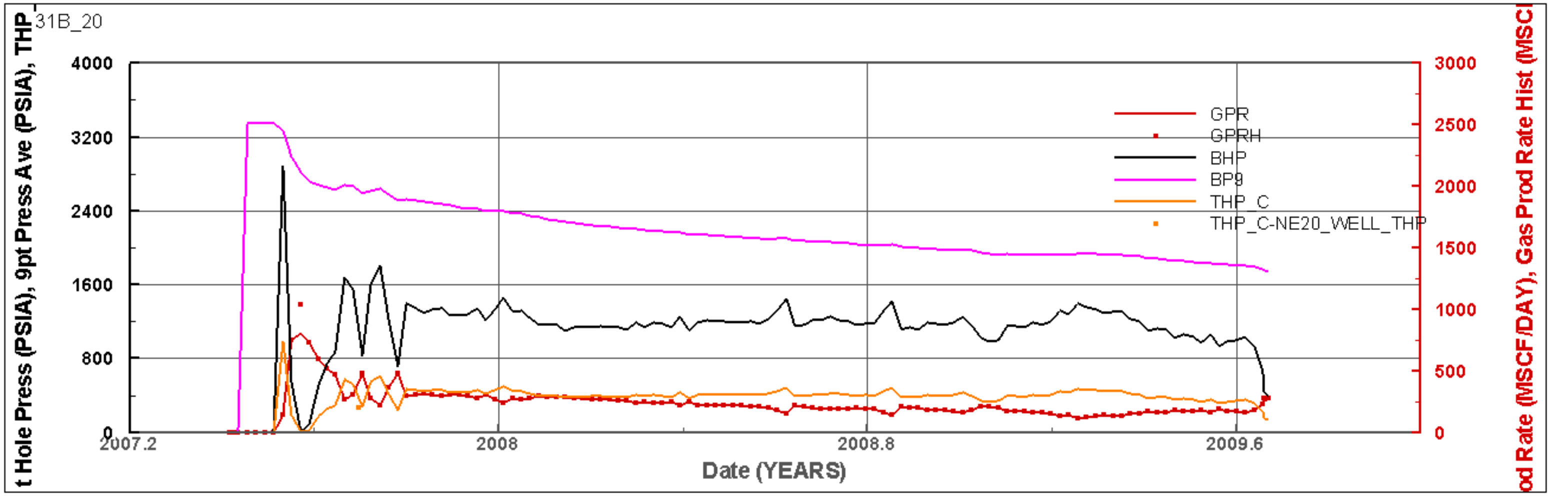
# Example of Well Simulation Results

High Rate Well Example (larger hydraulic fracture treatment)




Low Rate Well Example

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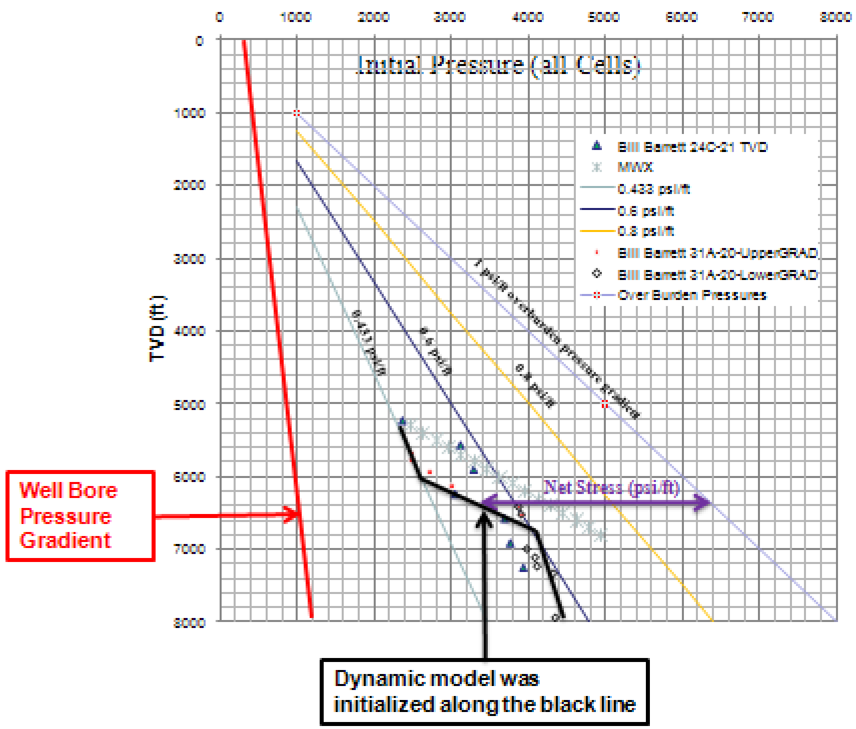
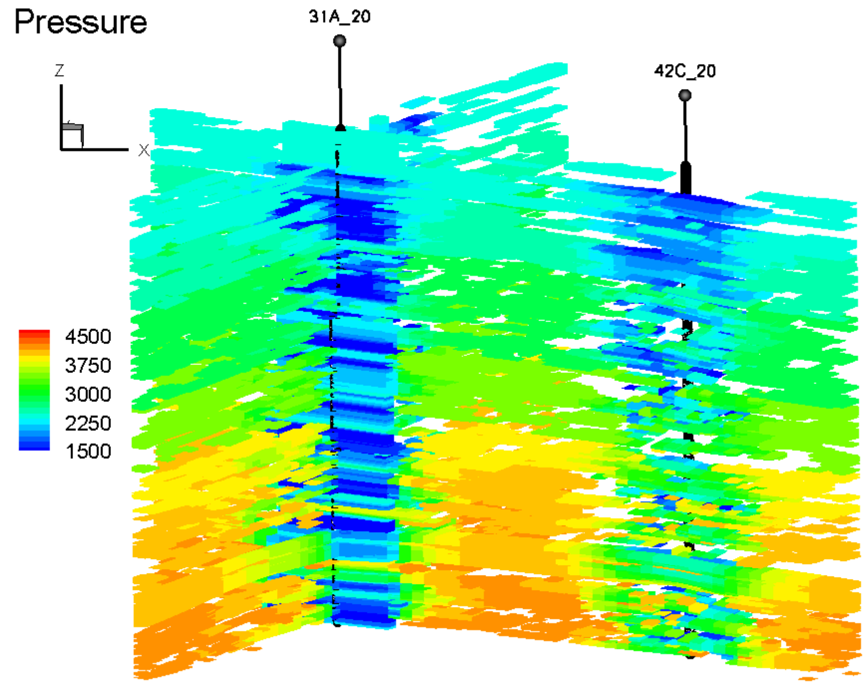
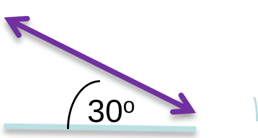
# Model Calculated Pressure Depletion

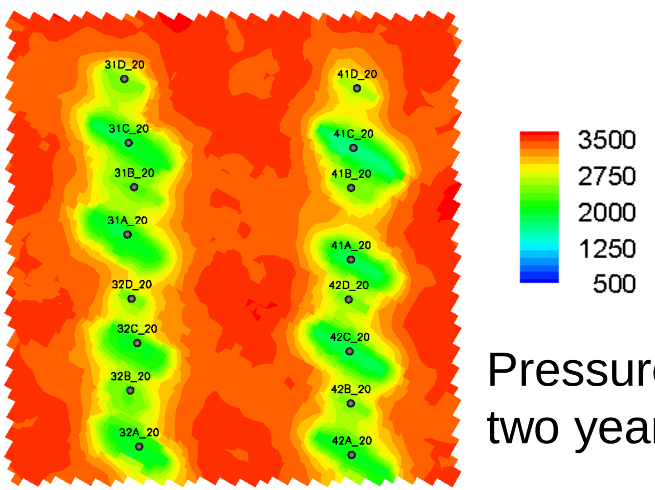



Cross-Section showing complex nature of pressure depletion

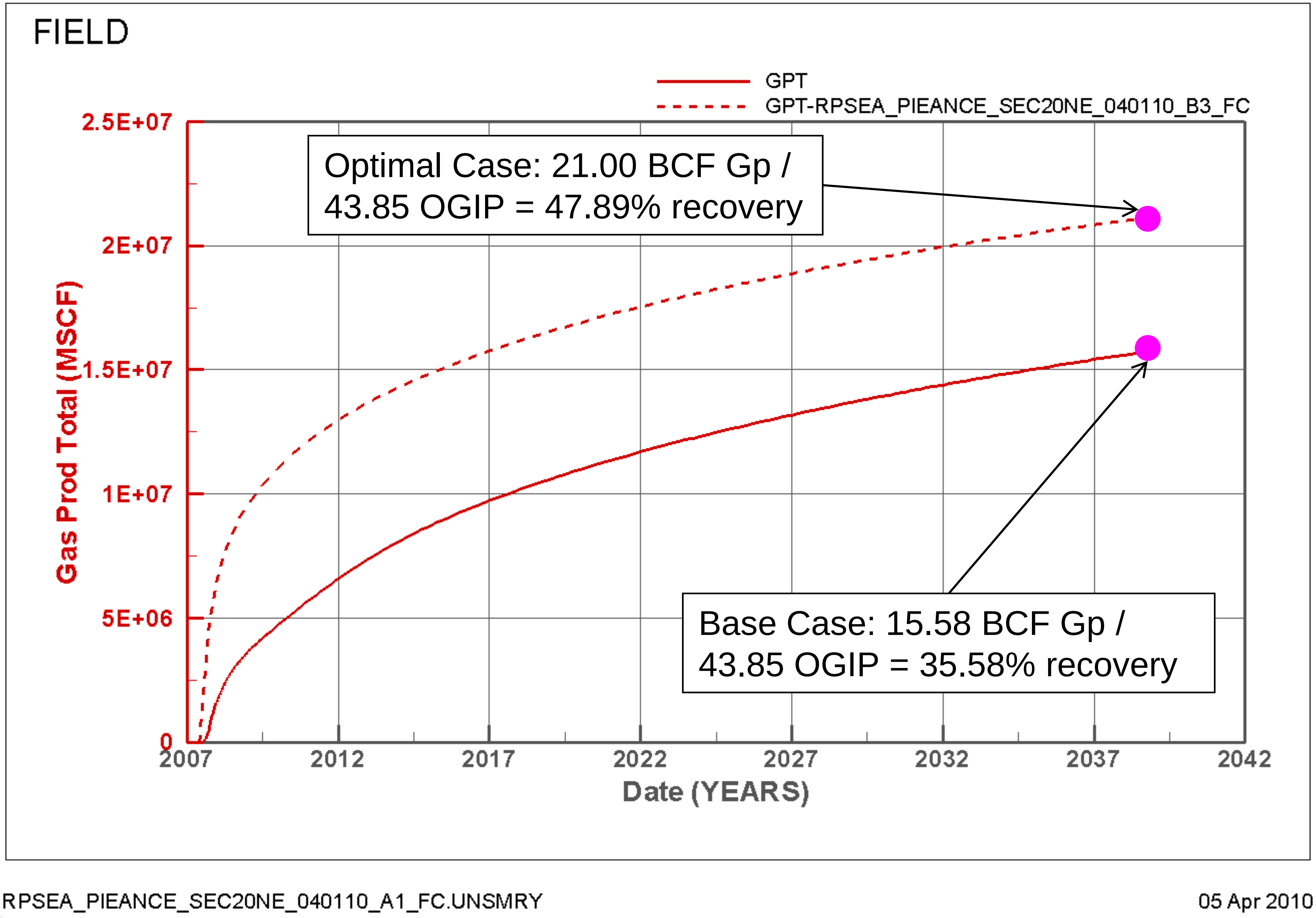
Hydraulic Fracture Orientation



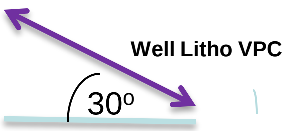

Pressure depletion after two years, current wells

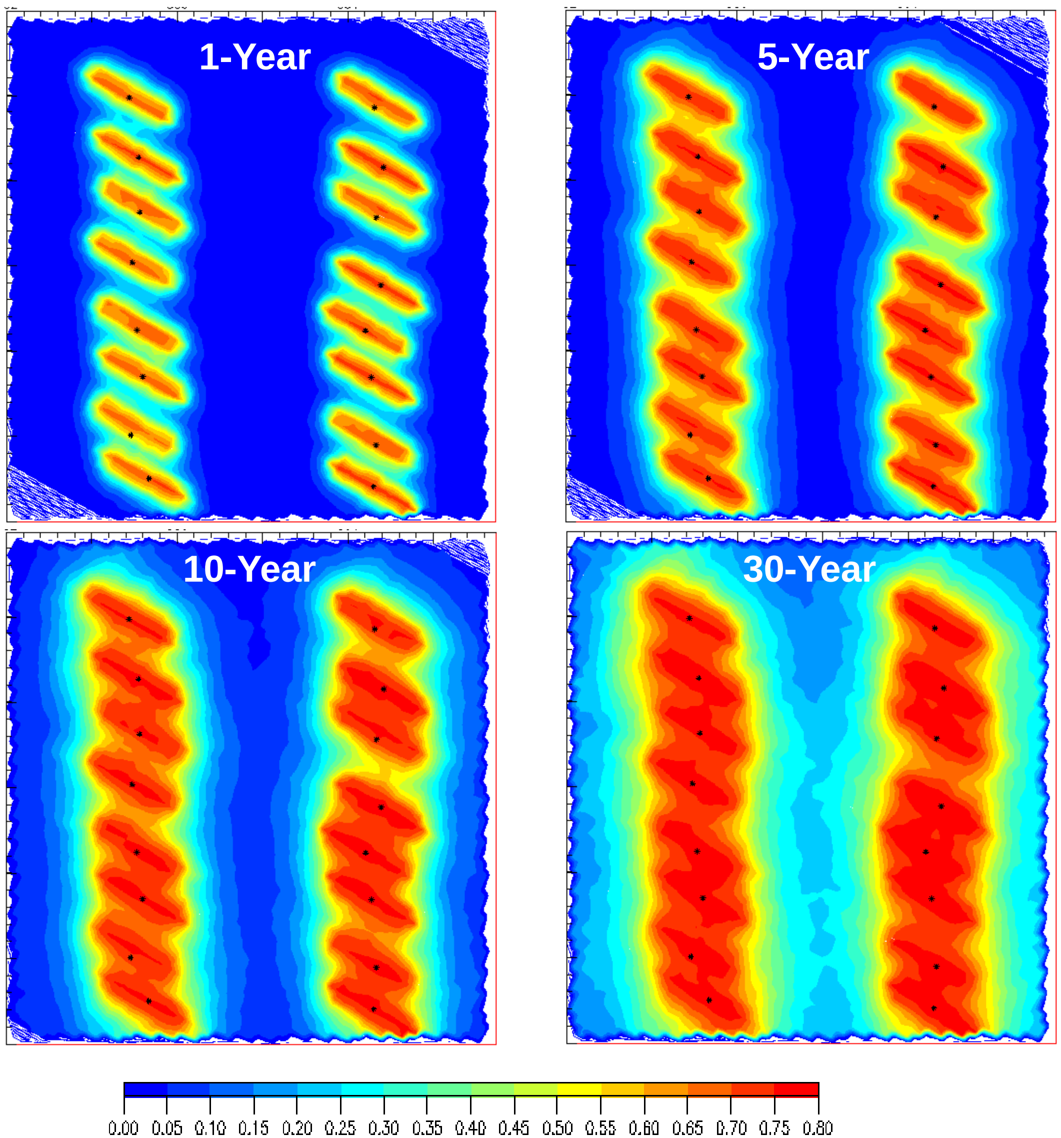
# 6) Simulator Predictions



# Optimal Case Long-Term Recovery

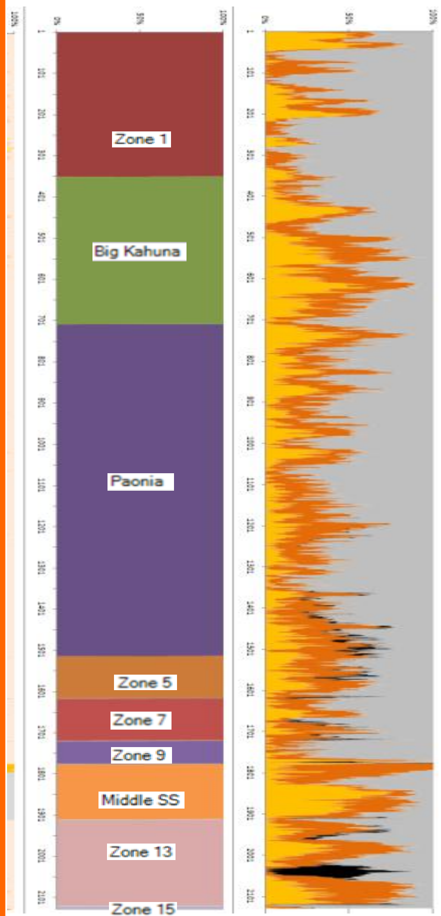
**Hydraulic Fracture Orientation**

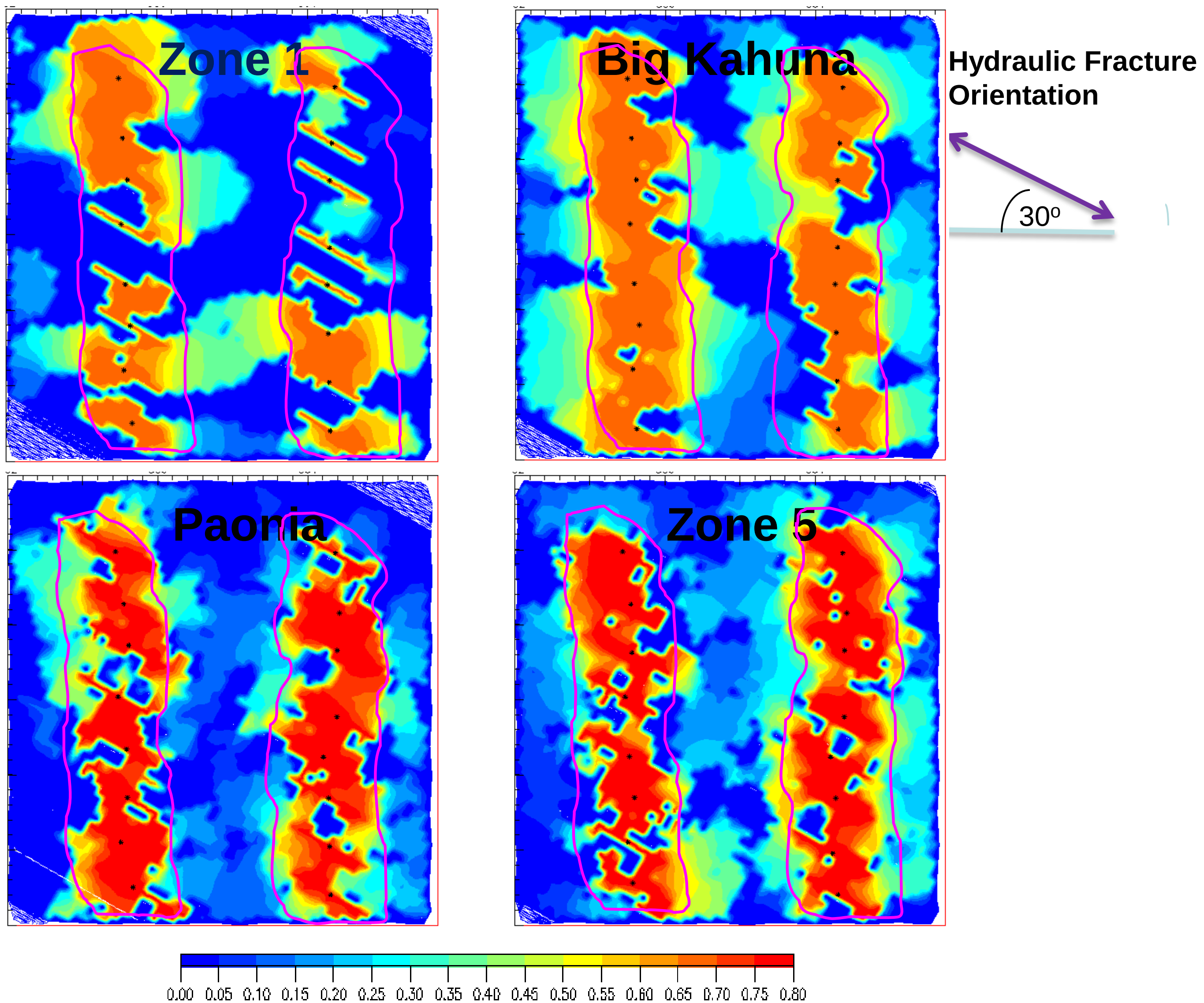



Recovery after 30 years, “optimal” hydraulic fractures (total = 48% OGIP)

# 30-Year for Several 25 ft Intervals




Recovery after 30 years, "optimal" hydraulic fractures, 25~30 ft thickness

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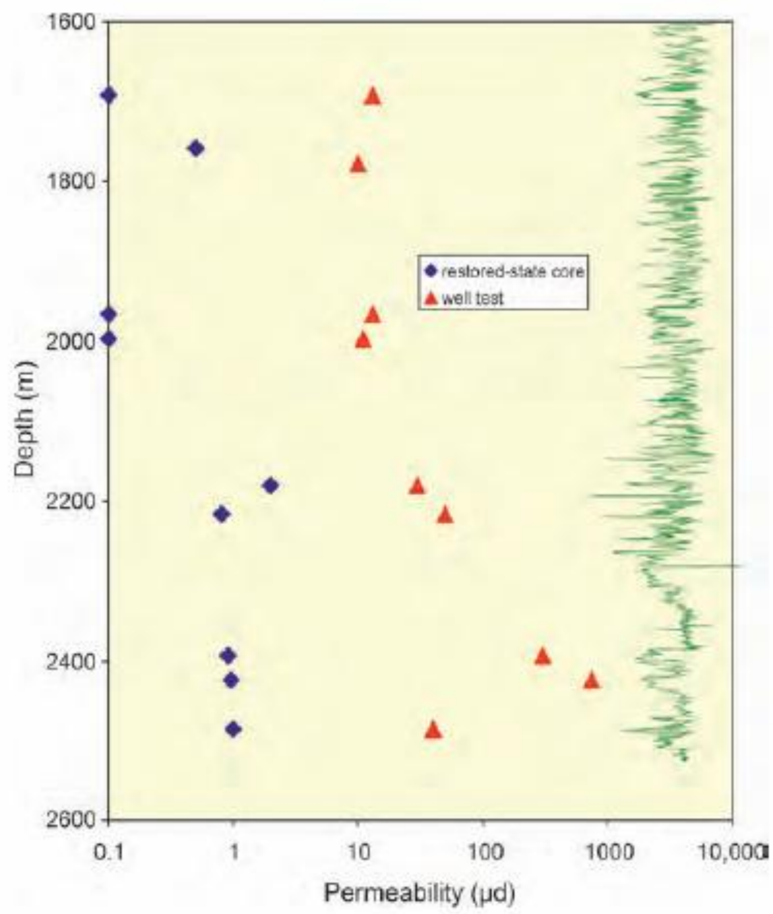
# Challenge 1: Natural Fractures

- There is evidence in the literature indicating that the natural fractures are important. This model can honor the historical gas rate assuming no natural fractures. This may be due to:
  - Underestimating the initial water volume
  - Underestimating initial matrix compaction
  - Overestimating the sand connectivity
  - Overestimating permeability between sand bodies




Norman R. Warpinski, and John C. Lorenz, 2008, "Analysis of the Multiwell Experiment Data and Results: Implications for the Base-centered Gas Model"

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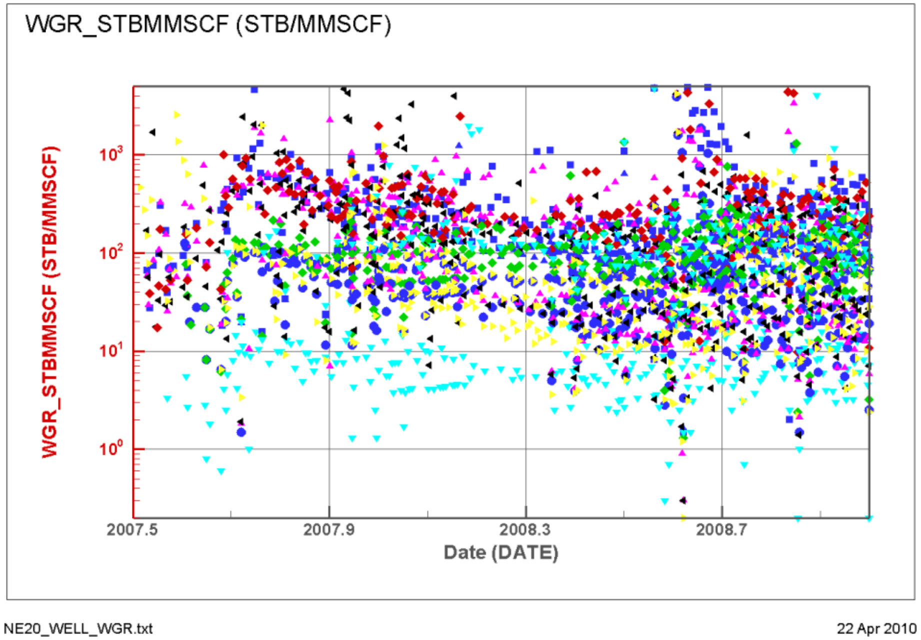
# Challenge 2: Water Production

- This model assumes immobile water. We believe that water has minimal impact on gas productivity (i.e. water and gas flow through separate pores or fractures). Thus other than the impact on lift efficiency we believe, that the long term performance is reasonably approximated. There are challenges representing mobile water in these systems:
  - What is the water source (no large source to sustain water rate from low compressibility water)
  - How to allow for water flow paths which will not become permeable flow paths for gas



# Summary

- An integrated approach has lead to realistic 3D geologic and dynamic models which are consistent with static data and historical performance.
- Such models are useful for estimating the impact of geologic uncertainty on early and long-time performance including well interference
- Hydraulic fractures dominate early performance; however, there is minimal data to constrain their properties leading to some non-uniqueness
- Future work will focus on calibration to different geologic modeling approaches (i.e.:
  - Sand distribution methods
  - Impact of natural fractures
  - Seismic constraints

# Acknowledgement


- RPSEA (Research Partnership to Secure Energy for America) for financial support
- Bill Barrett Corporation for providing much of the data and valuable insights
- CU-Boulder for geomodel and fracture analyses
- Other iReservoir and RPSEA team members for analyses and insights