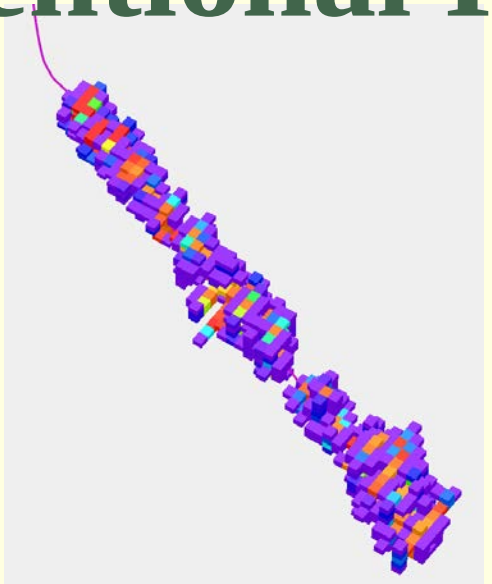
A Better Modeling Approach for Hydraulic Fractures in Unconventional Reservoirs



OUTLINE

- Numerical Simulation:

  Comparison of Conventional and

  NEW Approaches

- NEW Approach as a
  - Modeling Tool (understanding what has occurred)
    - Field Examples
  - Predictive Tool (investigating what might occur)
    - Field Examples

What Is Our Goal?

- To quantify the impact of different strategies
  - Well placement
  - Well spacing
  - Well orientation
  - Number of stages
  - Fracture treatment rates
  - Fracture treatment volumes
  - Cluster spacing (if applicable)
  - Perforation density (if applicable)

How Do We Achieve The Goal?

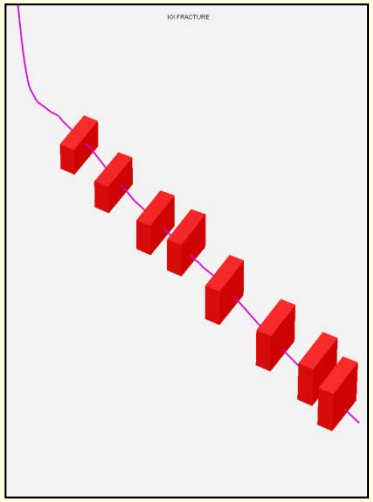
- Unlike the early days, we have thousands of wells and performance data
- Post-mortem analysis is the **key** to understand the controlling parameters
- This can only be achieved by sophisticated approaches that can account for the interaction among controlling parameters
- Must be able to predict outcomes for different well placement/completion strategies
- Must be able to predict outcomes for multi-well applications where interference is important

How Do We Achieve The Goal?

- We need very sophisticated, integrated (geomechanics/flow) simulation models that can be quickly **calibrated** for:
  - Fracking operation for all stages
  - Flow-back period for frack fluid
  - Production period for oil/gas/water
- Use the **calibrated** models to study alternatives:
  - Well placement, orientation, spacing
  - Completion design
  - Frack operation

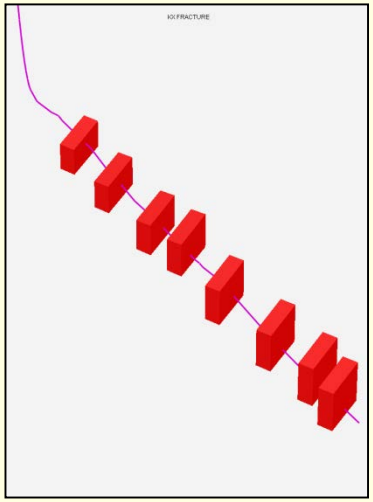
Conventional modeling approach

- Estimate reservoir matrix and natural fracture properties



Conventional modeling approach

- Estimate reservoir matrix and natural fracture properties
- Assume SRV geometry
  - Estimate fracture height
  - Estimate fracture half length
  - Estimate fracture frequency
  - Estimate distribution



Conventional modeling approach

- Estimate reservoir matrix and natural fracture properties
- Assume SRV geometry
  - Estimate fracture height
  - Estimate fracture half length
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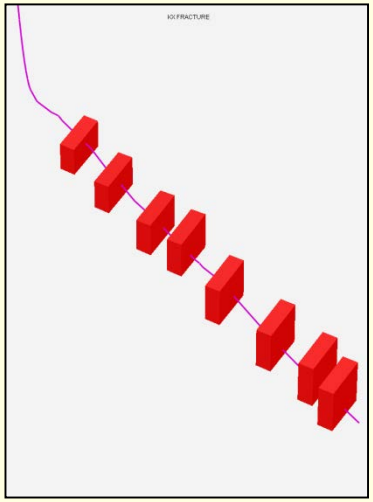
  - Estimate distribution
- Calibrate to post-fracturing production performance only
  - Has limited predictive capability



NEW modeling approach

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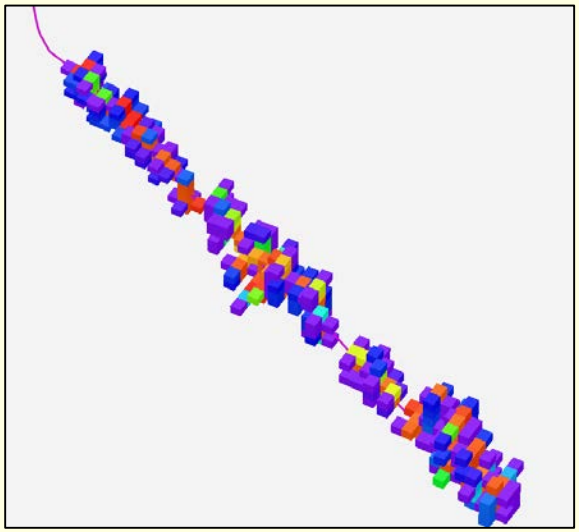
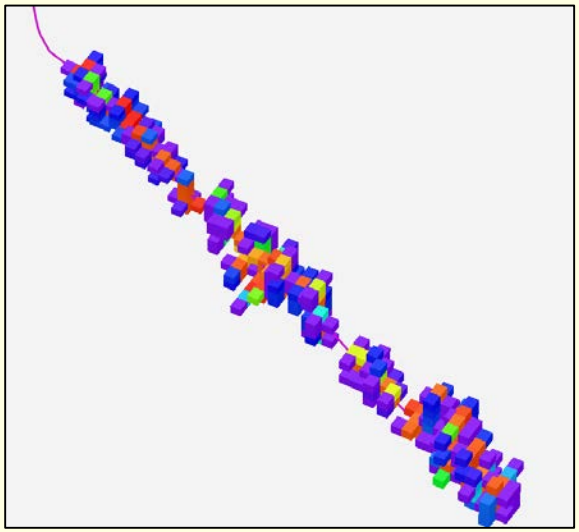


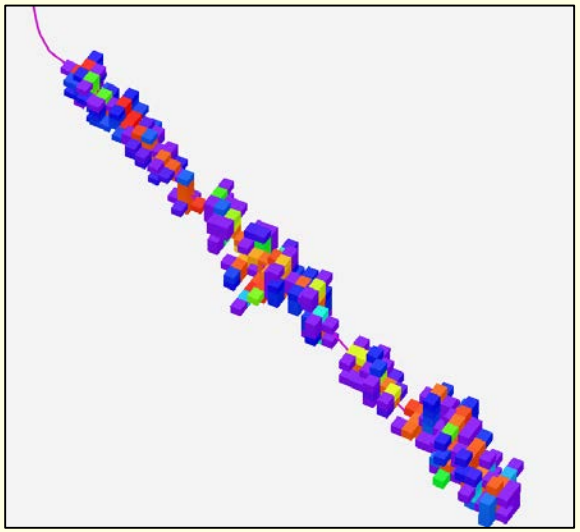
NEW modeling approach

- Estimate reservoir matrix and natural fracture properties
- Generate SRV geometry and properties as part of the calibration process



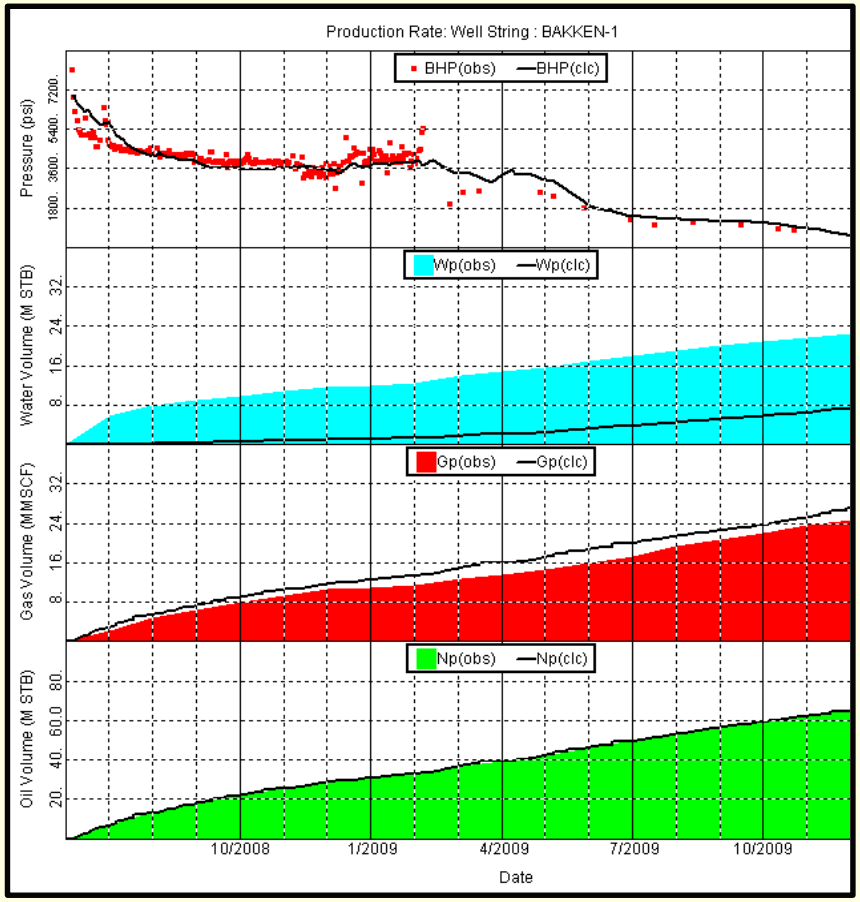
NEW modeling approach

- Estimate reservoir matrix and natural fracture properties
- Generate SRV geometry and properties as part of the calibration process
- Calibrate to the fracture treatment, flow back and production periods
  - Calibration through tuning of the geomechanical properties which define the SRV parameters
    - fracture height
    - fracture half length
    - fracture frequency
    - distribution (complexity, location of complexity)



Conventional\NEW approach

Conventional



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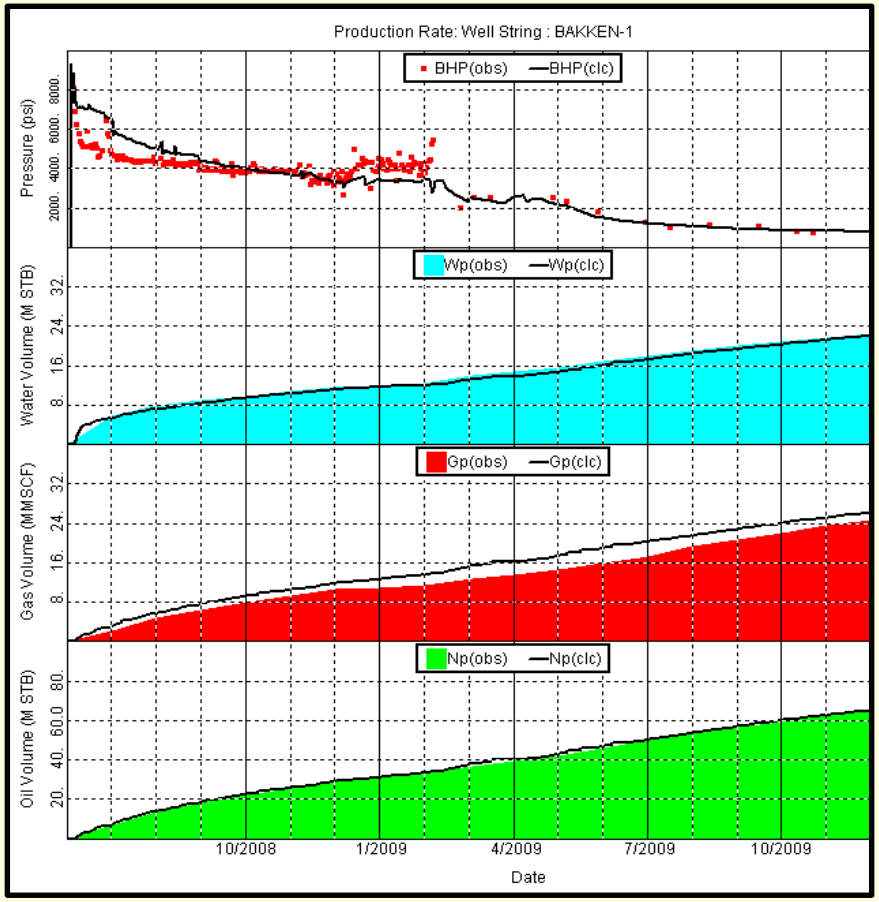
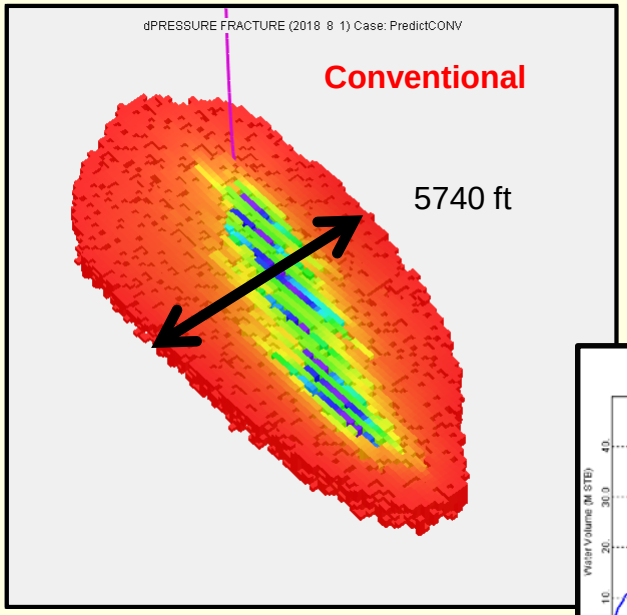
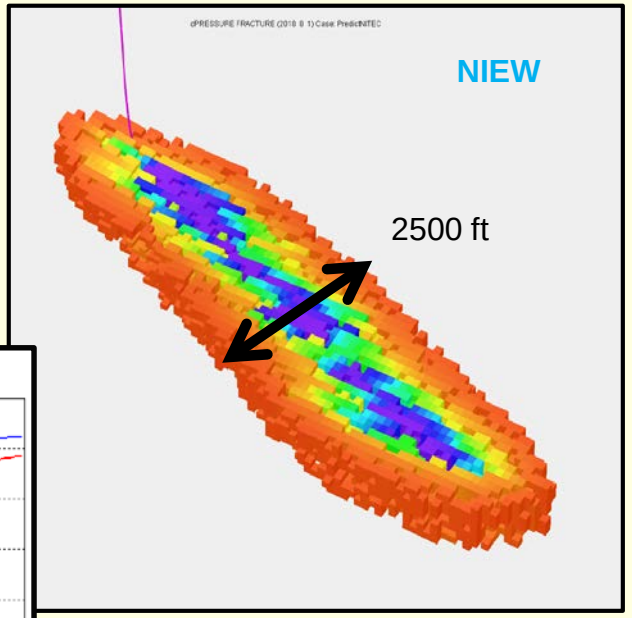
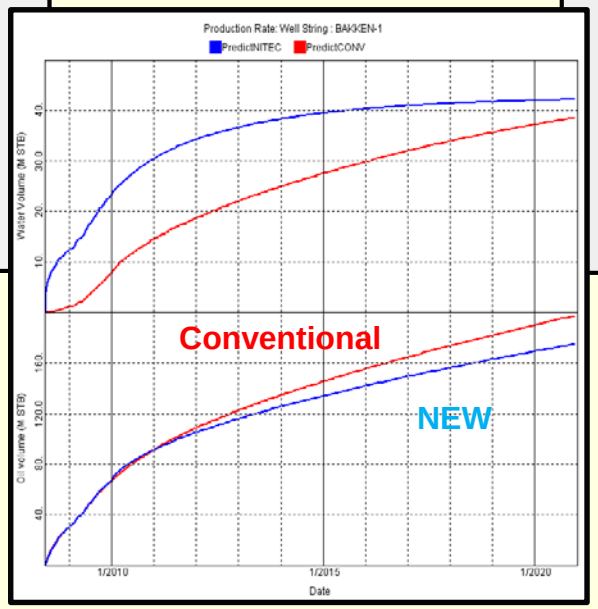


Conventional\NEW approach



Example~10 yrs





Difference in EUR
Difference in Drainage Area

SRV Generation – What We Used to Think

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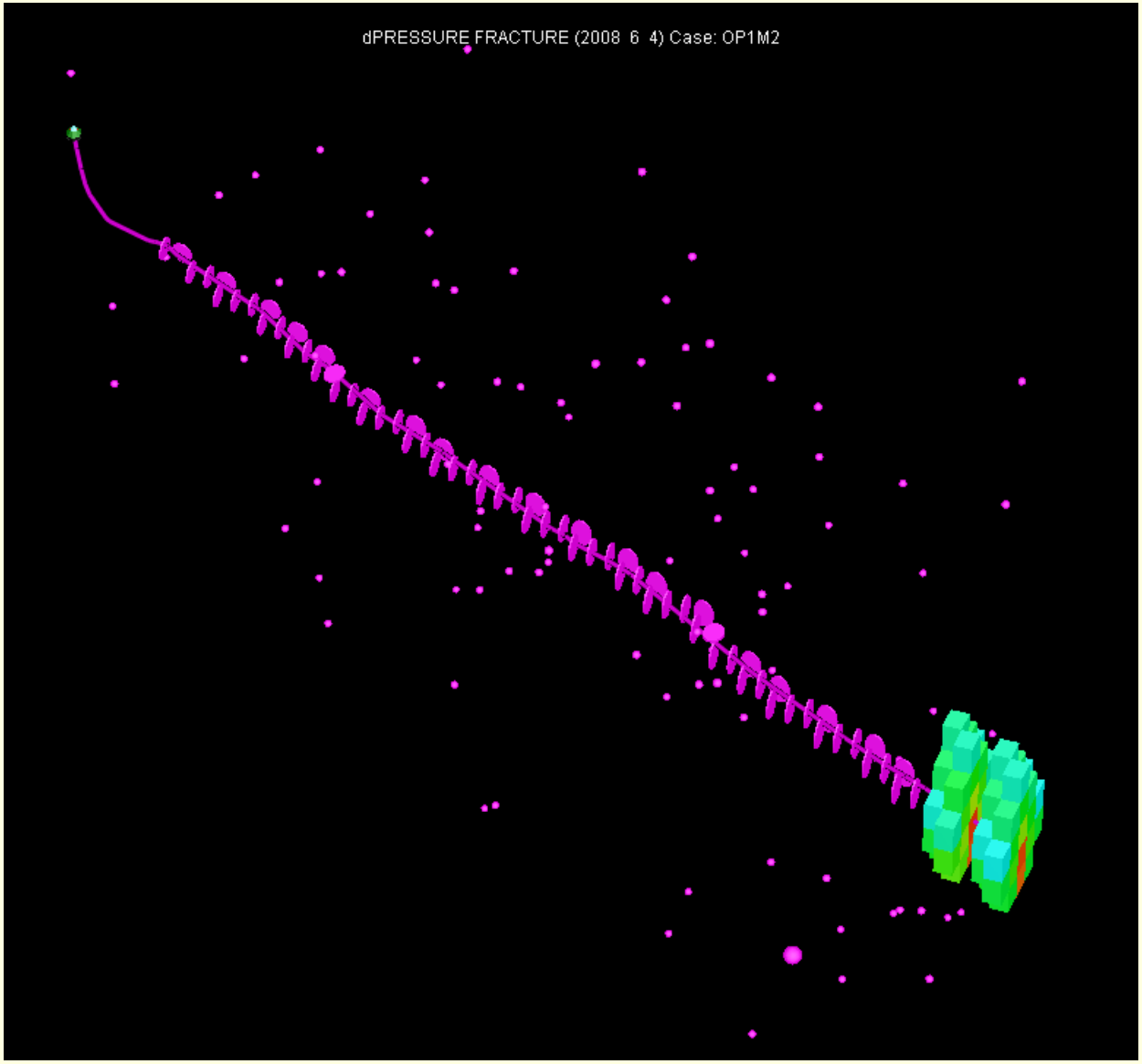

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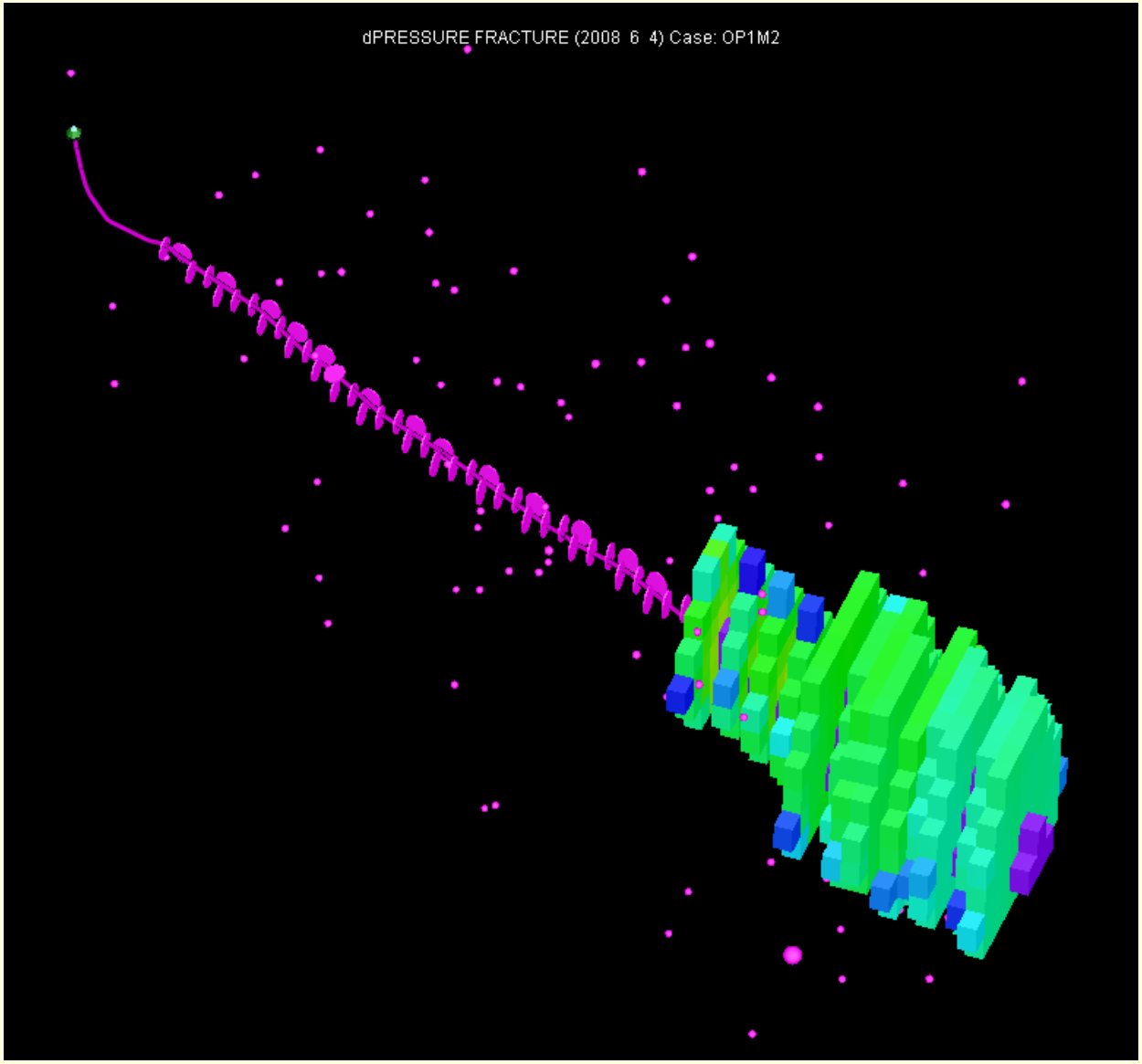

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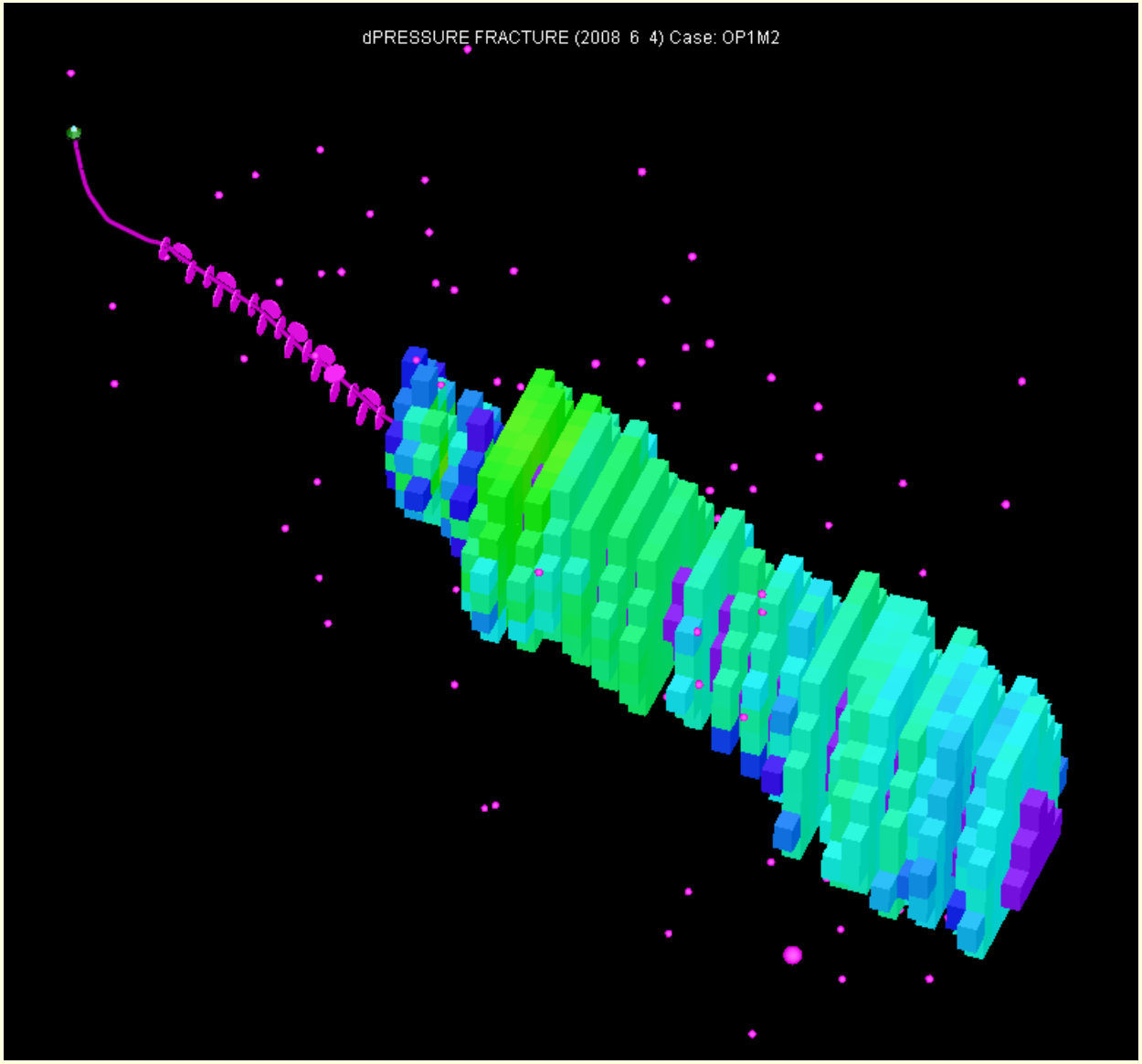

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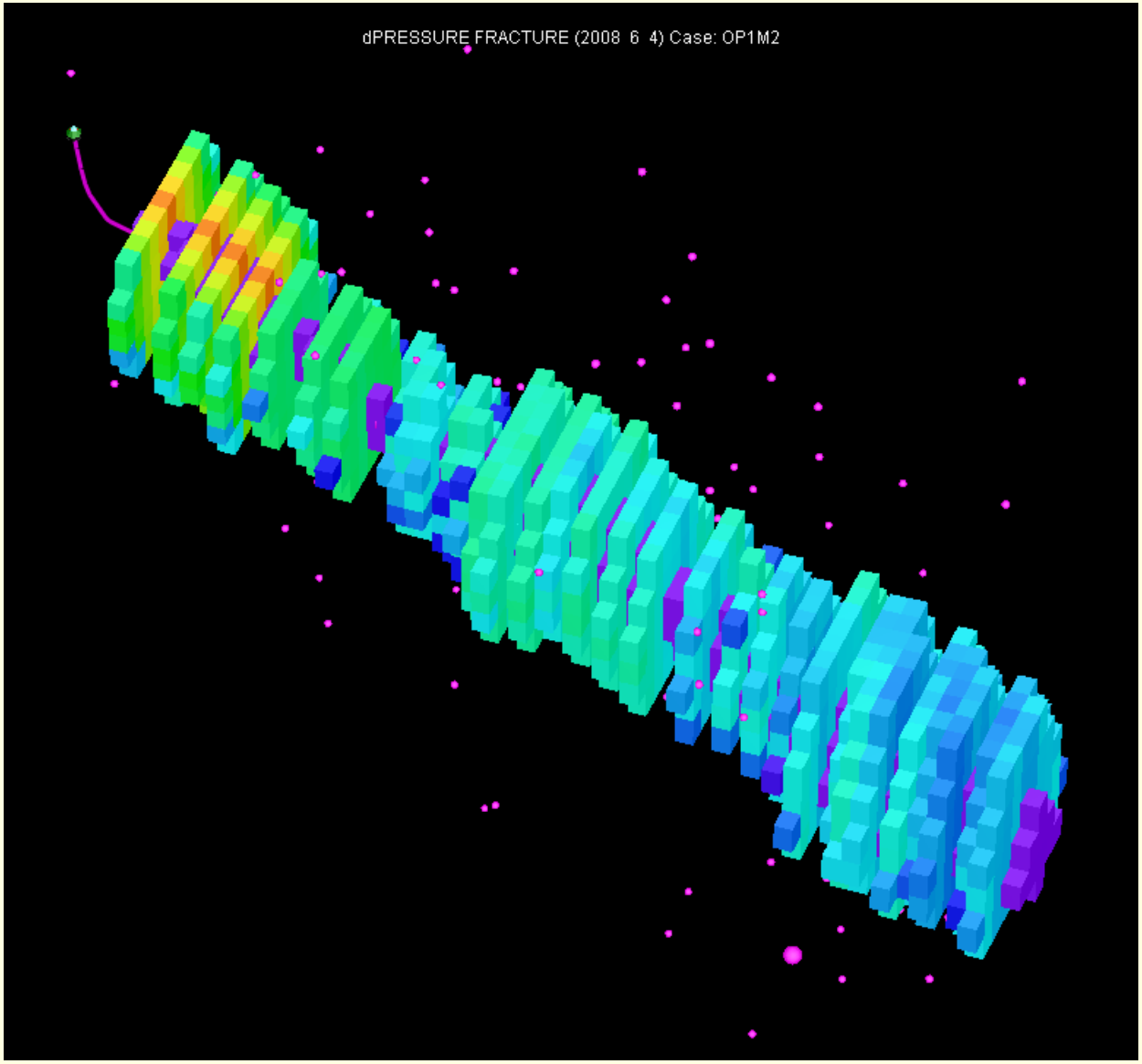

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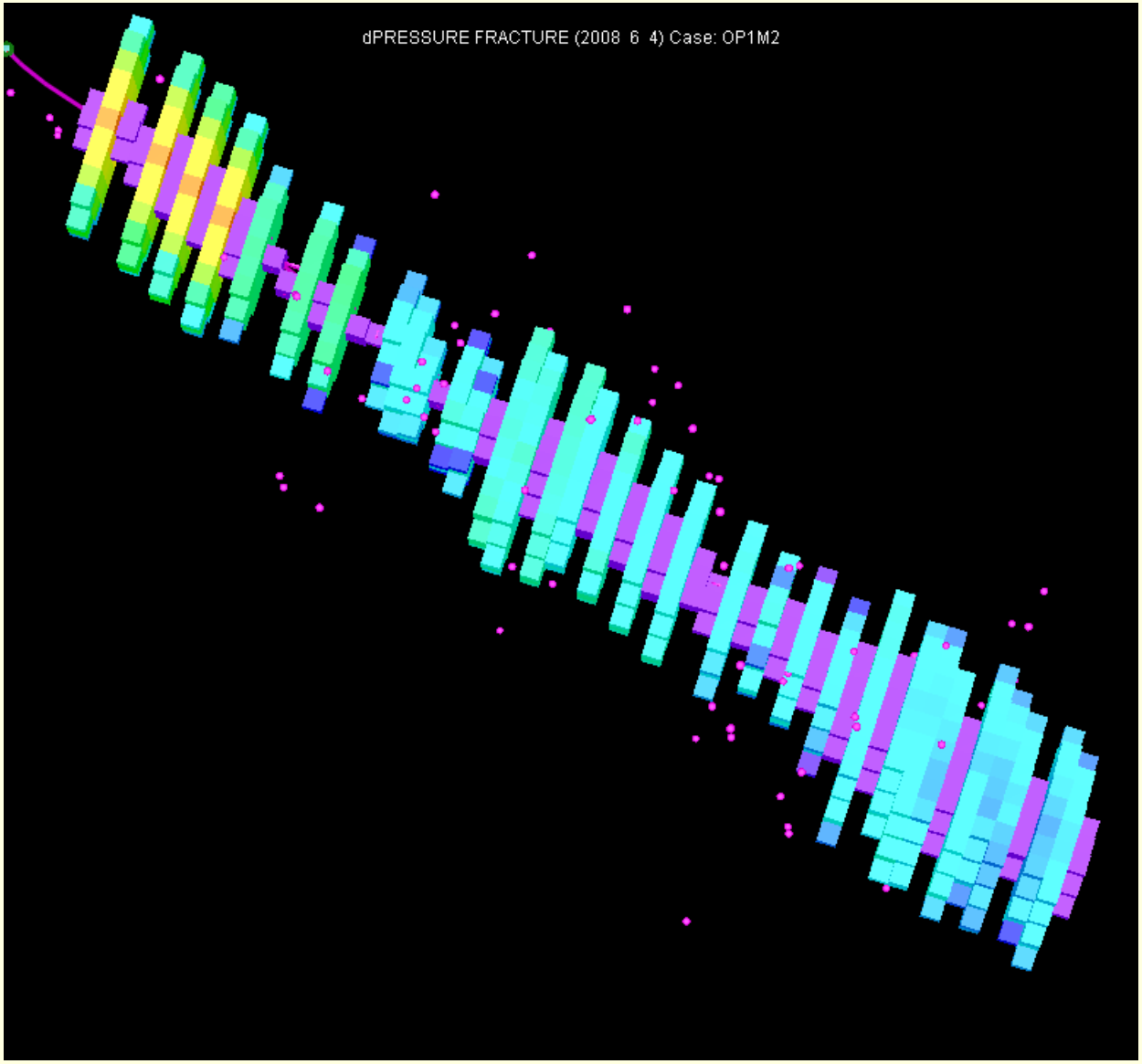

SRV Generation – What It Really Looks Like

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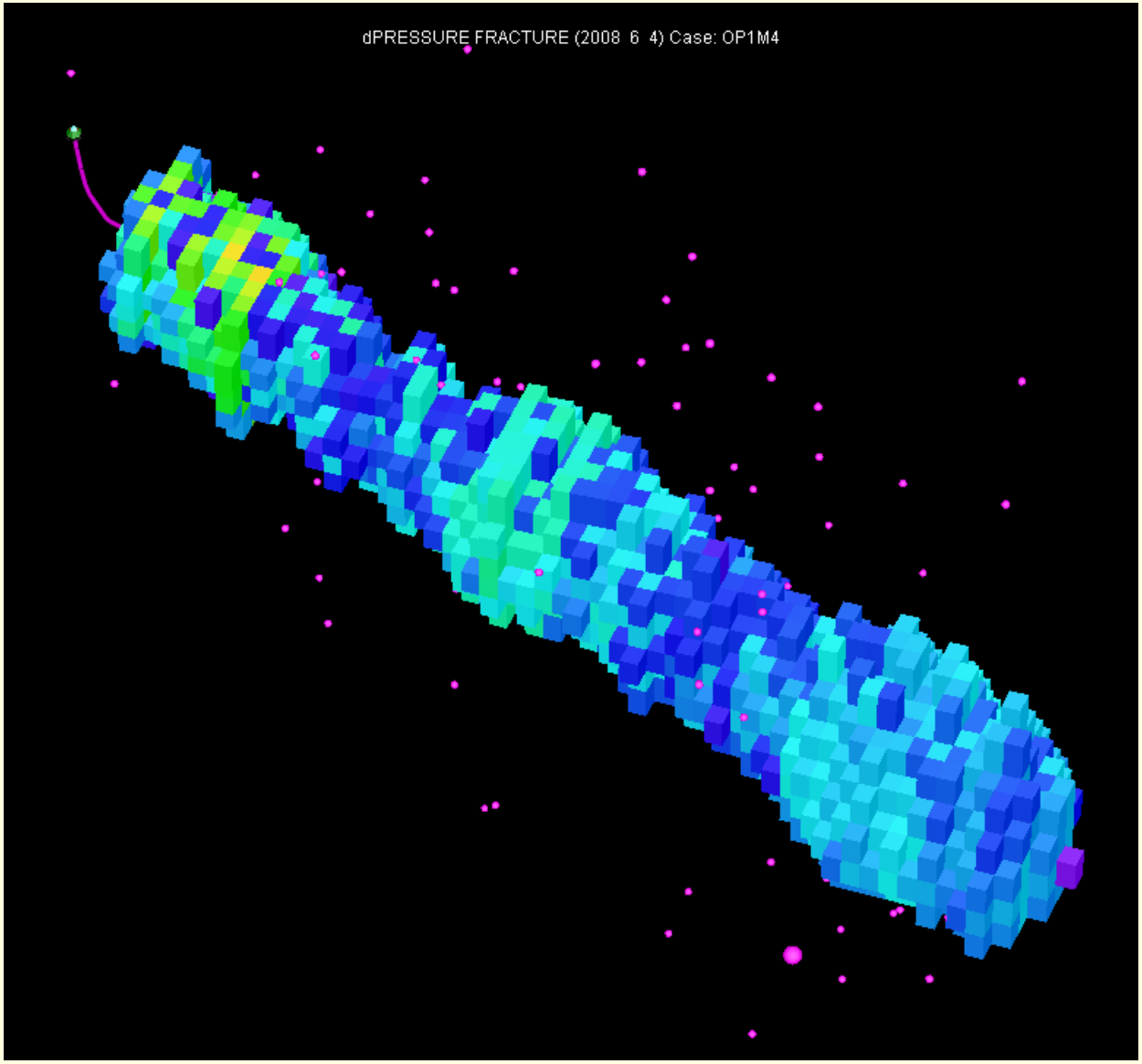

NEW Approach as a Modeling Tool

Use a finite difference simulator

with geomechanical capabilities,

in dual porosity mode,

to simulate the life of a hydraulically fractured well from the first stage of fracturing to the end of its productive life.

NEW Approach as a Modeling Tool

- SENSOR® is a finite difference simulator with pseudo geomechanical capabilities
  - Generates fractures by simulating the growth of the SRV during the frac treatment
- MatchingPro® is an assisted history matching program
  - Introduction of geomechanical properties multiplies the complexity of the history matching process

NEW Approach as a Modeling Tool

- Accounts for net pore pressure (stress) changes from initial conditions throughout the frac treatment (stage by stage) and during subsequent depletion

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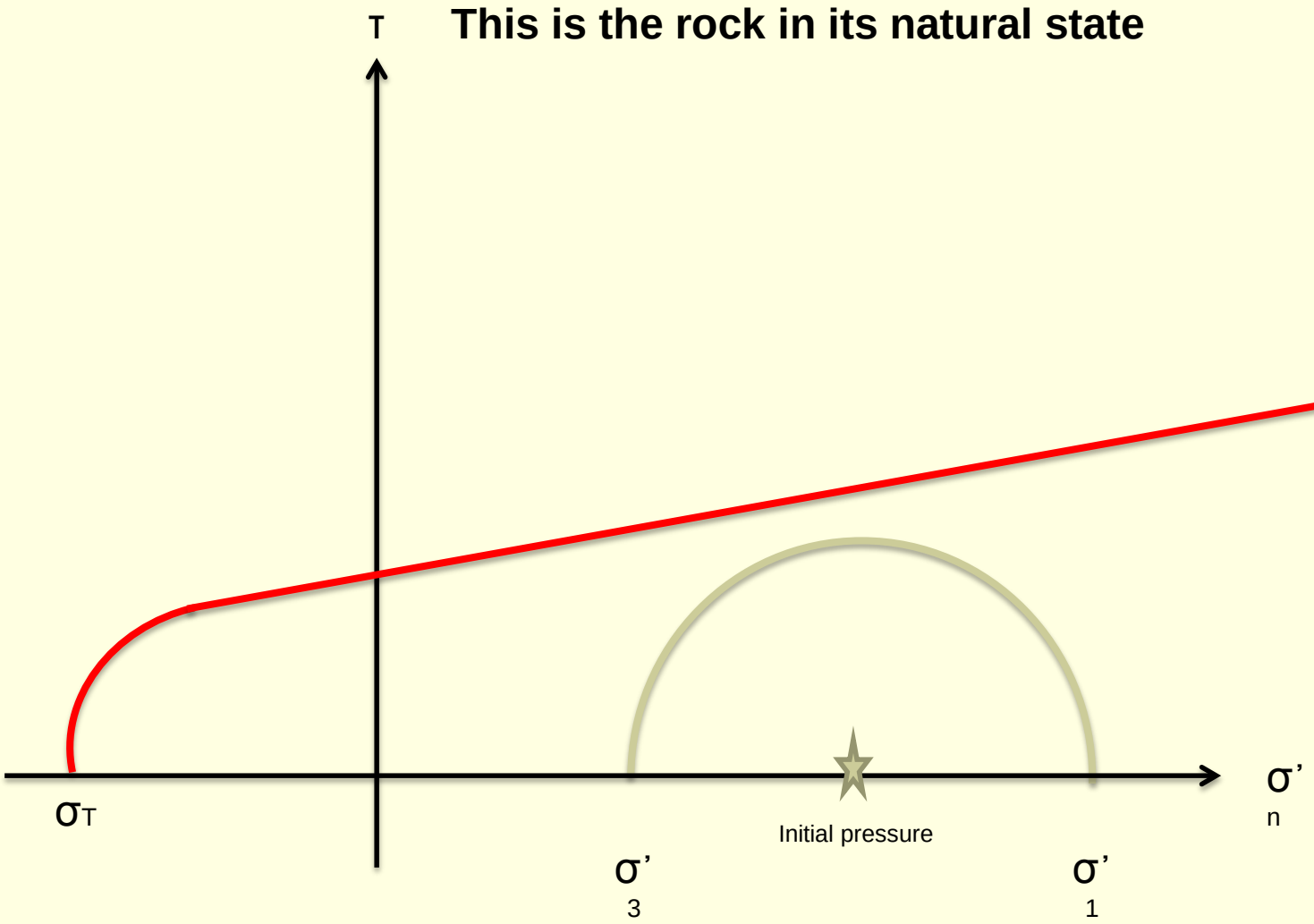
NEW Approach as a Modeling Tool

- Accounts for net pore pressure (stress) changes from initial conditions throughout the frac treatment (stage by stage) and during subsequent depletion
- Process allows for tensile and shear rock failures
- Accordingly the net pore pressure impacts
  - fracture pore volume and transmissibility and
  - the matrix-fracture communication (TEX) change

Mohr-Coulomb Failure Criteria



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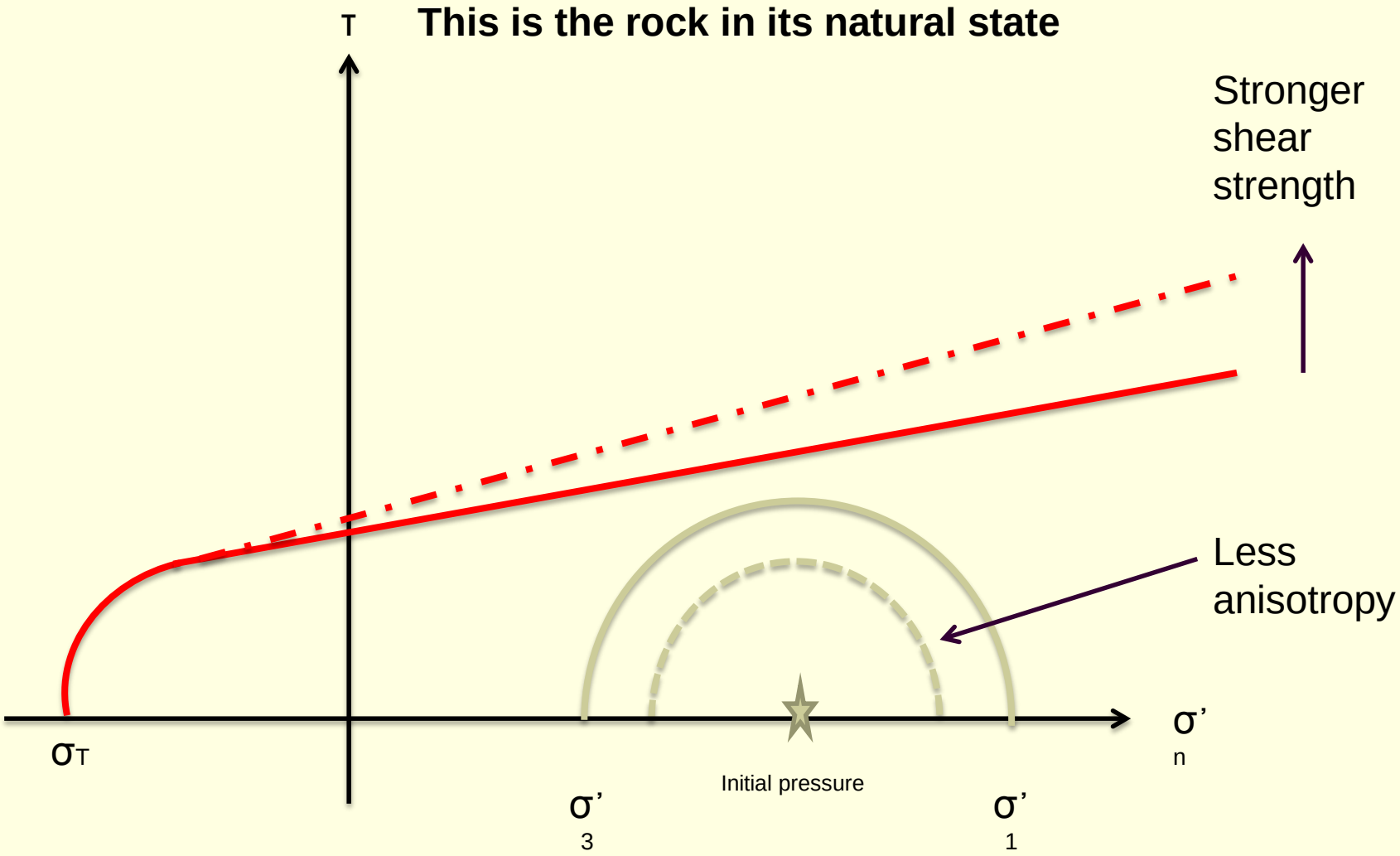

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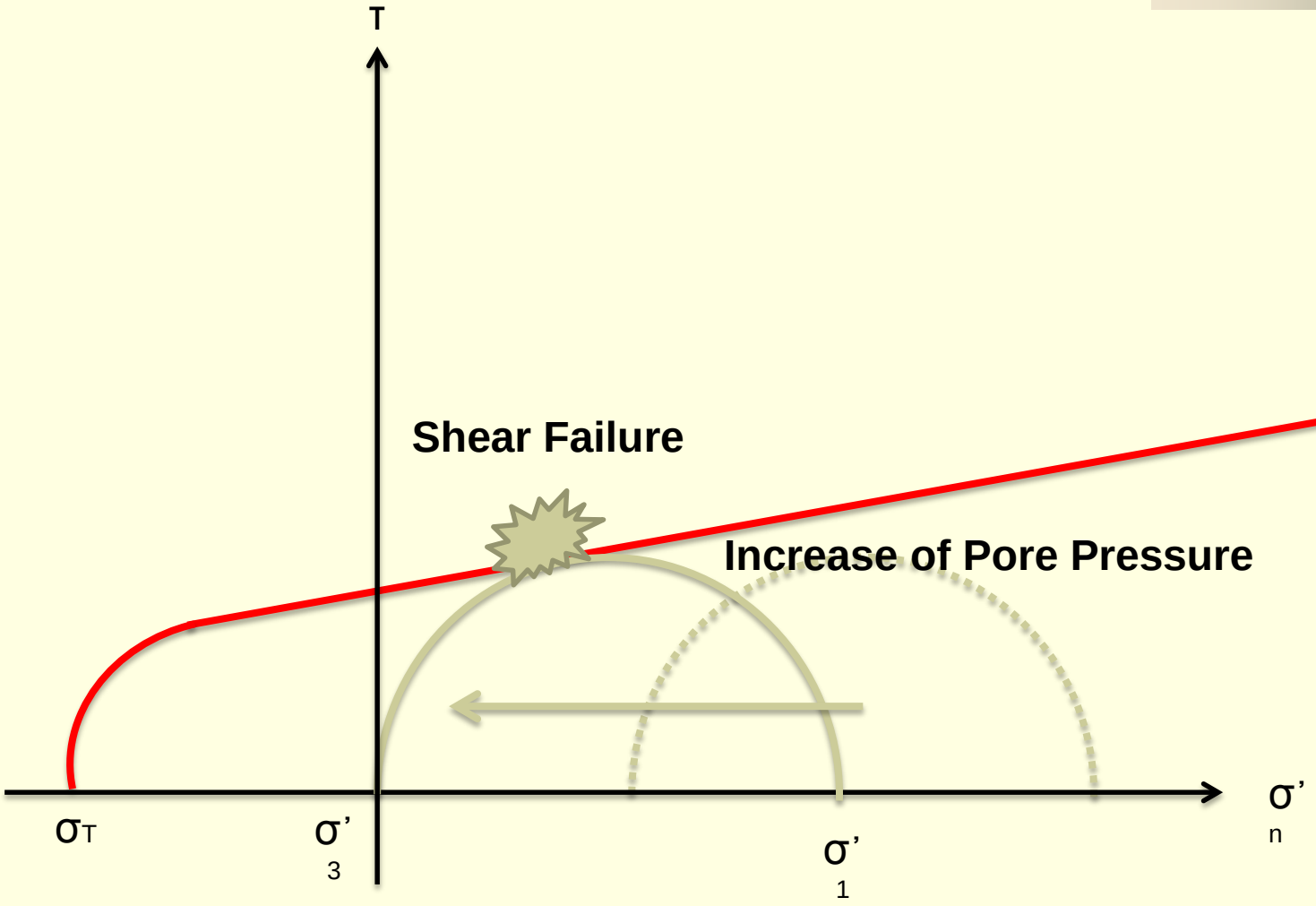

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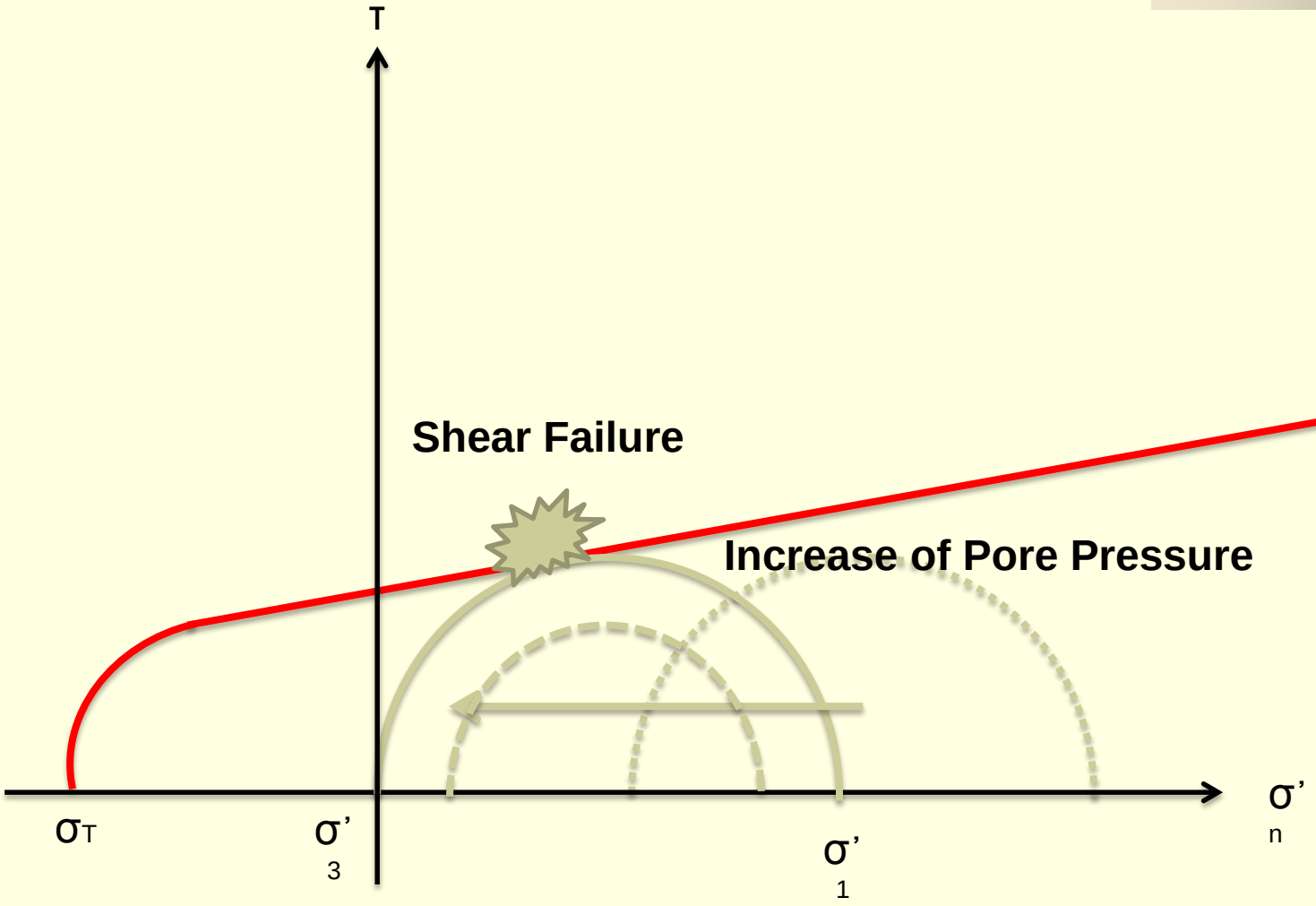
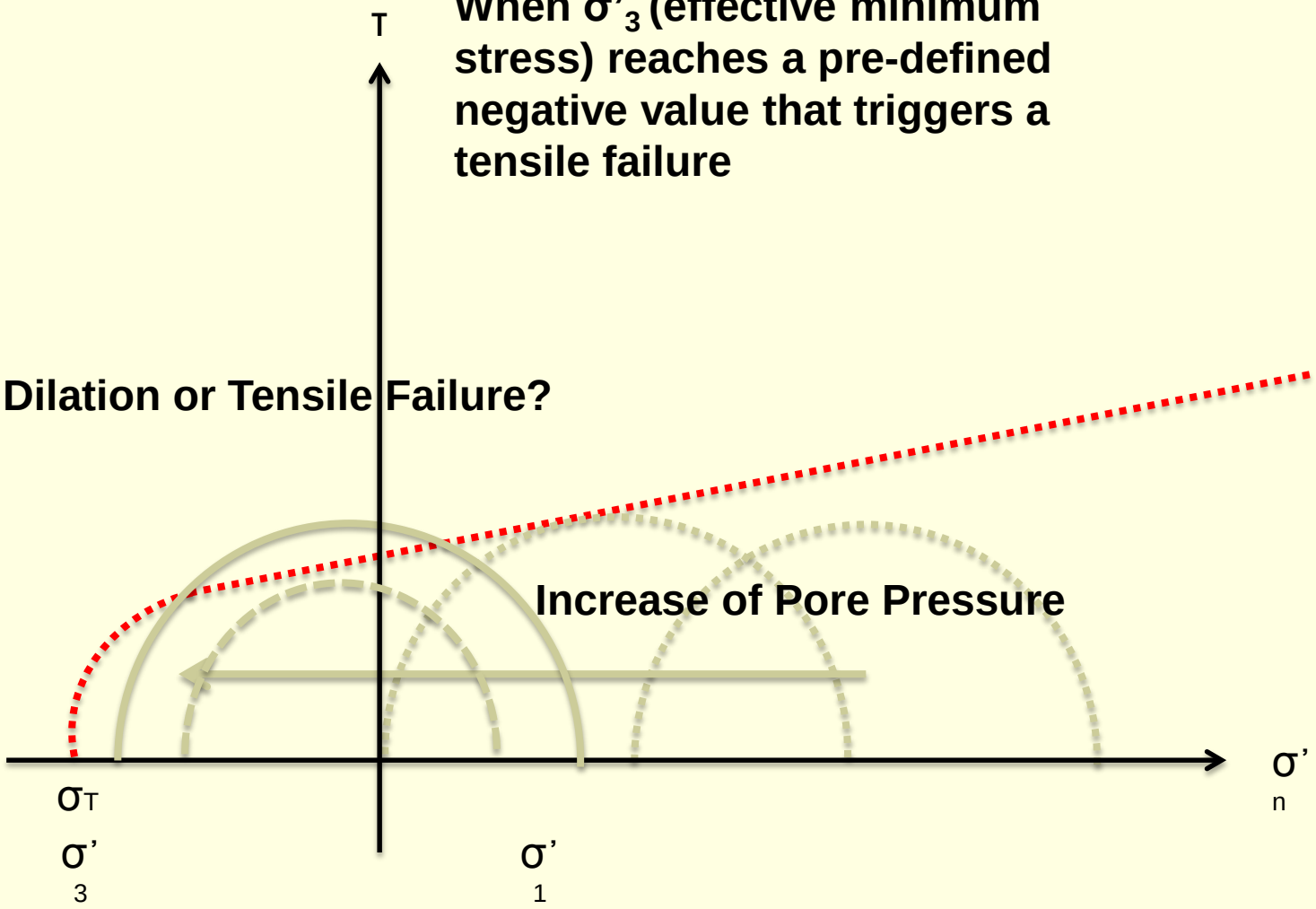


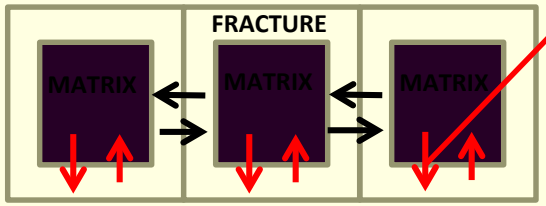
Mohr-Coulomb Failure Criteria

When σ'_3 (effective minimum stress) reaches a pre-defined negative value that triggers a tensile failure



Fracture Complexity and Distribution

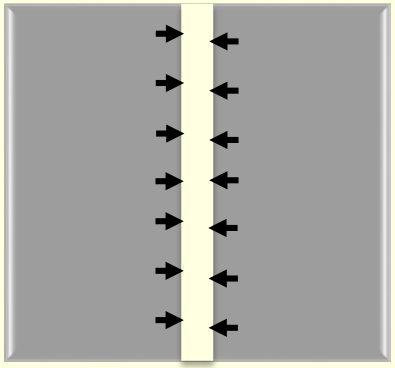
- Flow in dual porosity systems



TEX determines the flow between matrix and the fracture

- More complex fractures result in more fluid transfer between matrix and fracture media

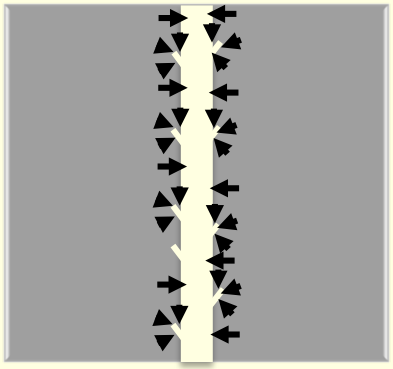
Bi-Wing Fracture Simple Geometry



Increasing TEX – Increasing fracture complexity

- Increasing fracture density within the matrix adjacent to the bi-wing frac.

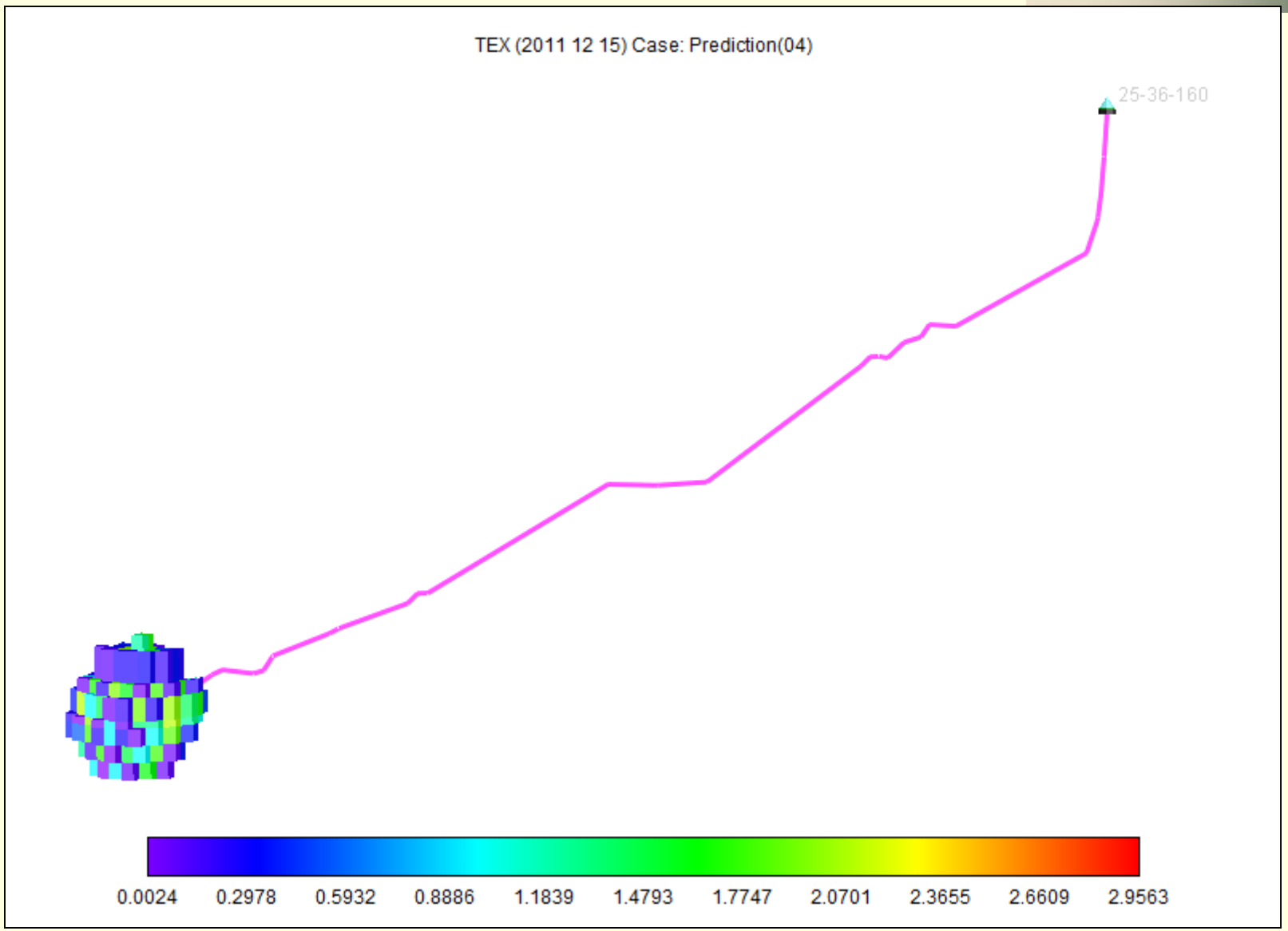
Bi-Wing Fracture Complex Geometry



Example SRV Generation

- Stage by Stage SRV growth
- The next slides show the stage by stage SRV generation (14 stages)
- Color indicates TEX
  - Higher TEX values indicate greater communication between the fracture and matrix systems

Study #1


TEX (2011 12 15) Case: Prediction(04)
25-36-160
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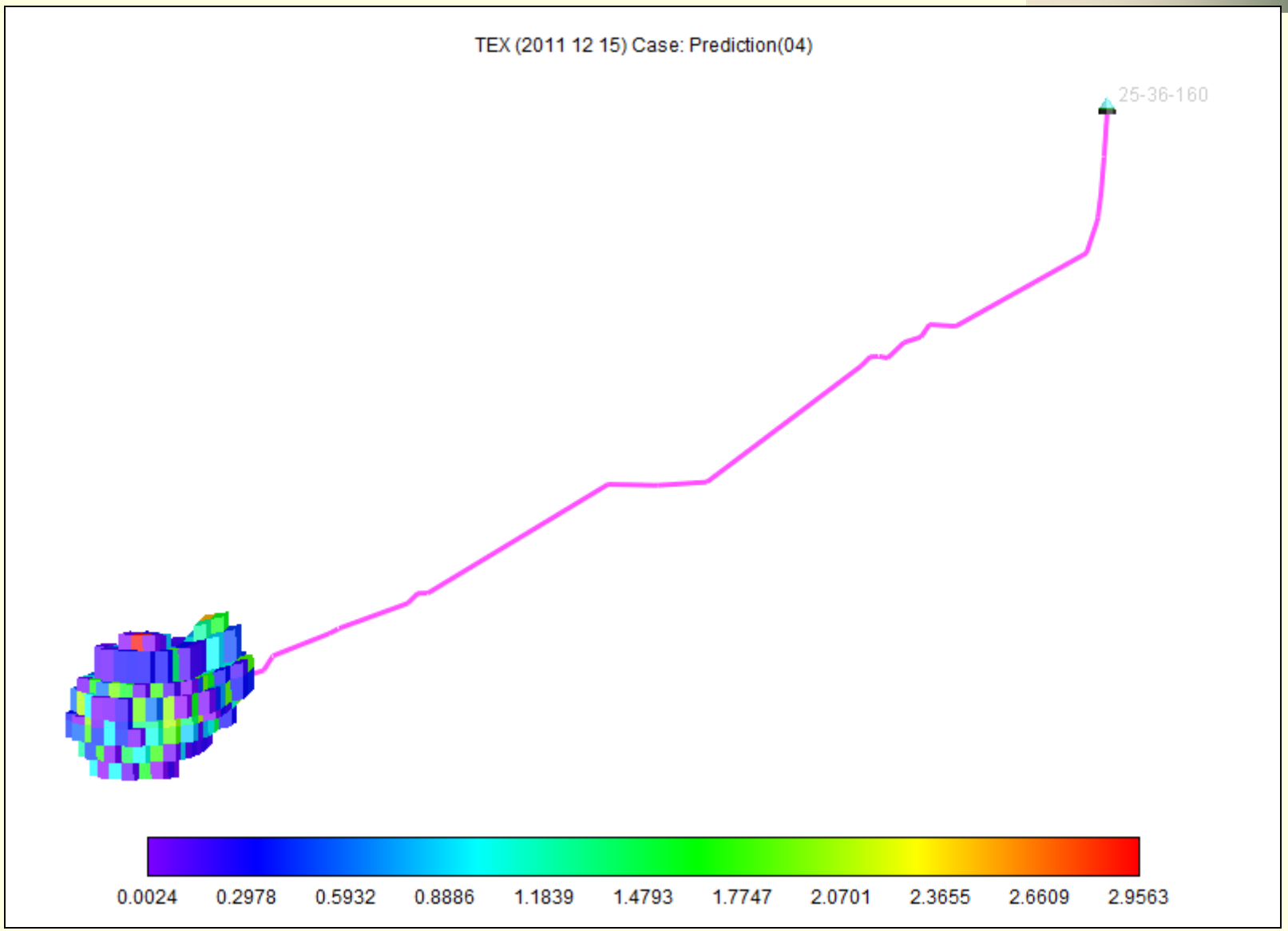
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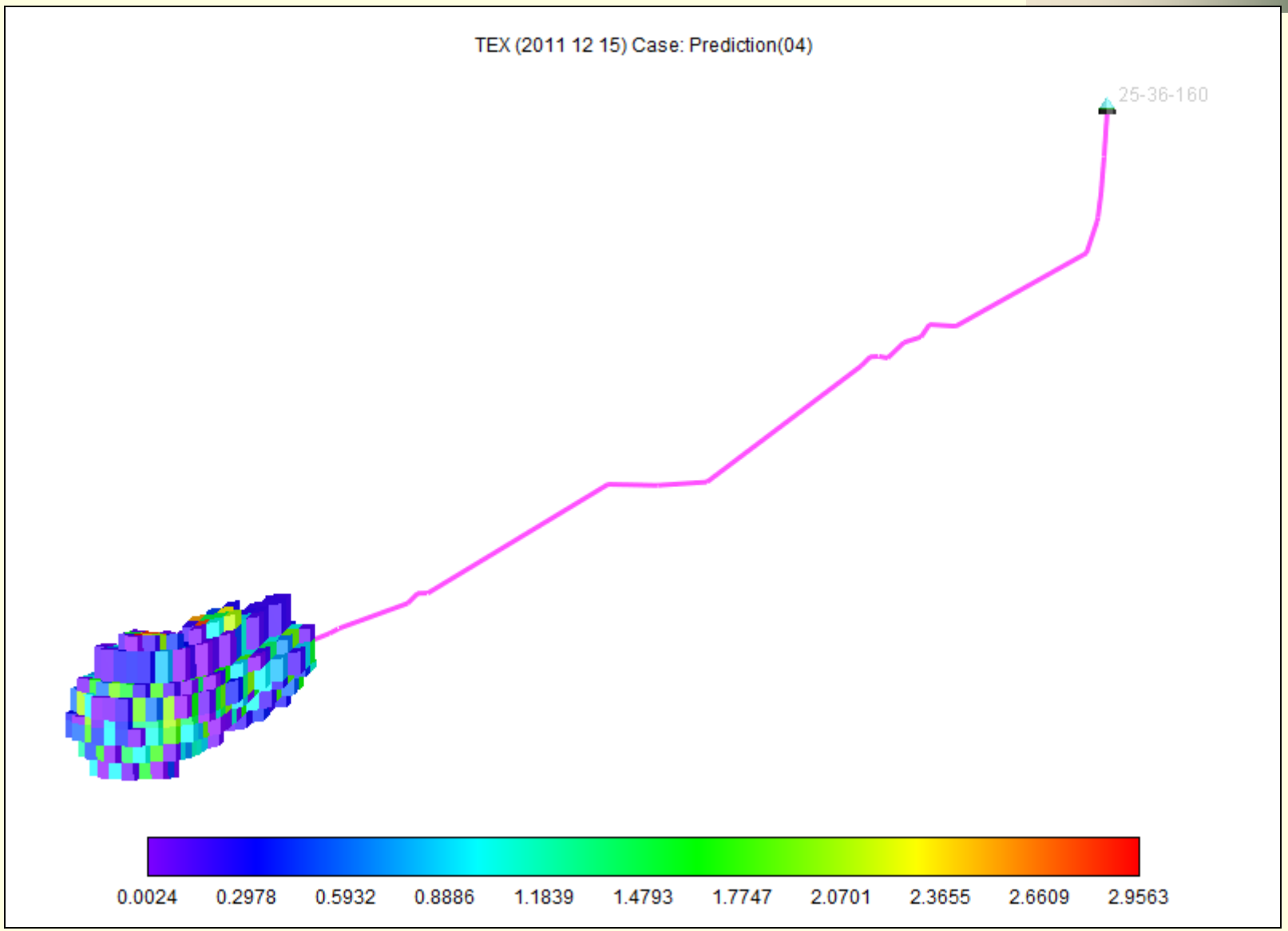
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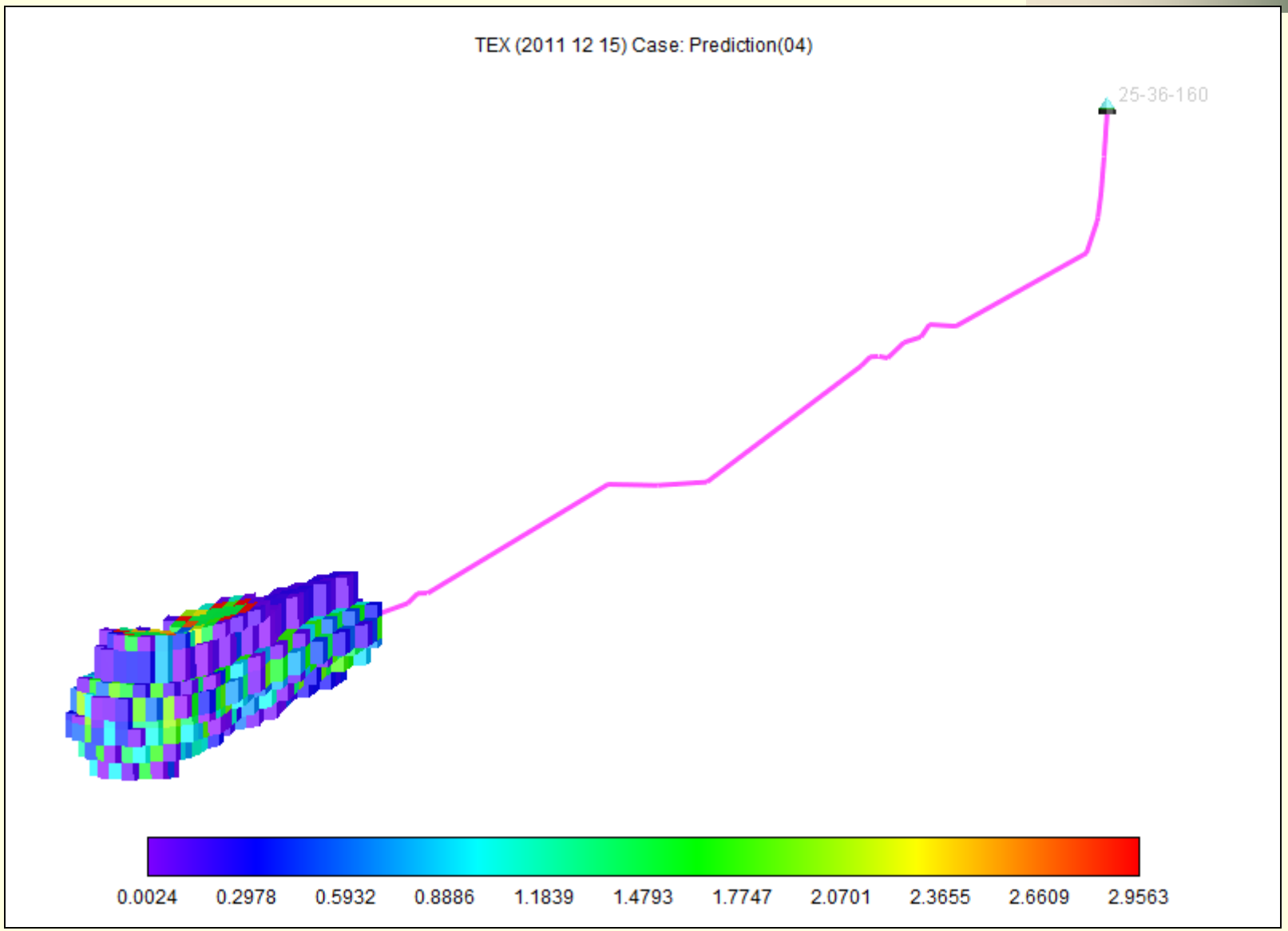
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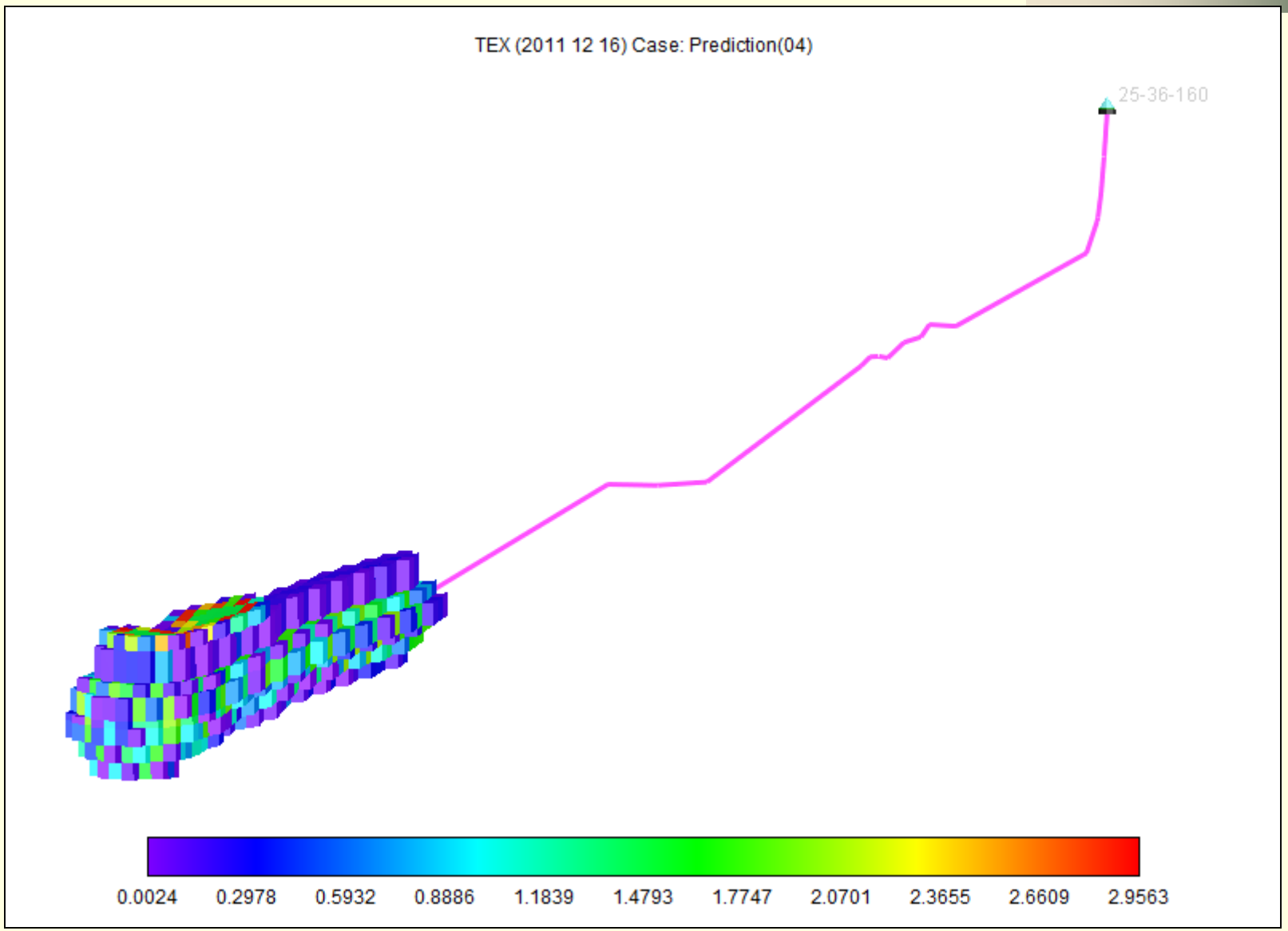
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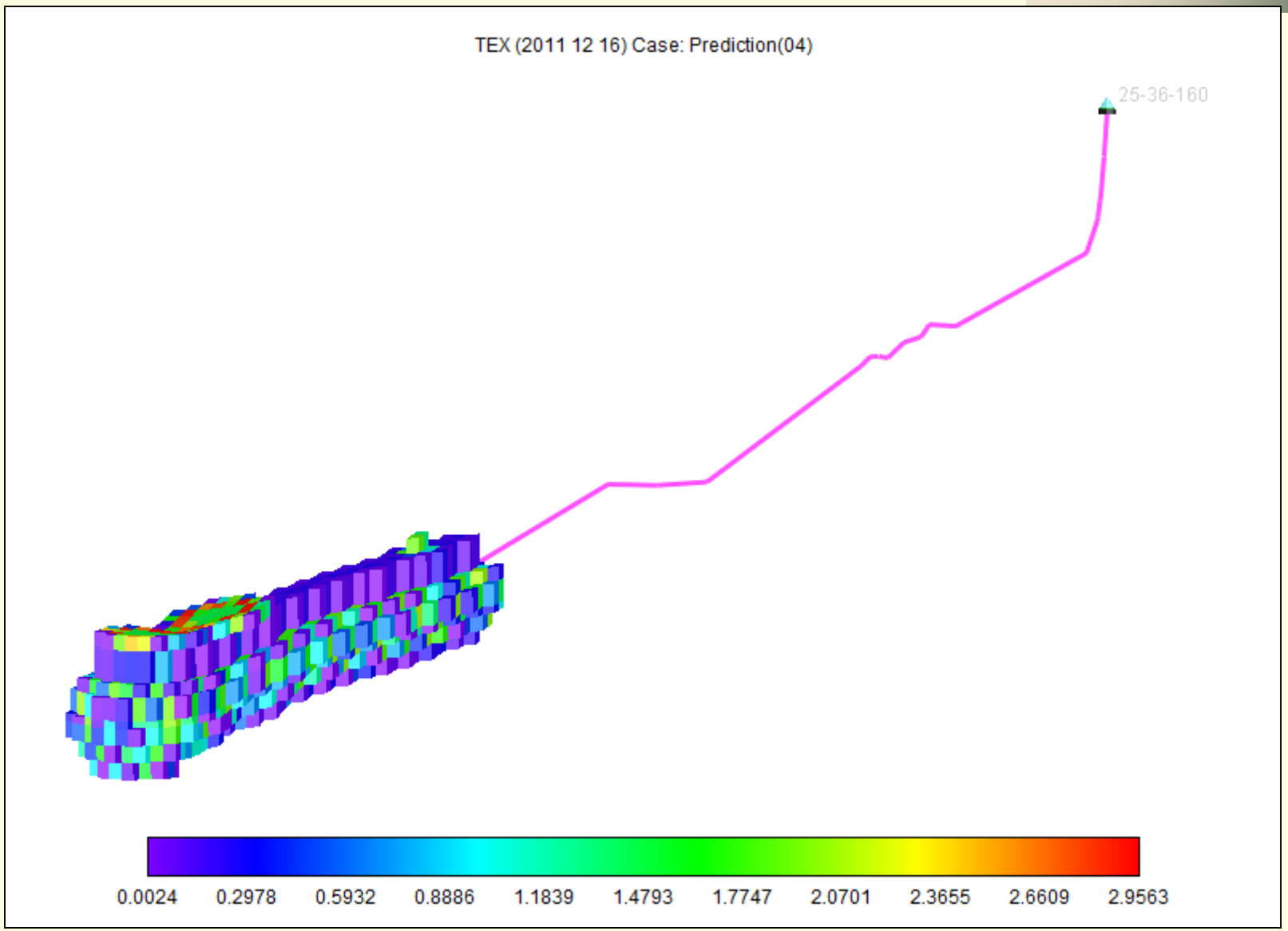
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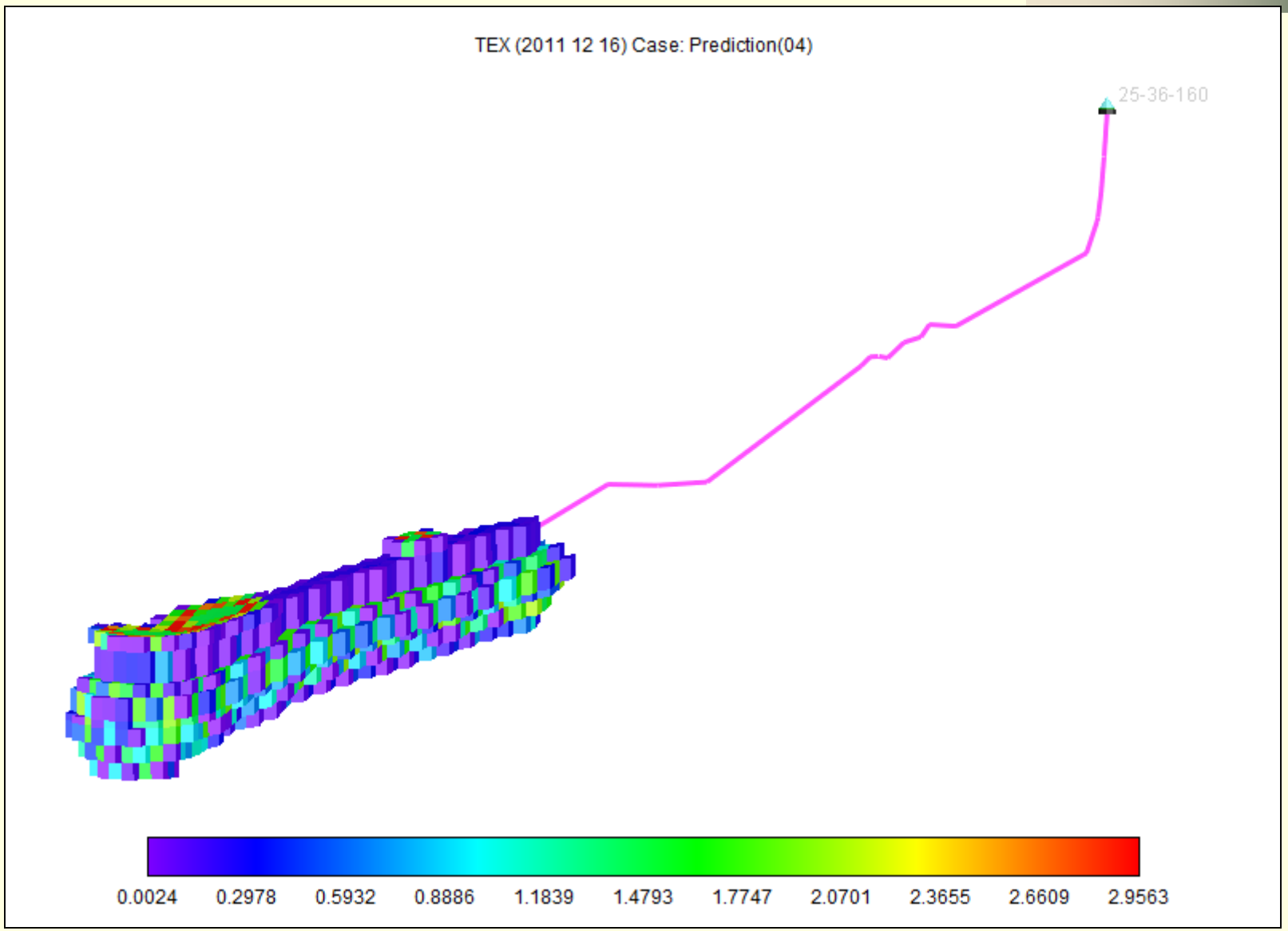
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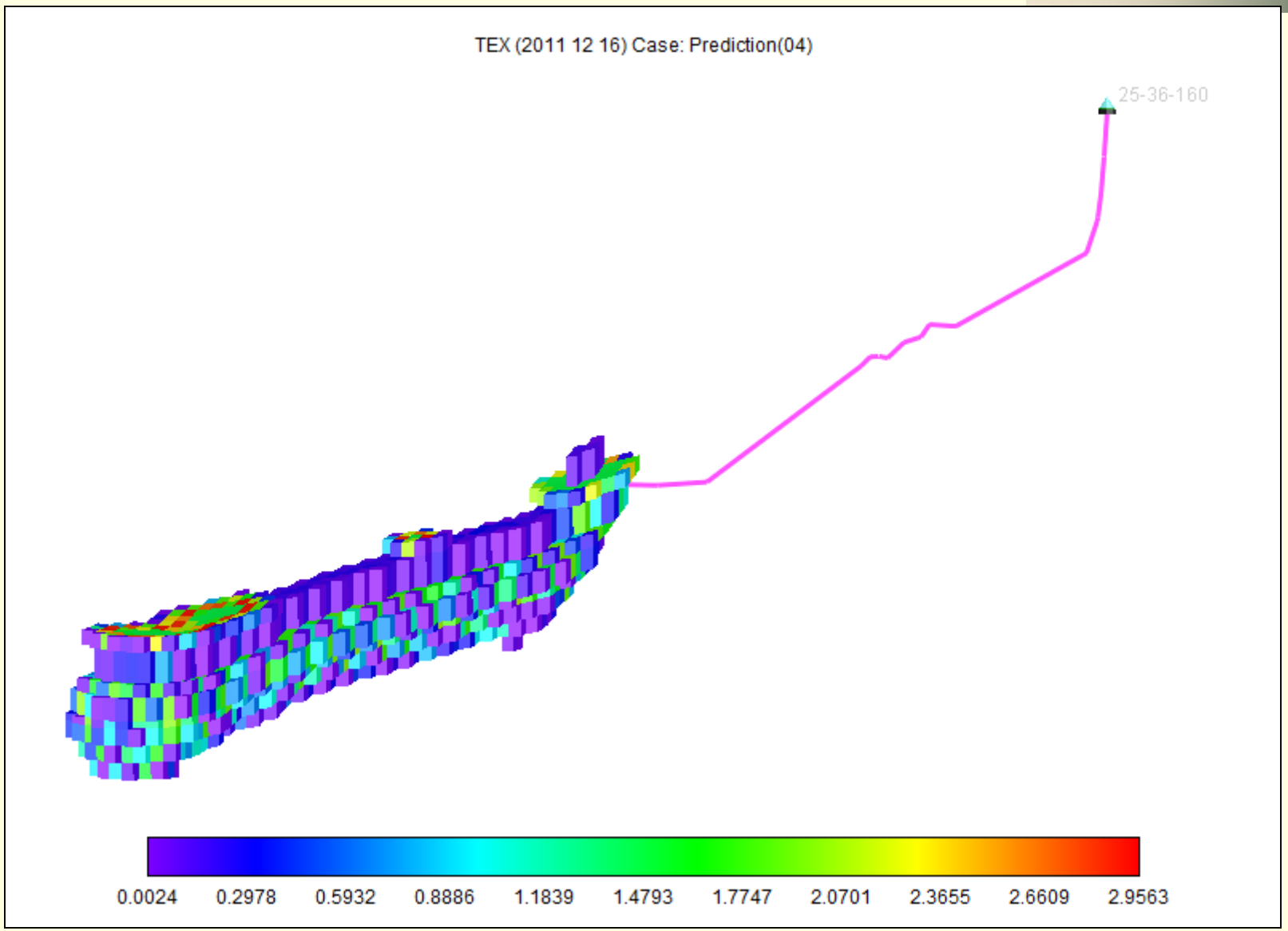
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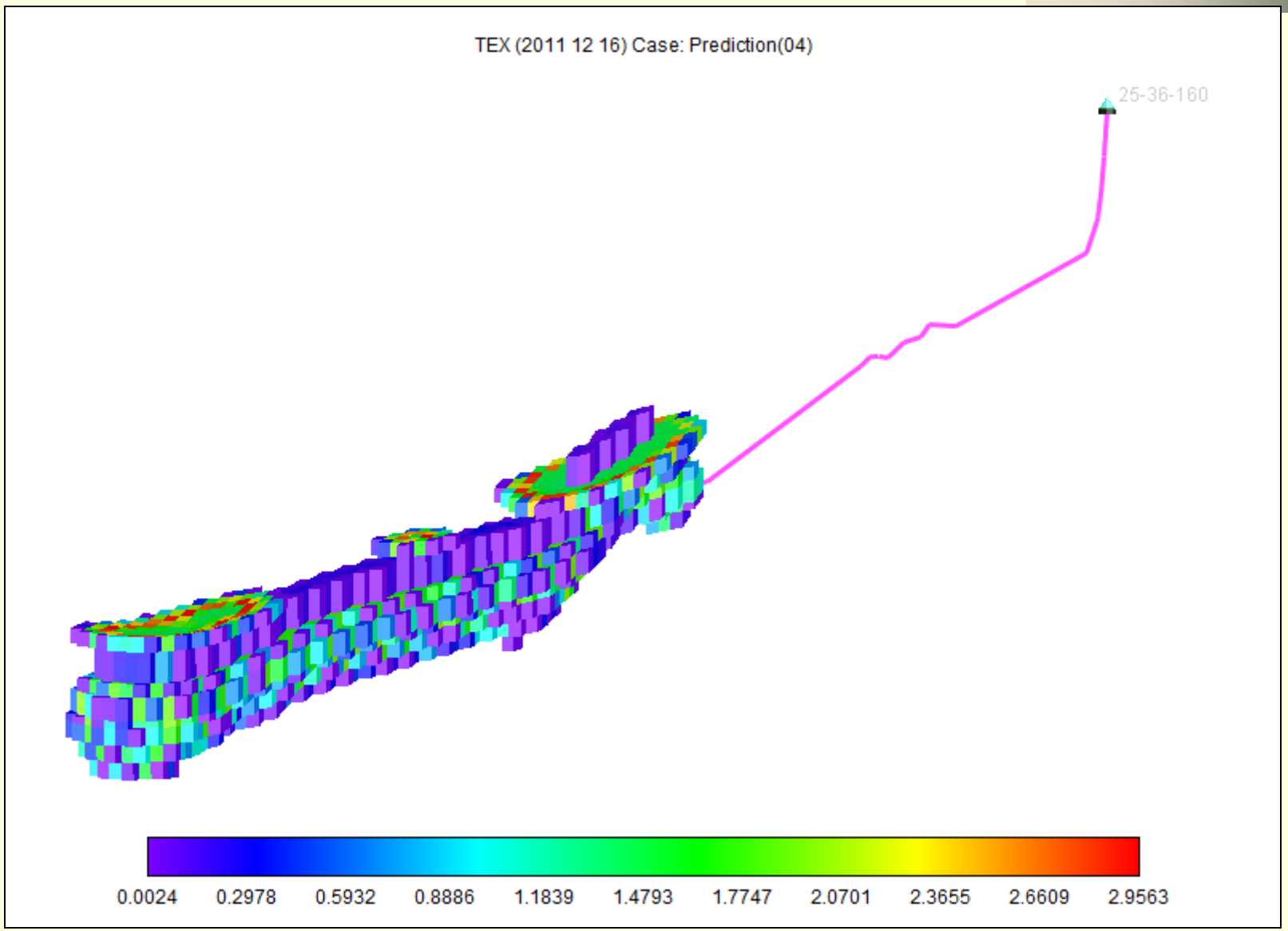
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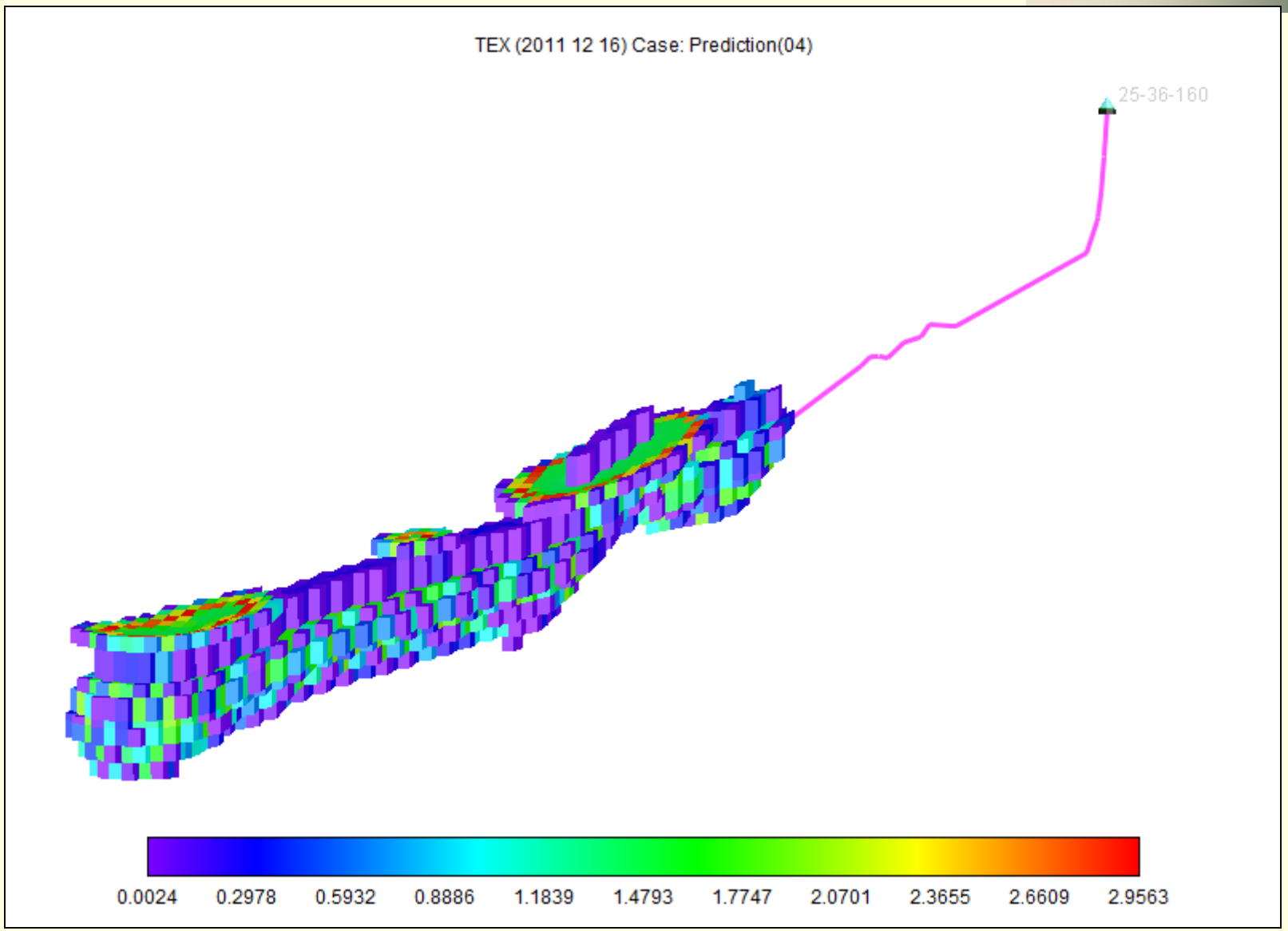
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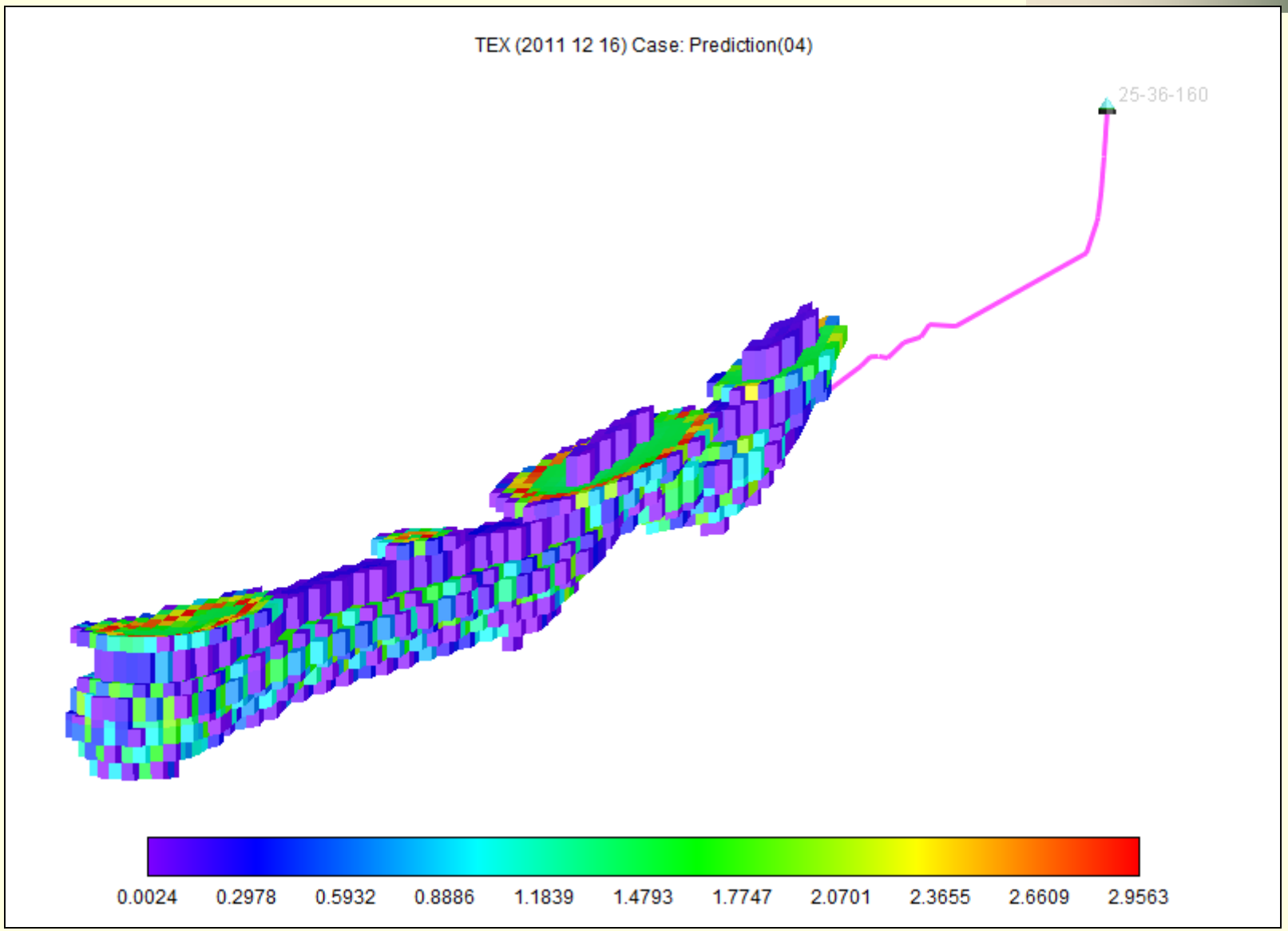
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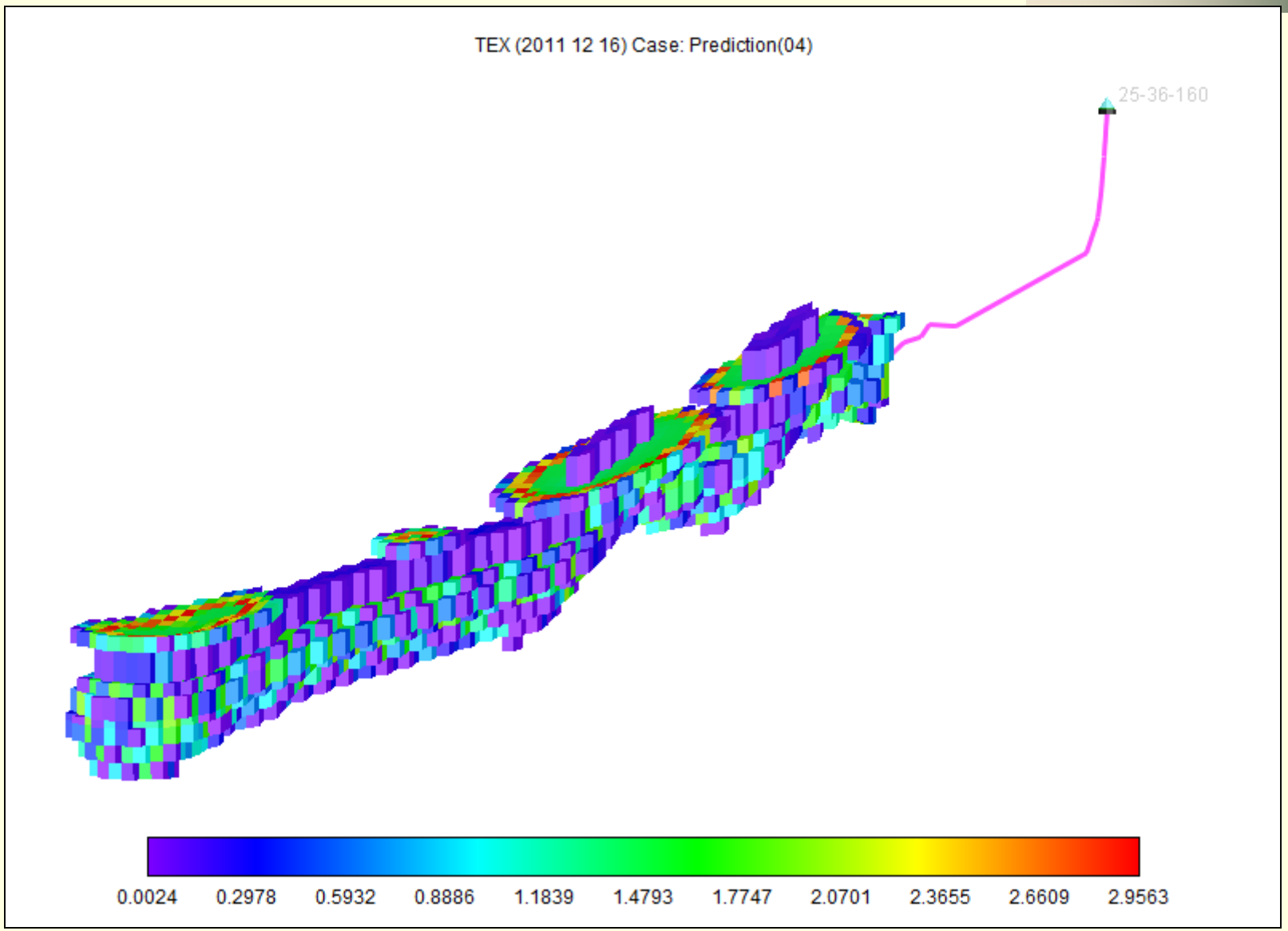
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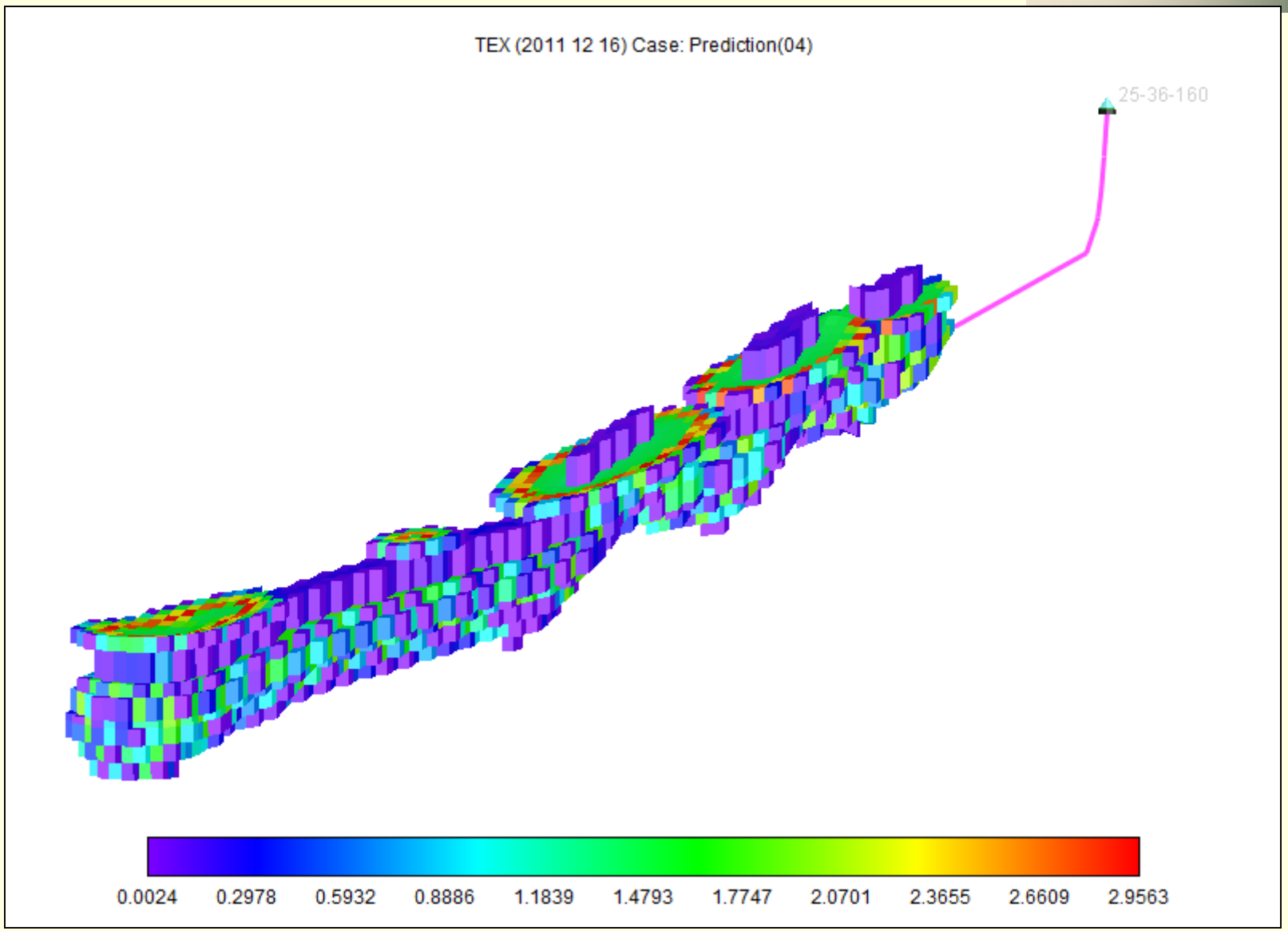
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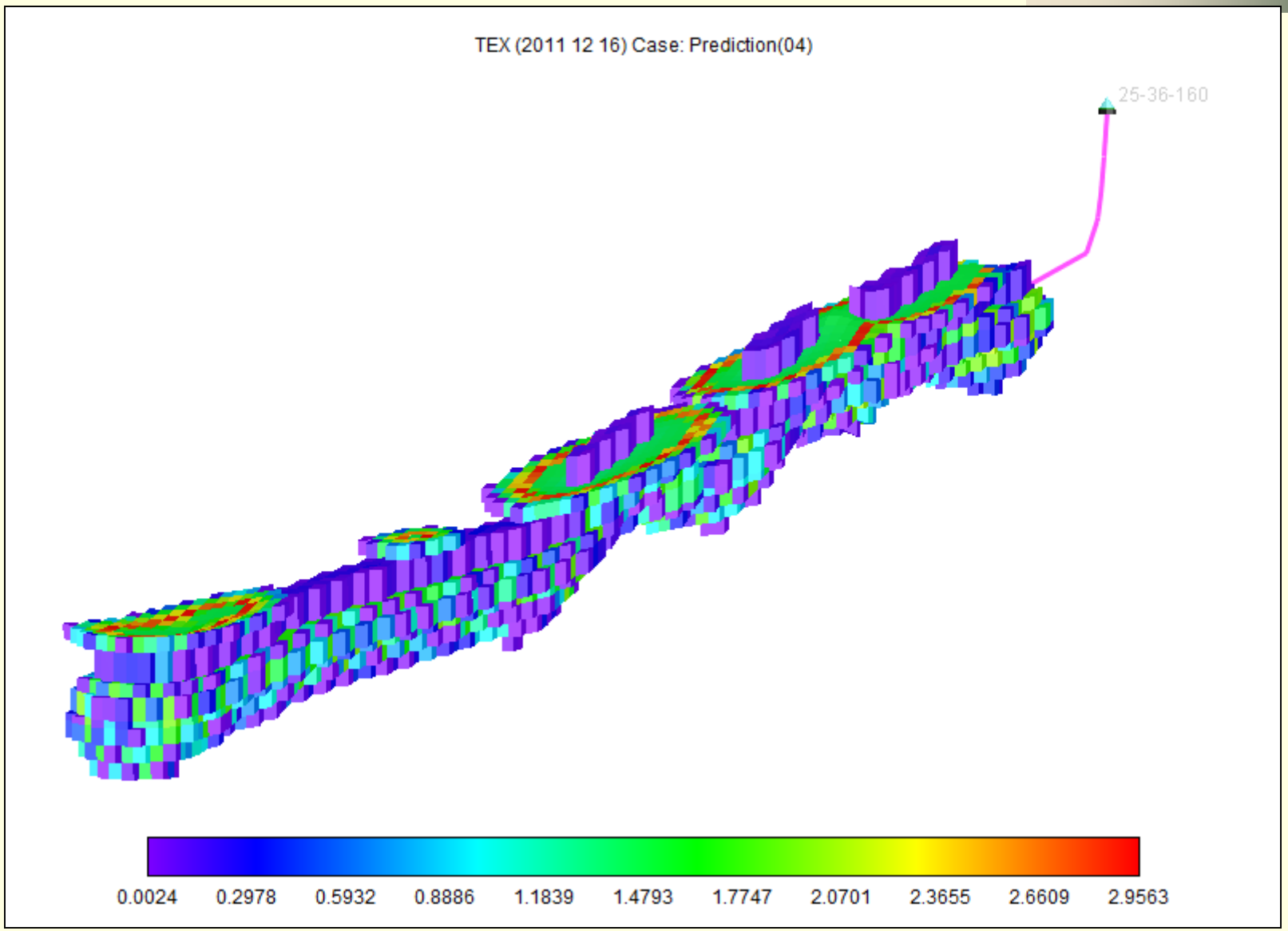
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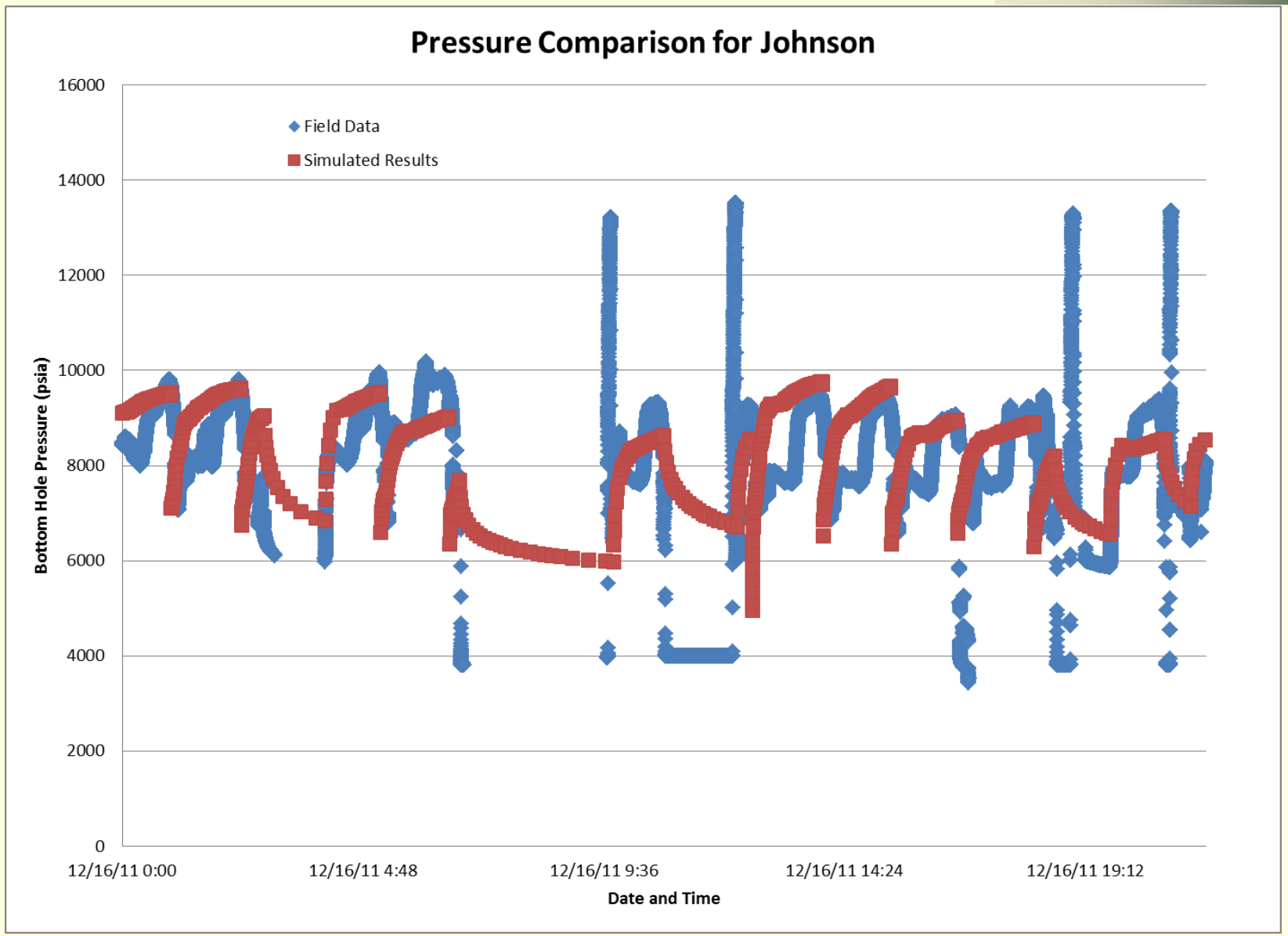
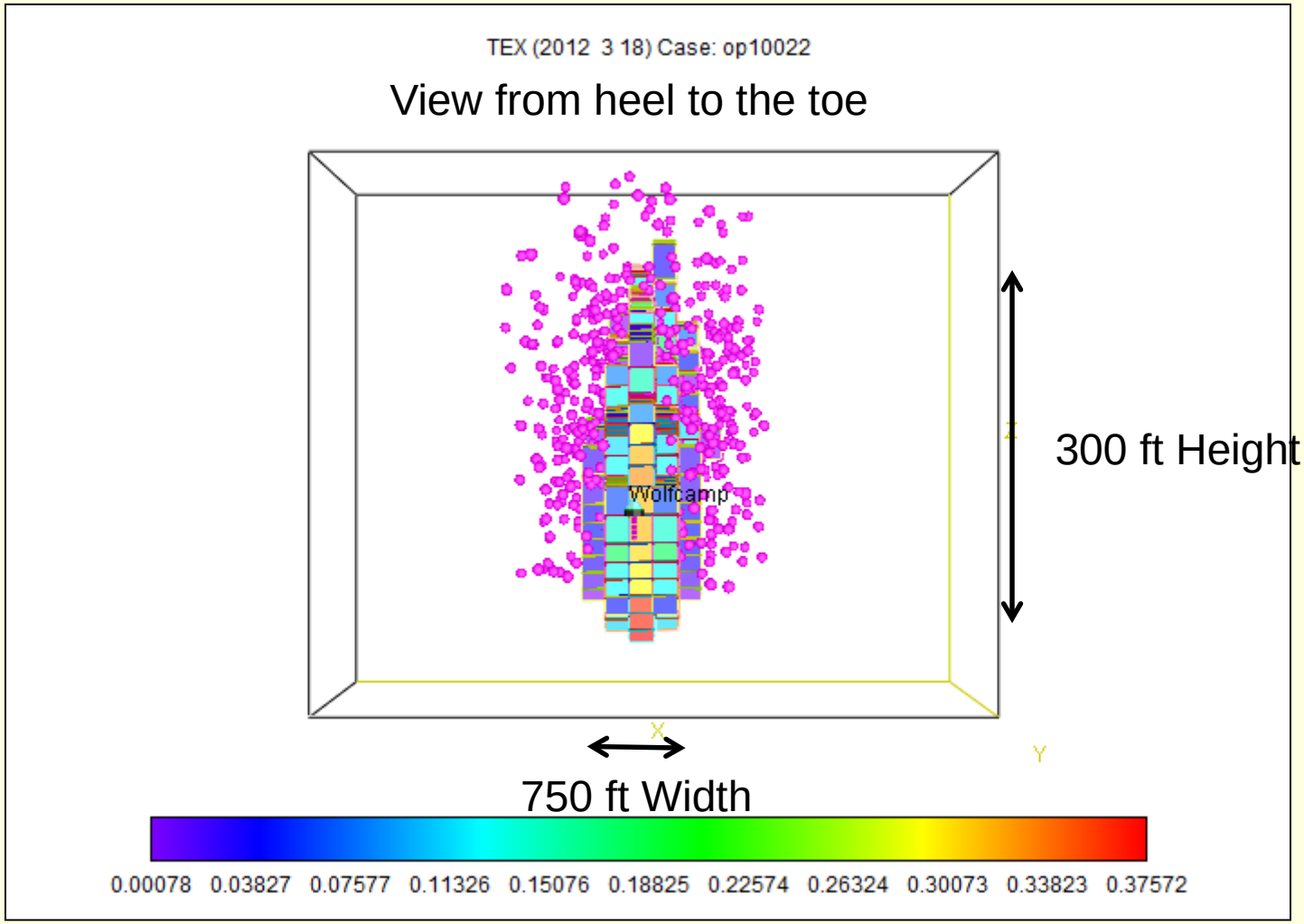
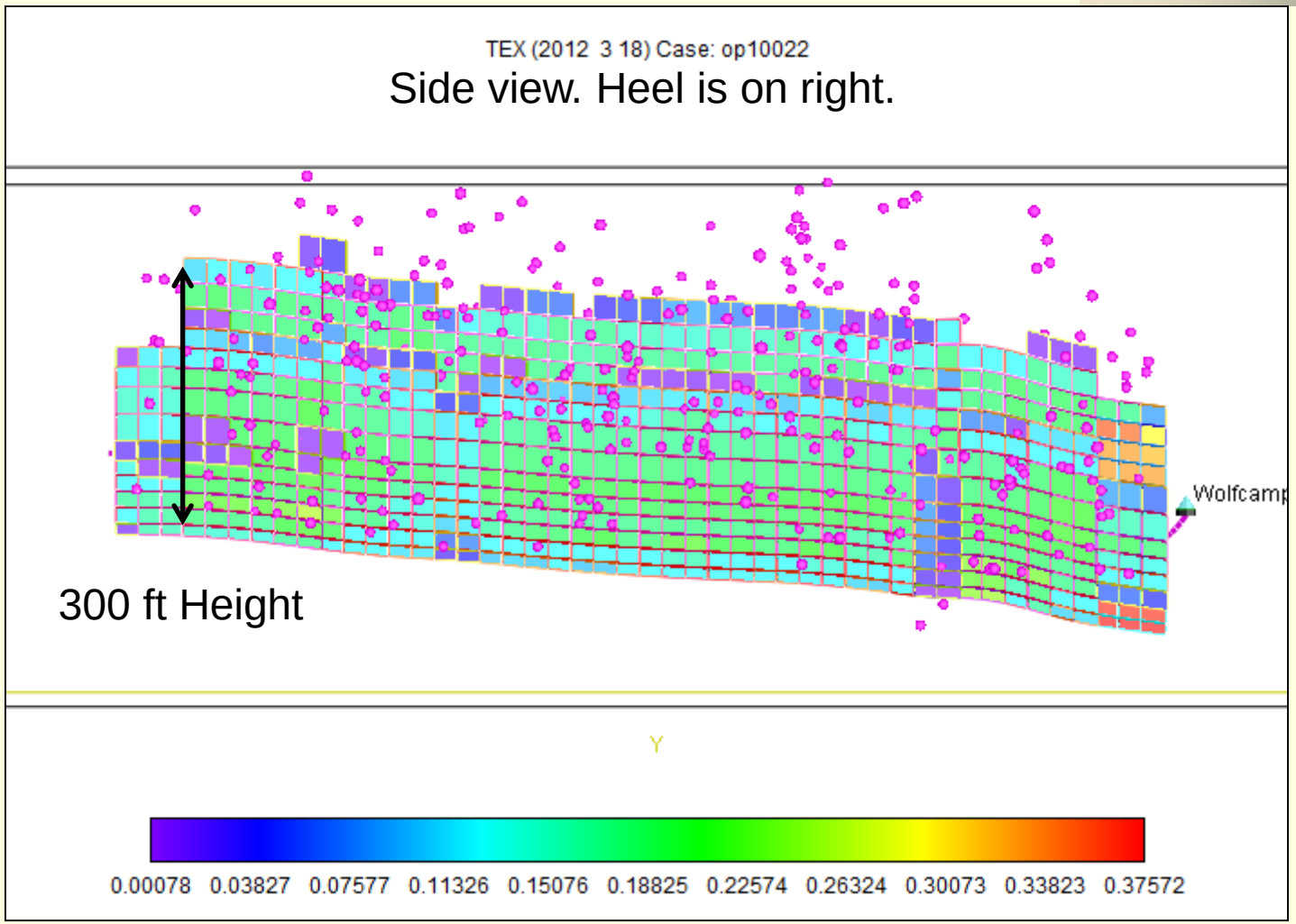
Calibration to the Frac Stages



SRV Aspect Ratio

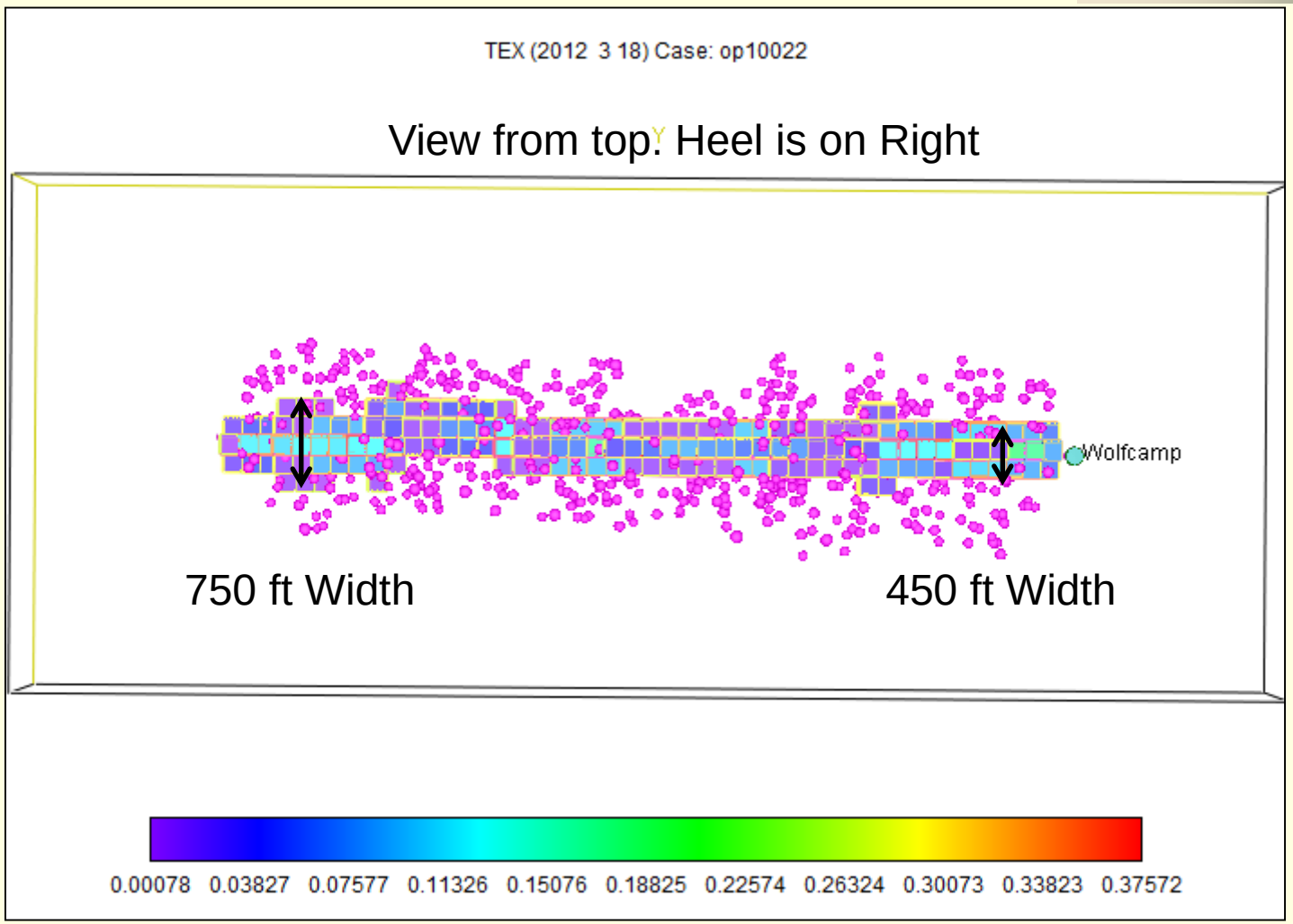


SRV Aspect Ratio



TEX Value

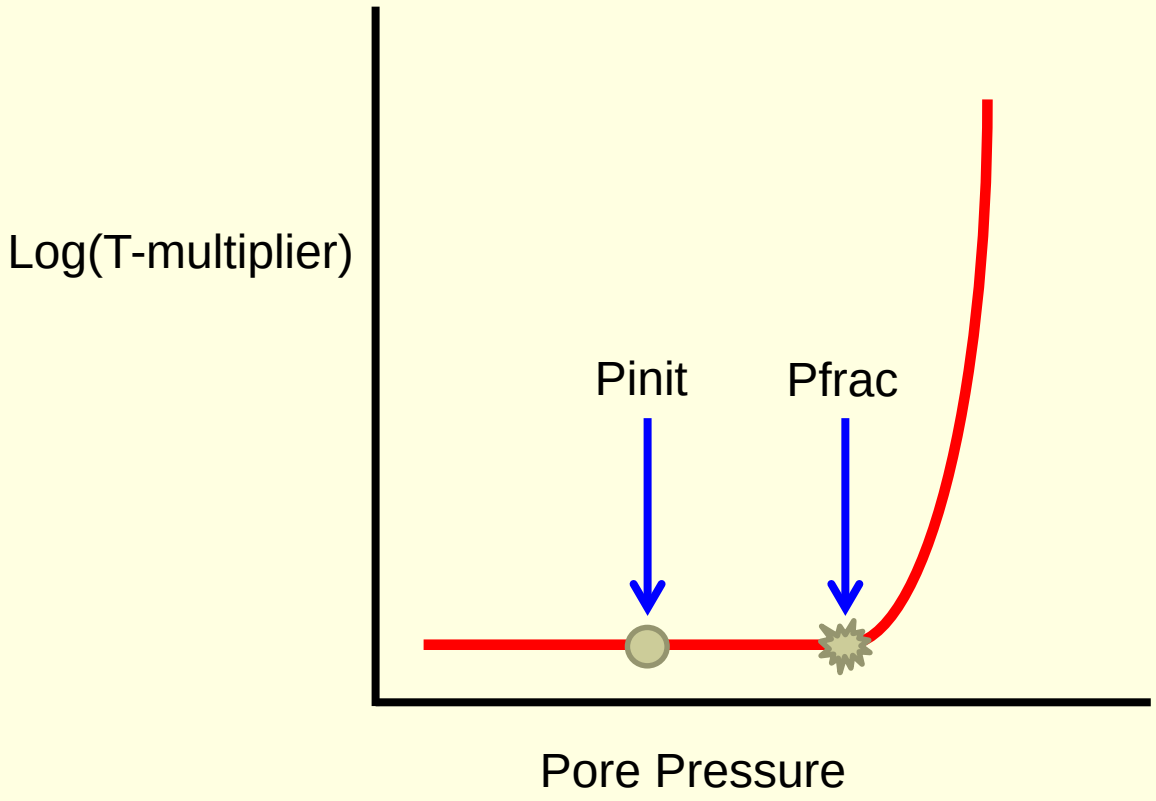
SRV Aspect Ratio



SRV Closure

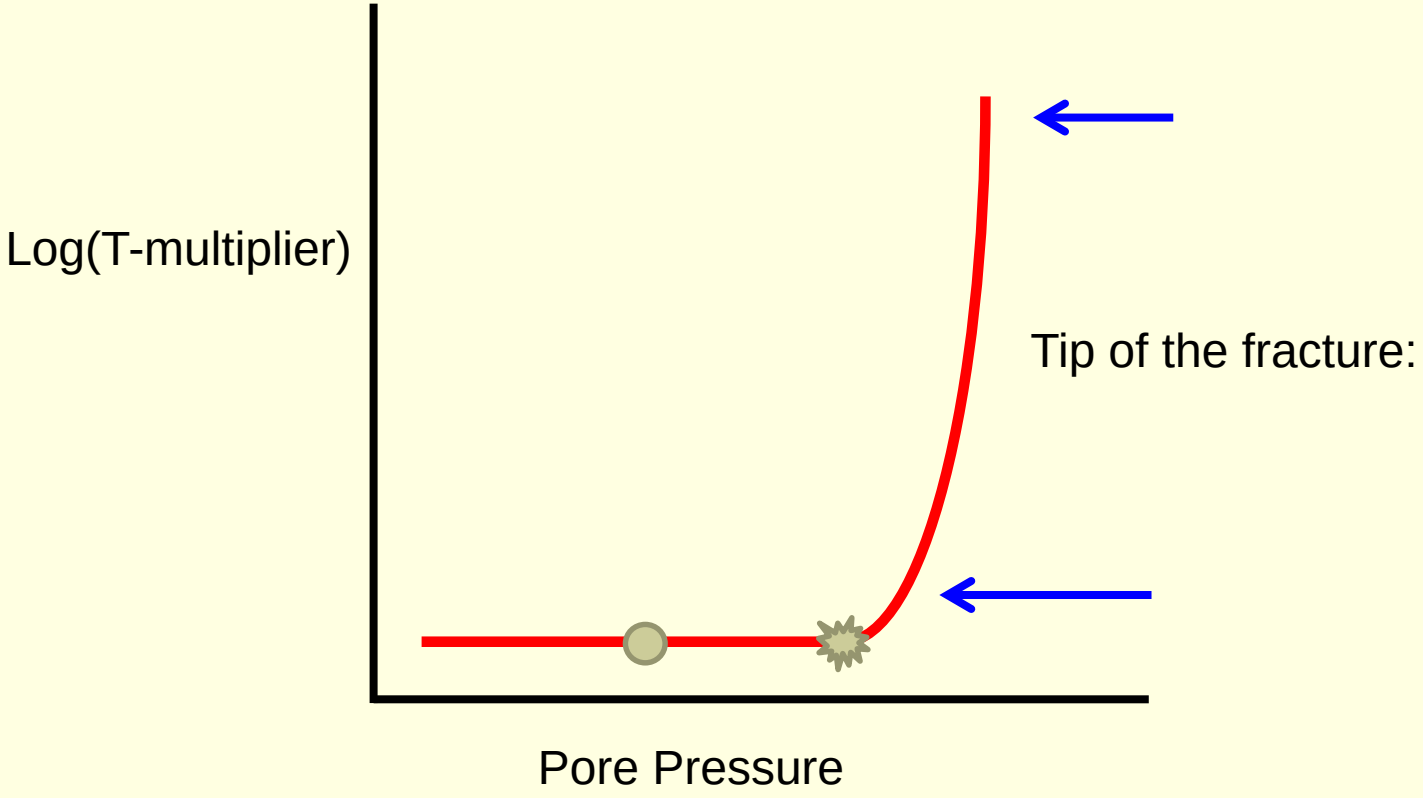
- After the SRV is generated during the hydraulic fracture treatment, the connectivity reduces as the result of depletion
- Simulation data table determines the transmissibility reduction as a function of pore pressure

Fracture Closure

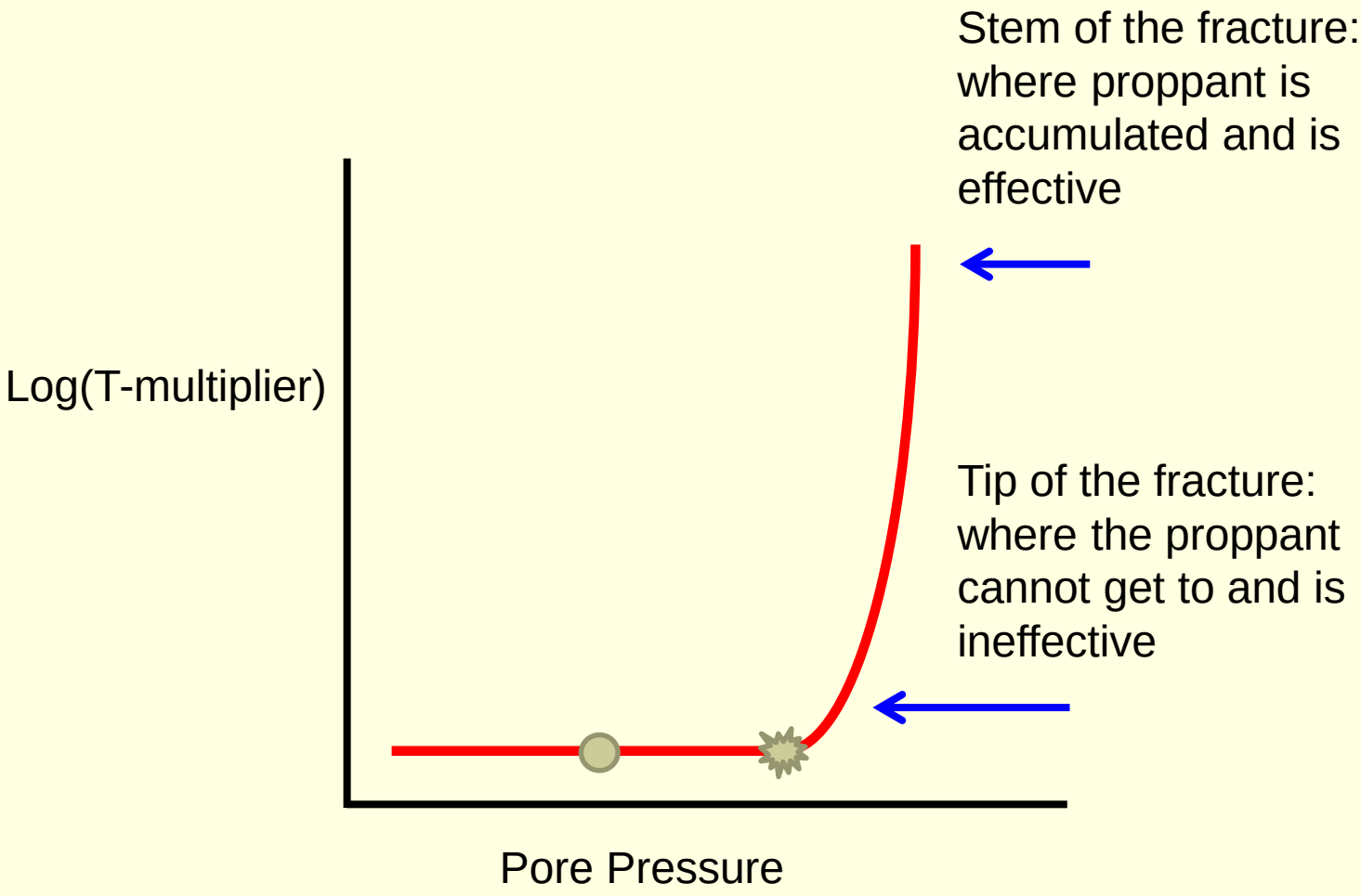


Fracture Closure

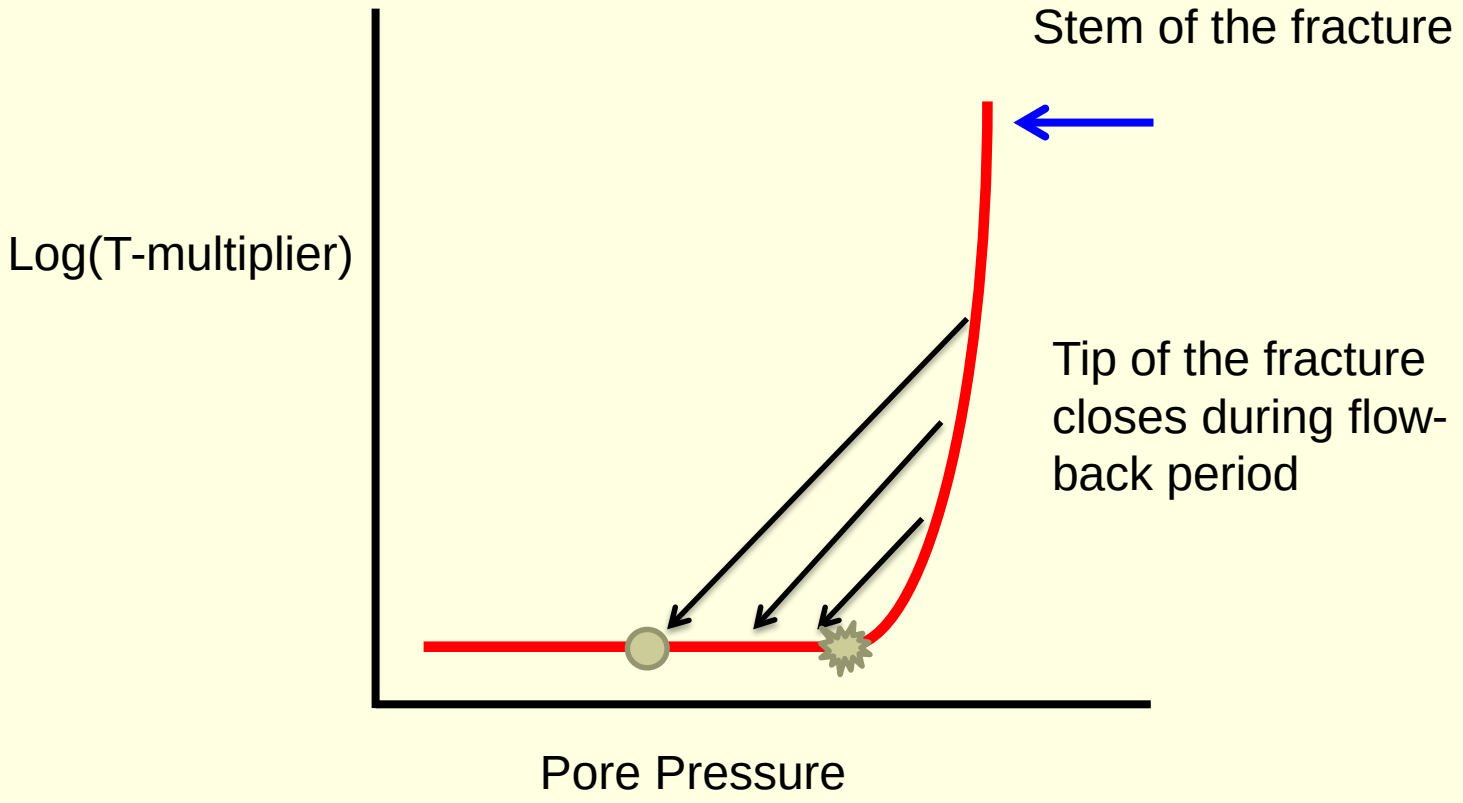
Stem of the fracture:



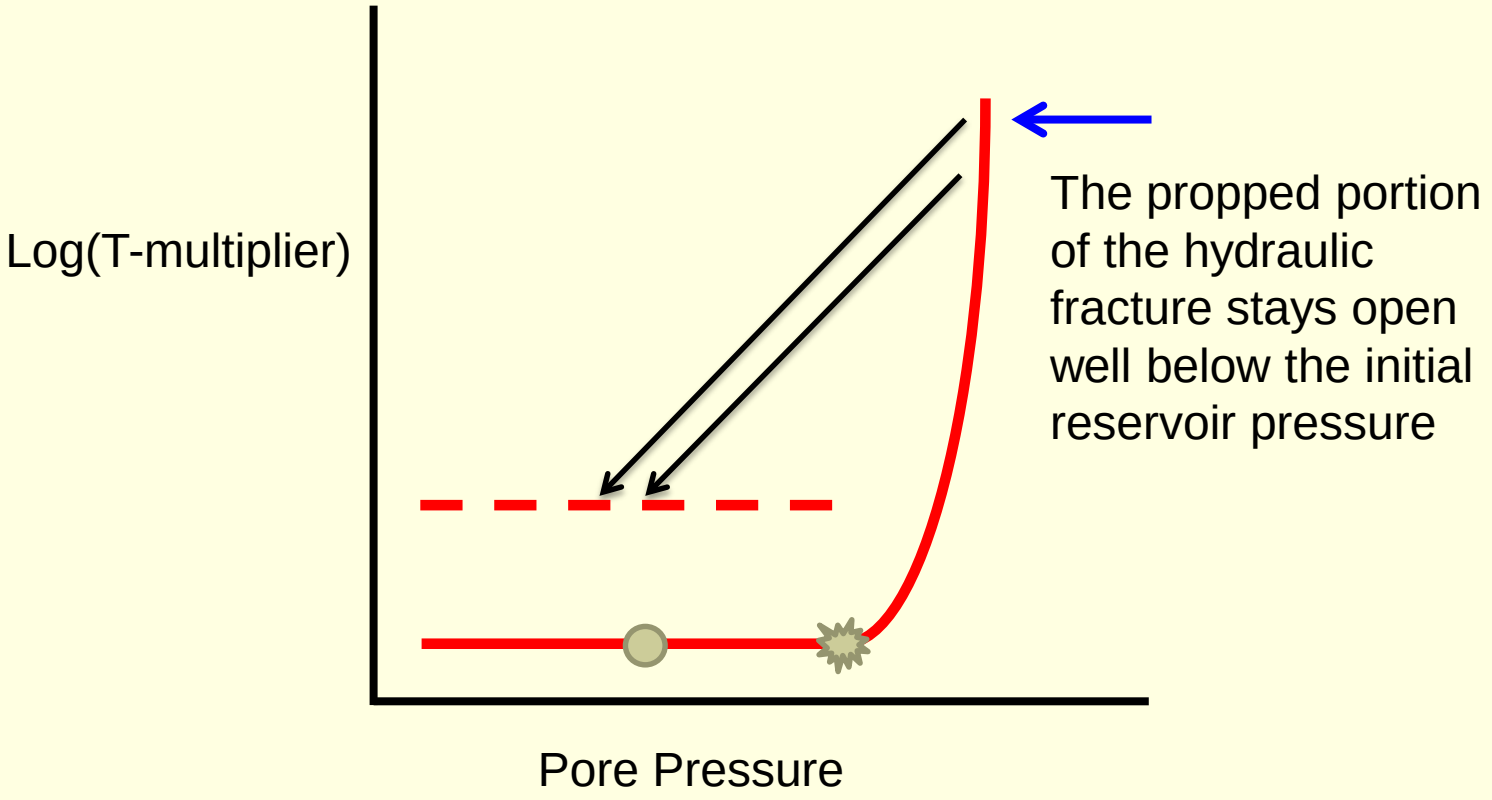
Fracture Closure



Fracture Closure



Fracture Closure



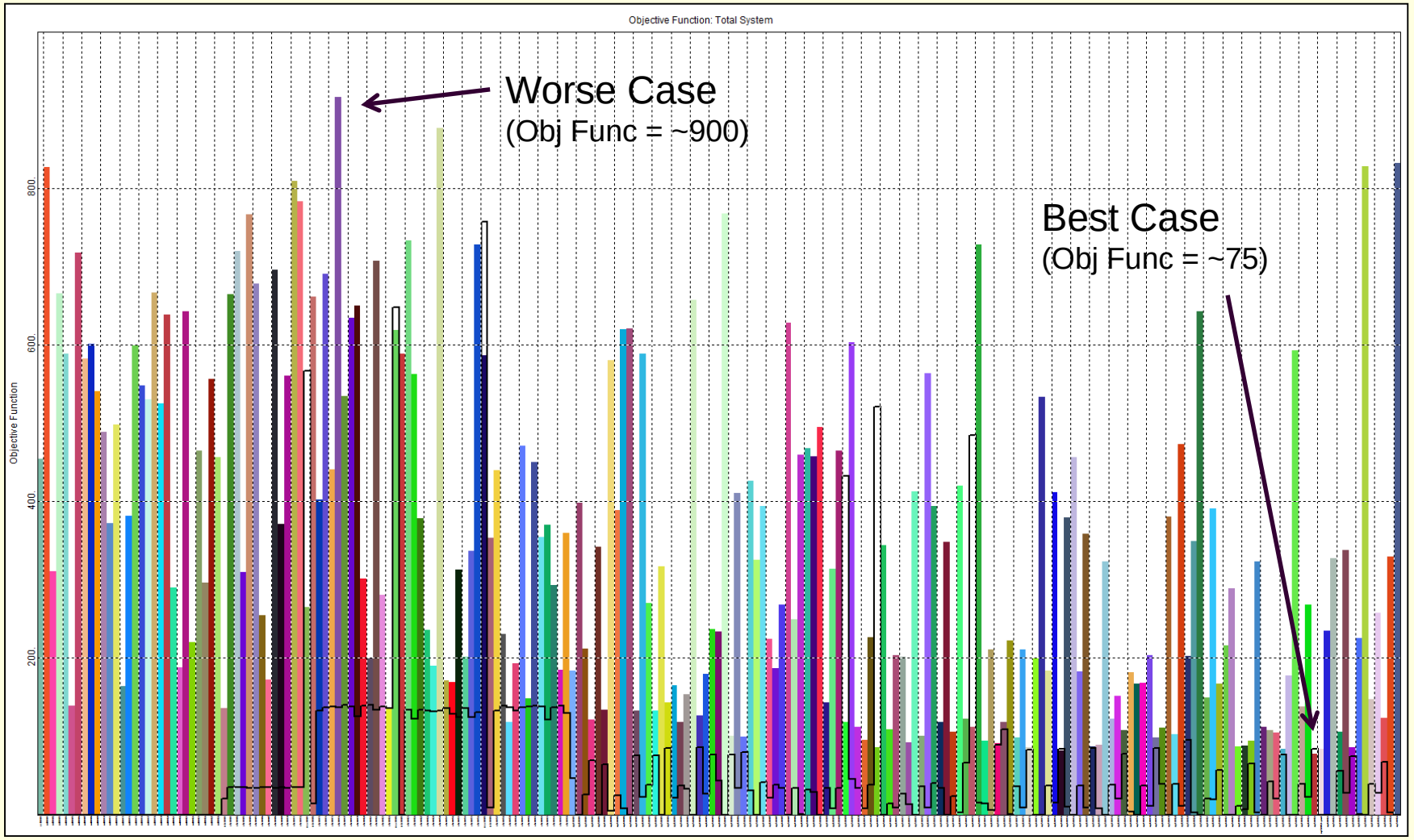
Assisted History Matching (AHM)

- Large number of parameters means that history matching by hand is difficult
- MatchingPro is an assisted history match (AHM) program that uses an objective function to assess and generate new solutions
- User specifies which parameter values to vary and by how much

AHM

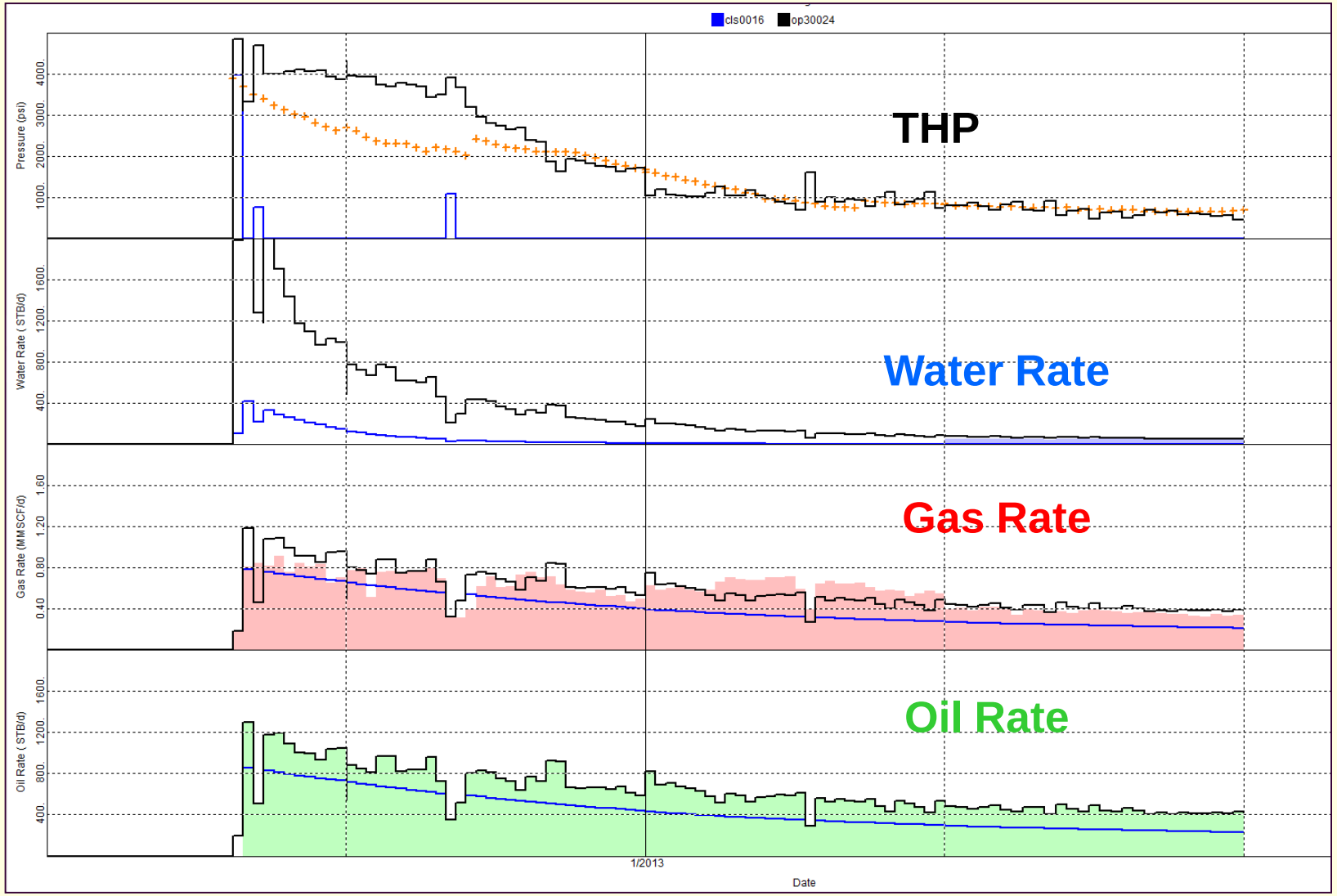
- Objective function based on the following data
  - Hydraulic Fracturing Period
    - Inject measured volumes of fluid
    - Constrained by maximum injection BHP
  - Flow back and Production Period
    - Produce correct quantities of fluid
      - Oil
      - Gas
      - Water
    - Match the pressure of the natural flow period
    - Match the monthly volumes of produced fluids

AHM



Approximately 200 runs

AHM Results



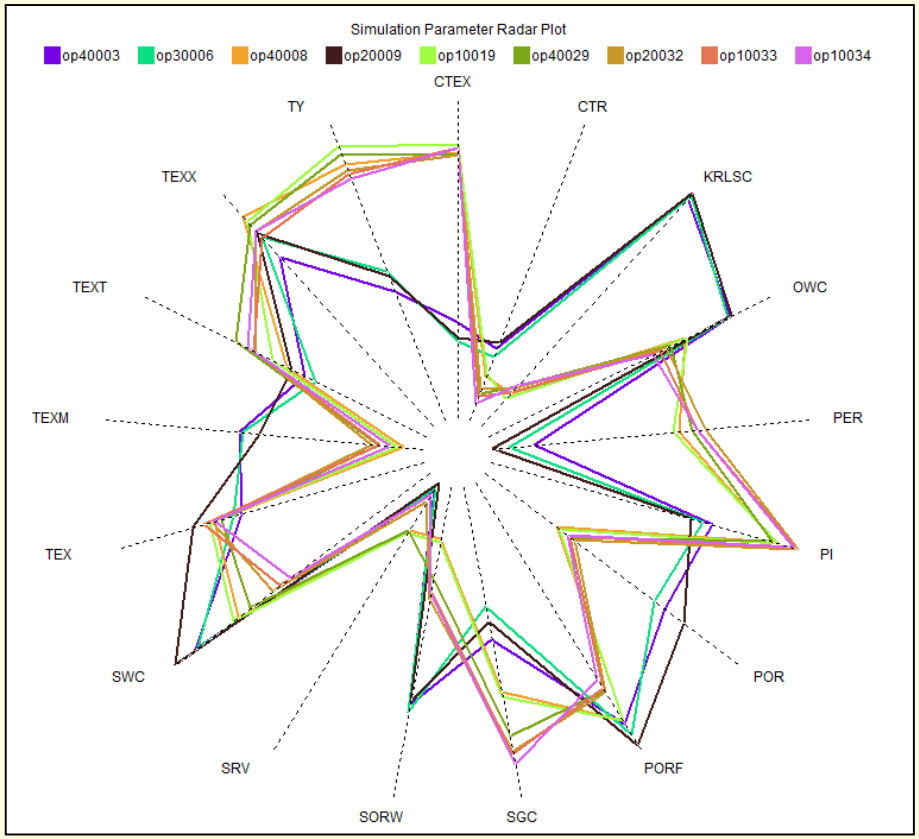
Worse Case - Blue

Best Case - Black

MatchingPro

- Simulating fracture treatments results in a large number of unknown parameters

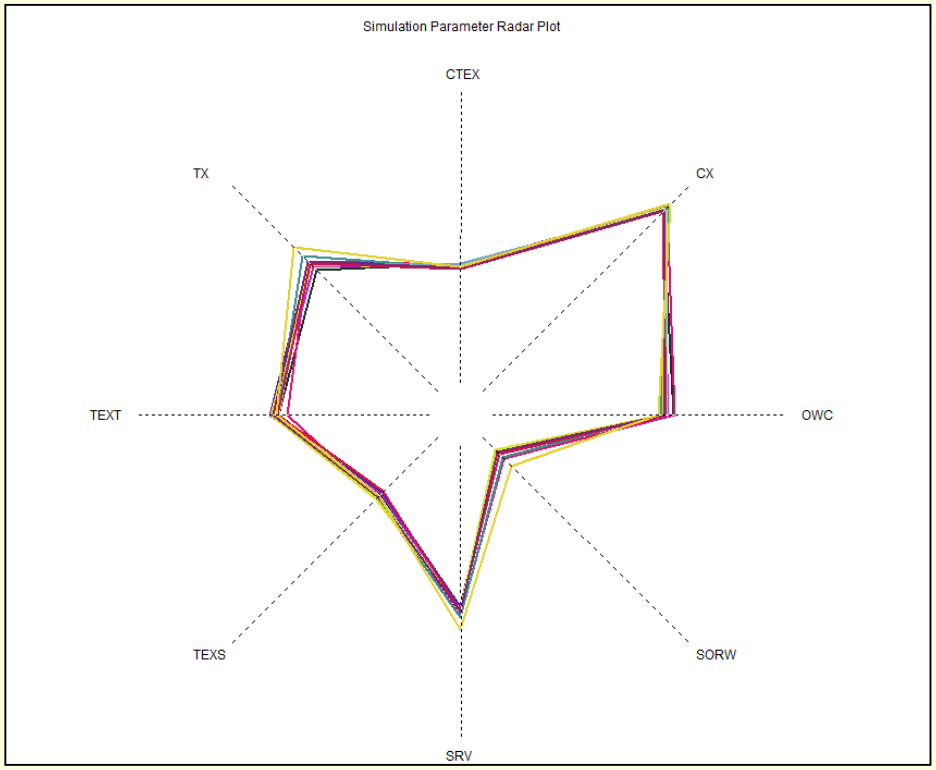
Parameter space



Up to 18 parameters during investigation phase

MatchingPro

- These eight variables proved to be the most important for one of our projects



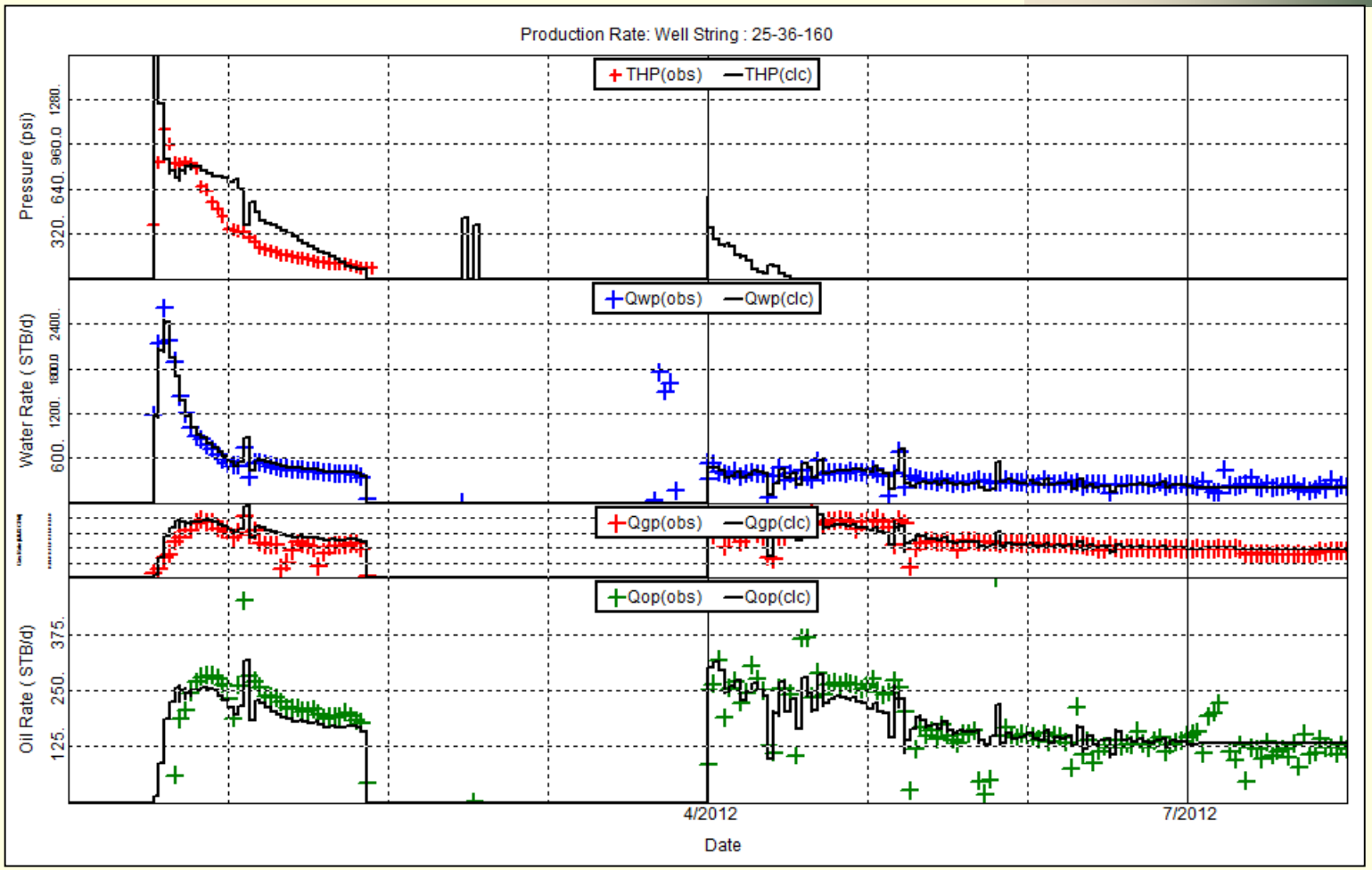
Number of parameters reduced in later phase of calibration

CTEX: TEX compressibility
CX: TX compressibility
OWC: Oil Water Contact
SORW: Residual oil saturation to water
SRV: SRV Growth Factor
TEXS: TEXMOD from shear failure
TEXT: TEXMOD from tensile failure
TX: X direction transmissibility modifier

Project Results

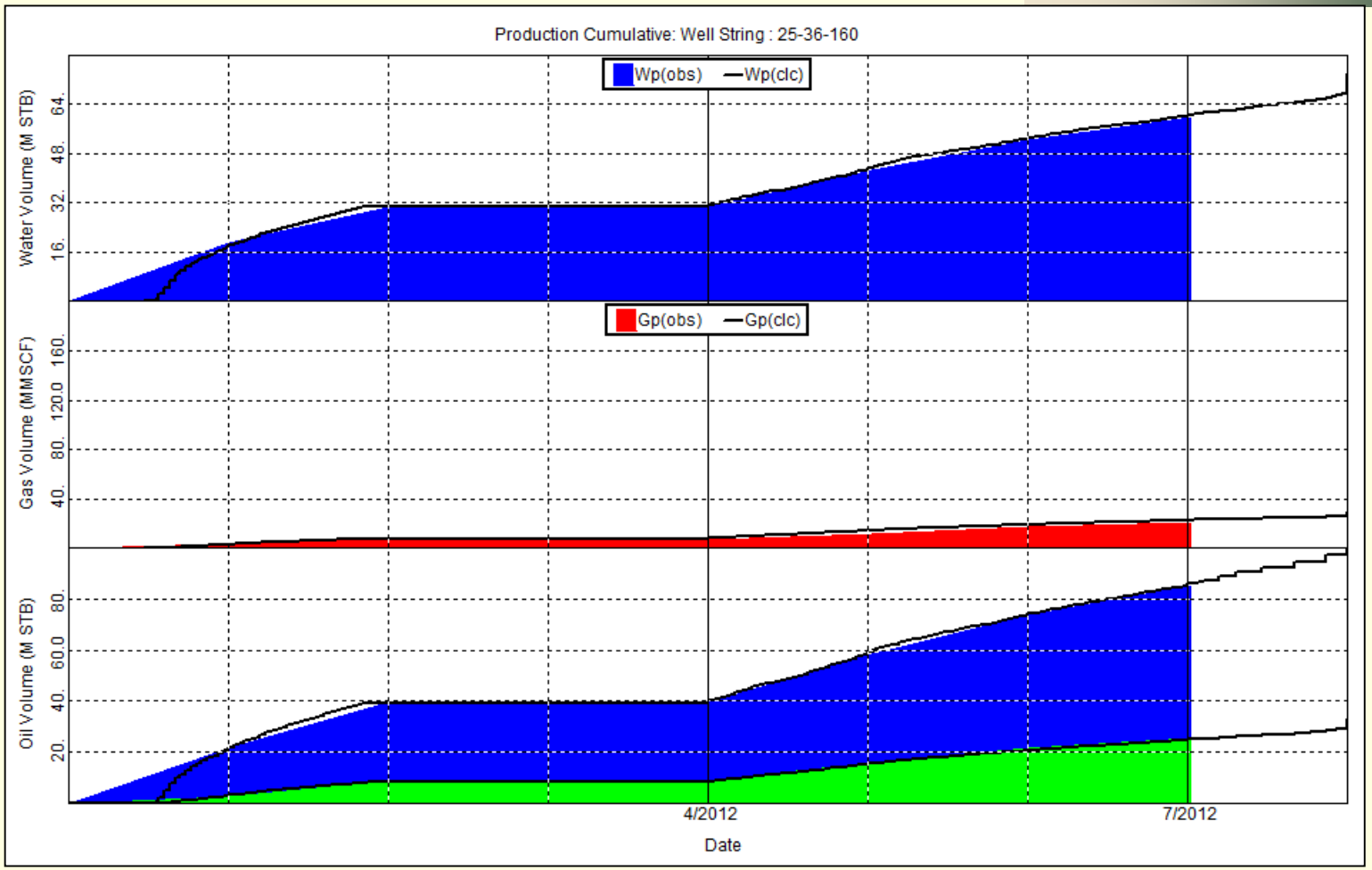
- 4 Projects:
  - Project #1: Bakken
  - Project #2: Bakken(same field as #1)
  - Project #3: Wolfcamp
  - Project #4: Eagleford

Project #1



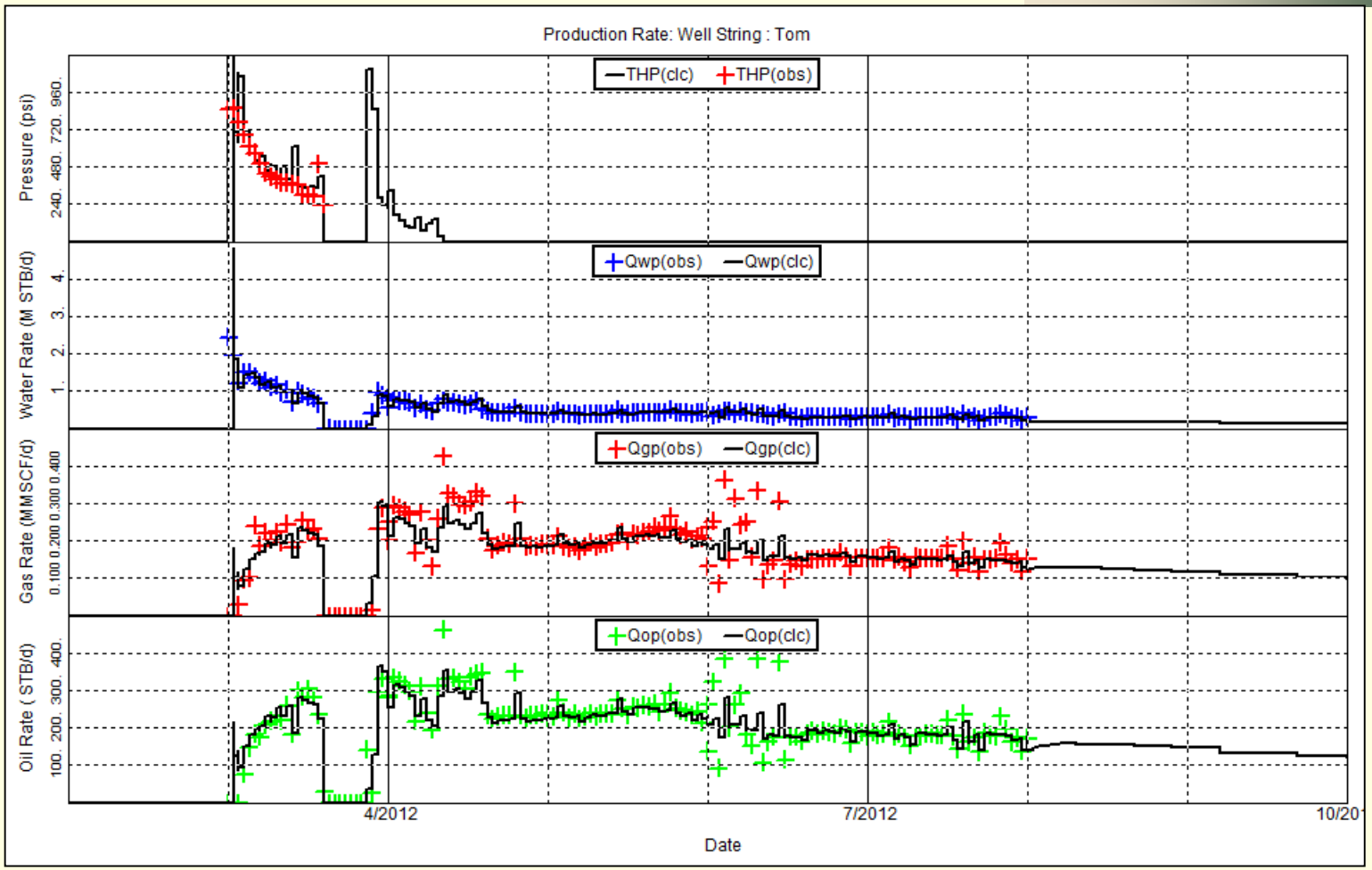
Solid lines represent simulated data.
Colored points indicate measured data

Project #1



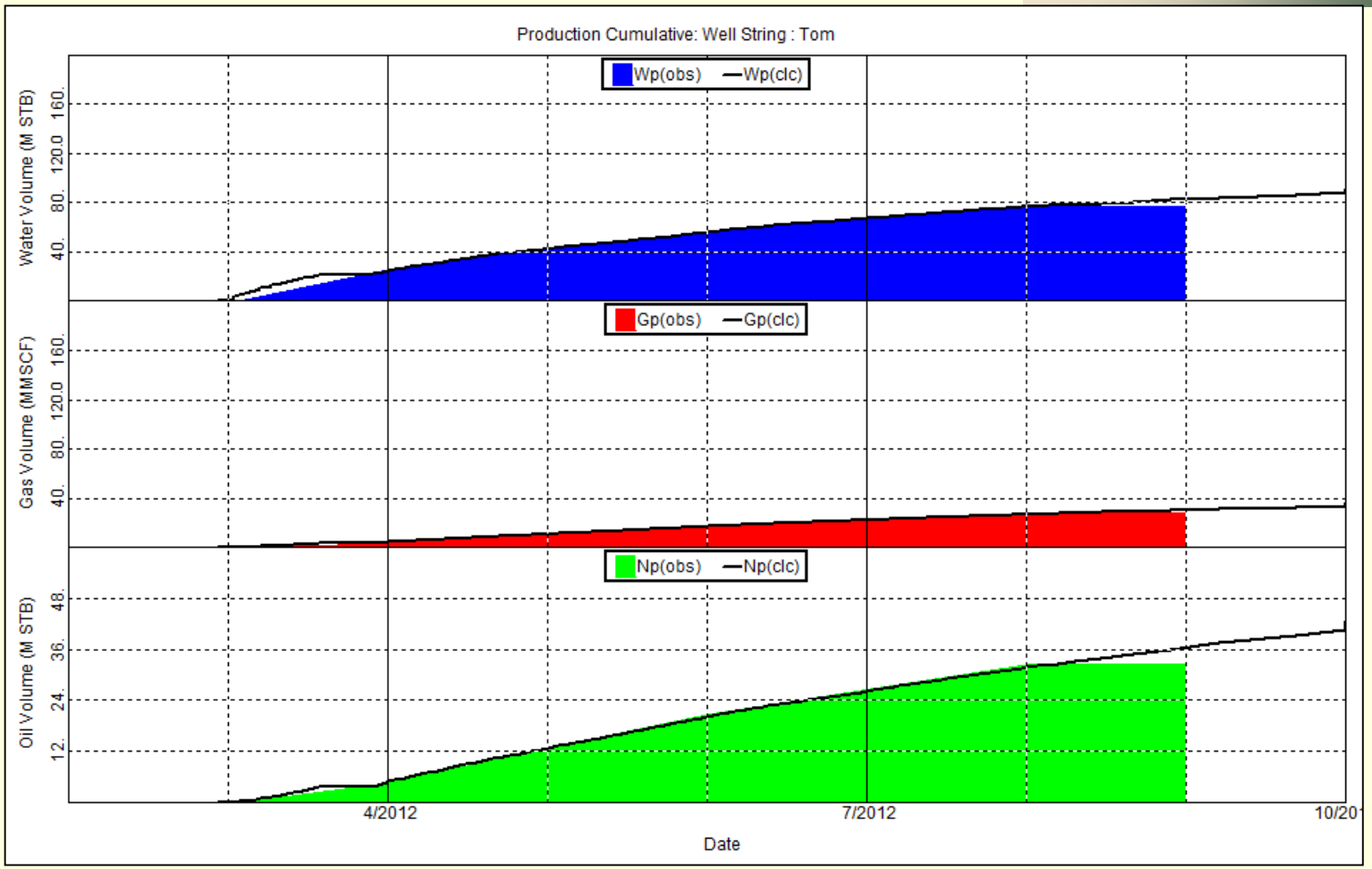
Solid lines represent simulated data.
Shaded areas indicate measured data

Project #2



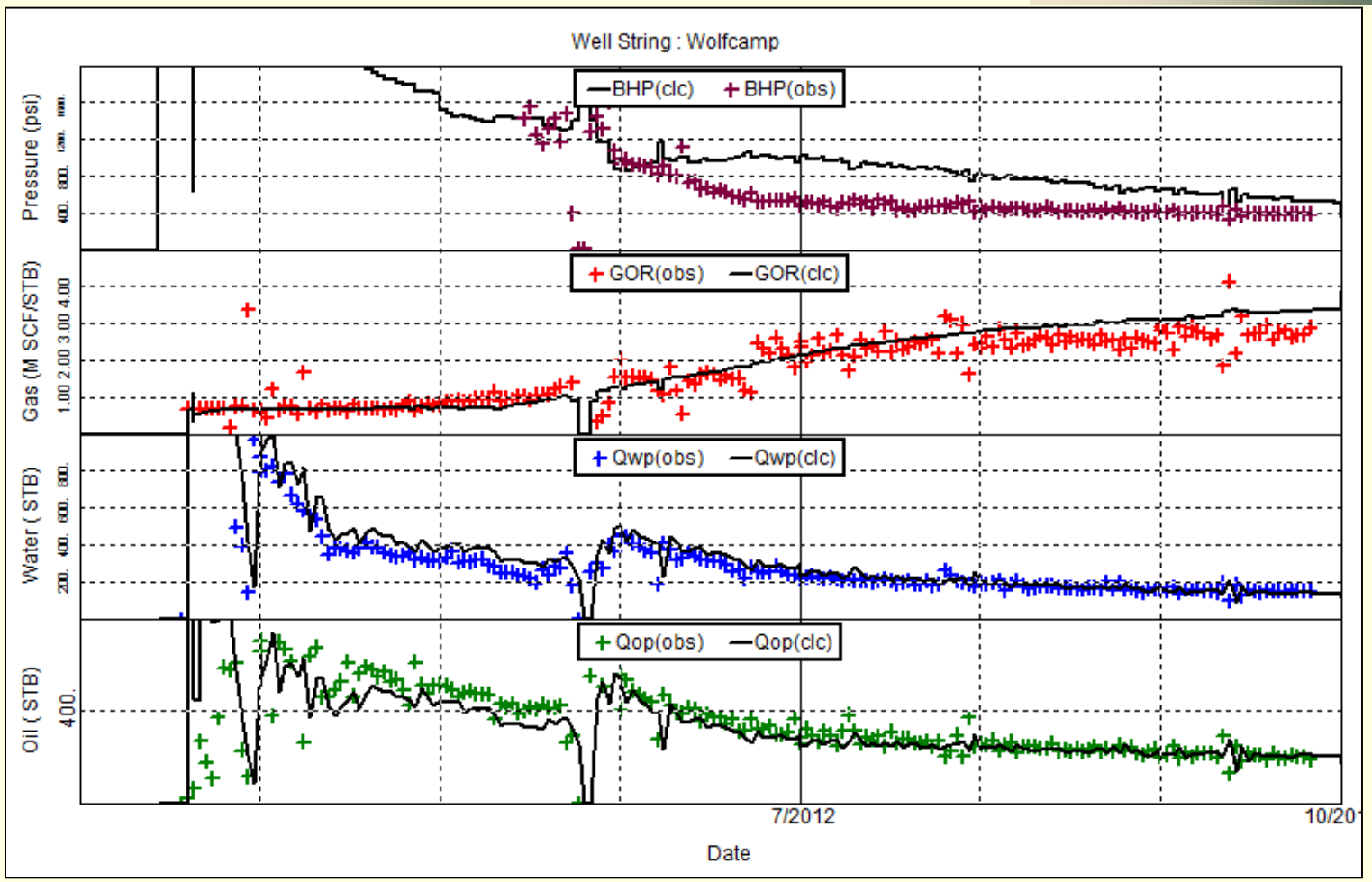
Solid lines represent simulated data.
Colored points indicate measured data

Project #2



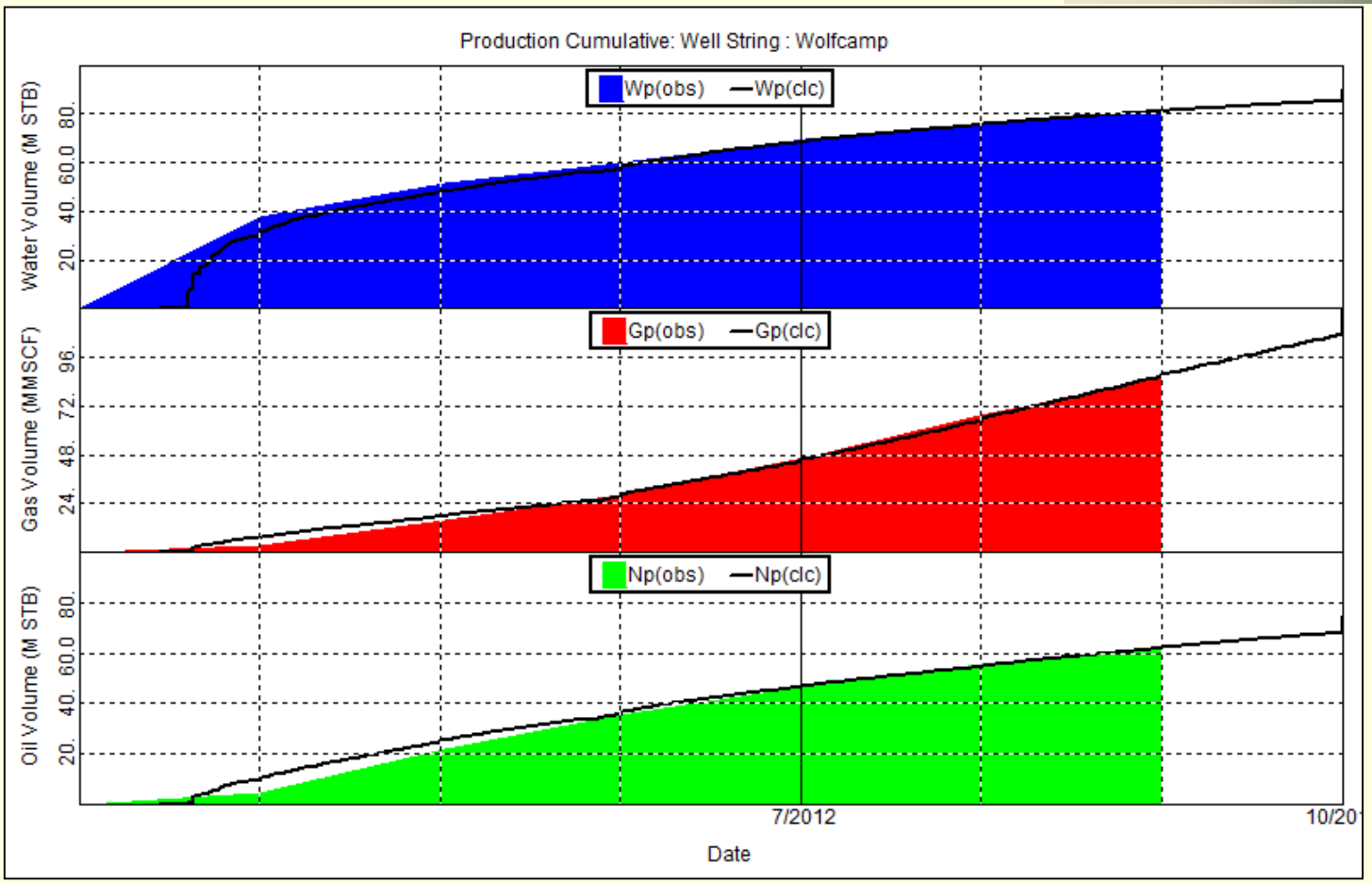
Solid lines represent simulated data.
Shaded areas indicate measured data

Project #3



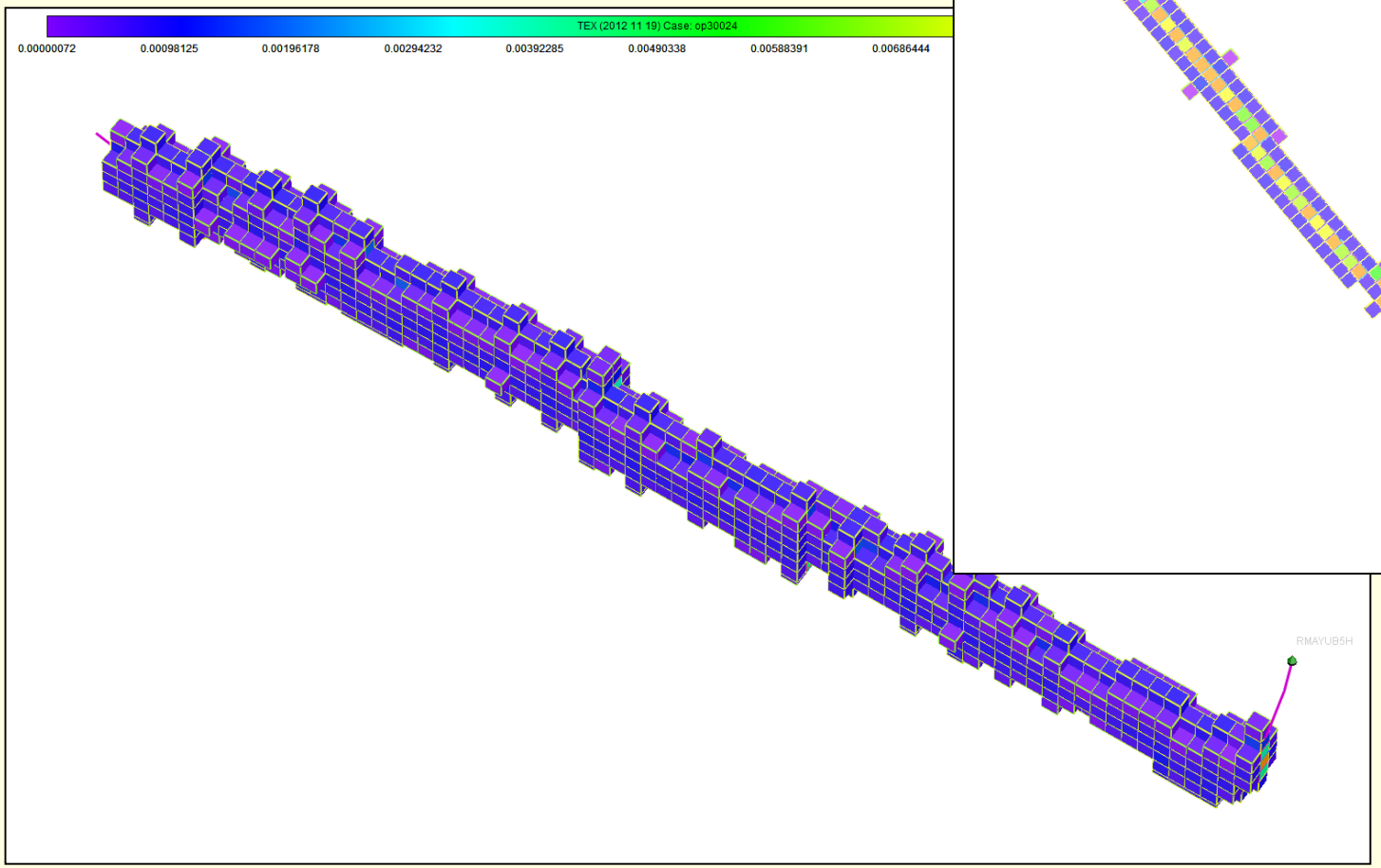
Solid lines represent simulated data.
Colored points indicate measured data

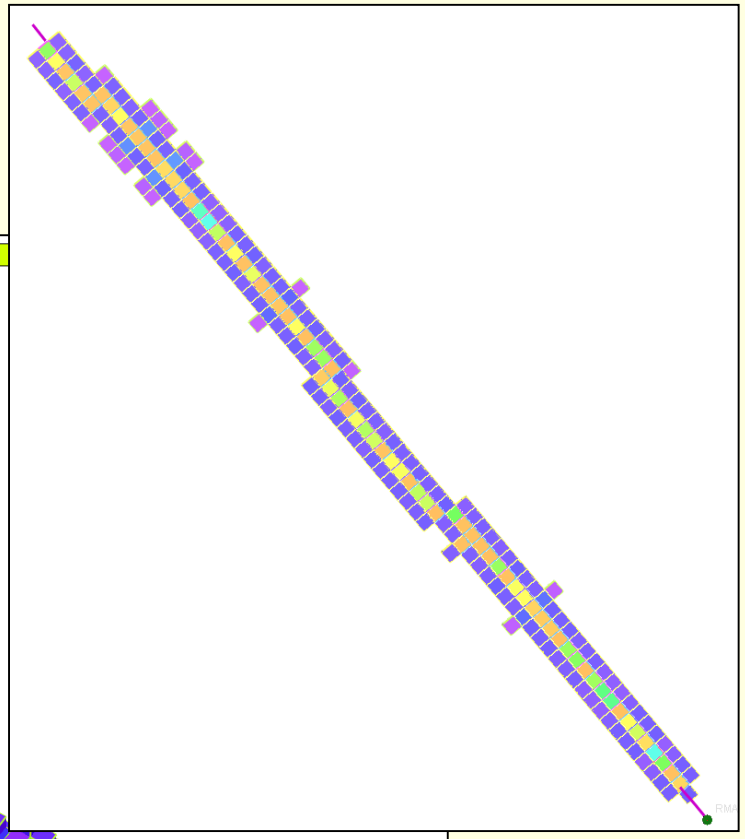
Project #3



Solid lines represent simulated data.
Shaded areas indicate measured data

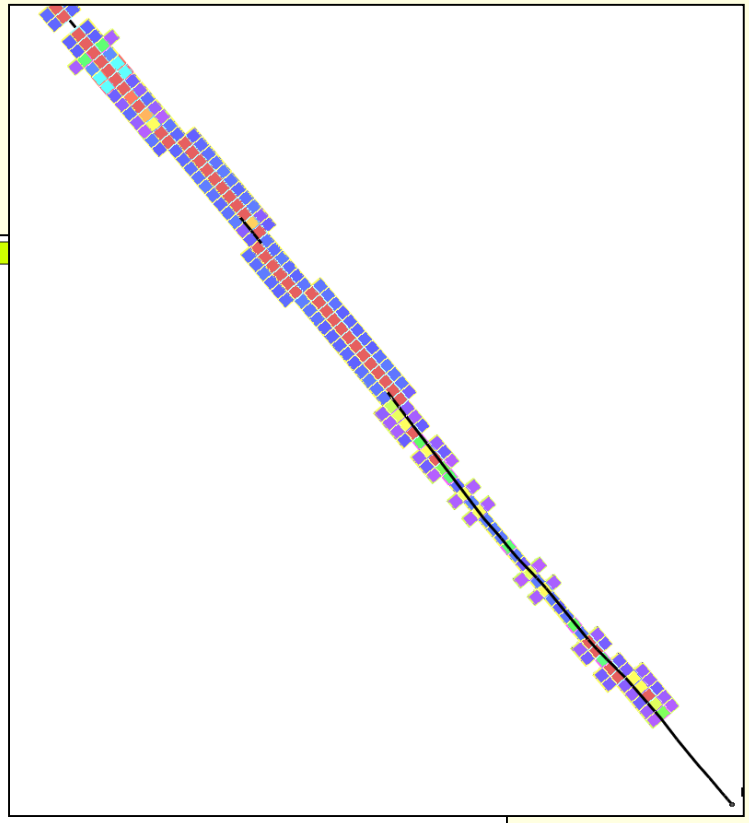
Project #4 – Well 1

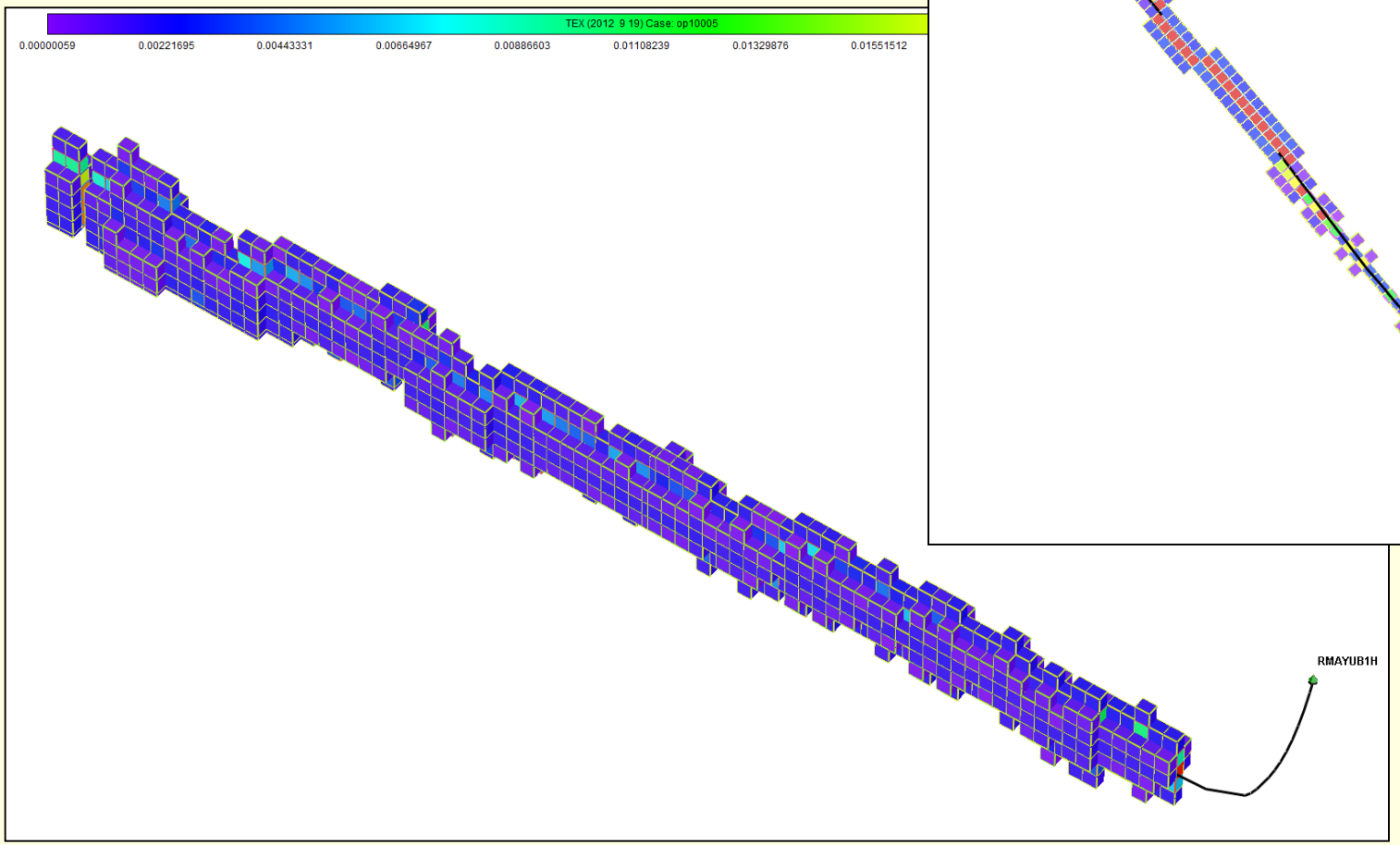




Project #4 – Well 2

Frac volume	± 5 %
Length	± 10 %



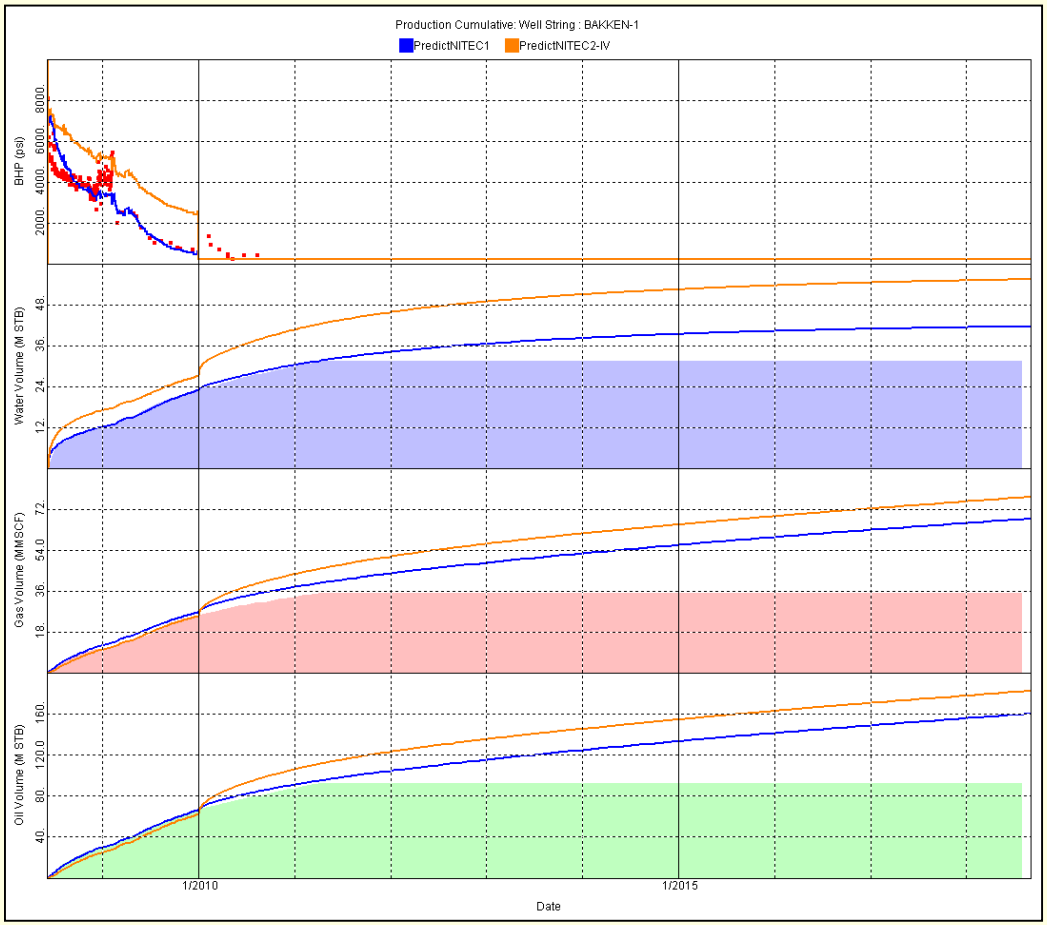


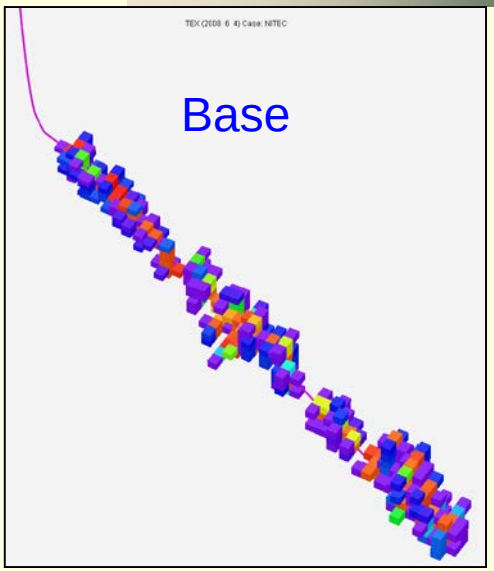
NEW Approach as a Predictive tool

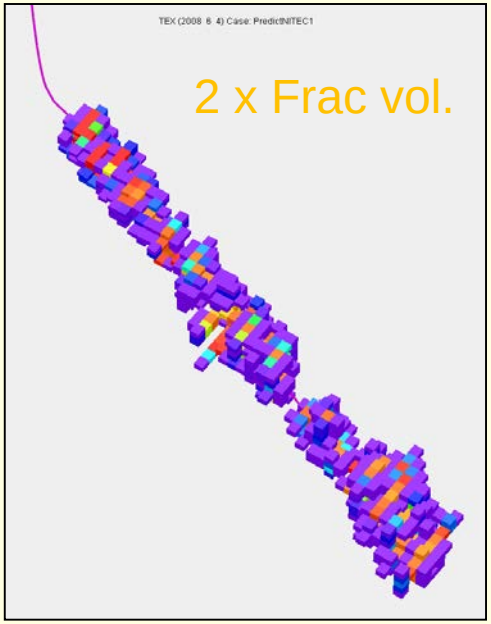
- Conventional approach has limited predictive capability if completion practices change
- Once calibrated, NEW approach has predictive capabilities
- Alternative scenarios can be run to quantify the impact of different strategies
  - Well placement/spacing
  - Well orientation
  - Fracture treatment volumes
  - Fracture treatment rates
  - Number of stages
  - Placement of stages

Optimize Fracture Treatment Volume

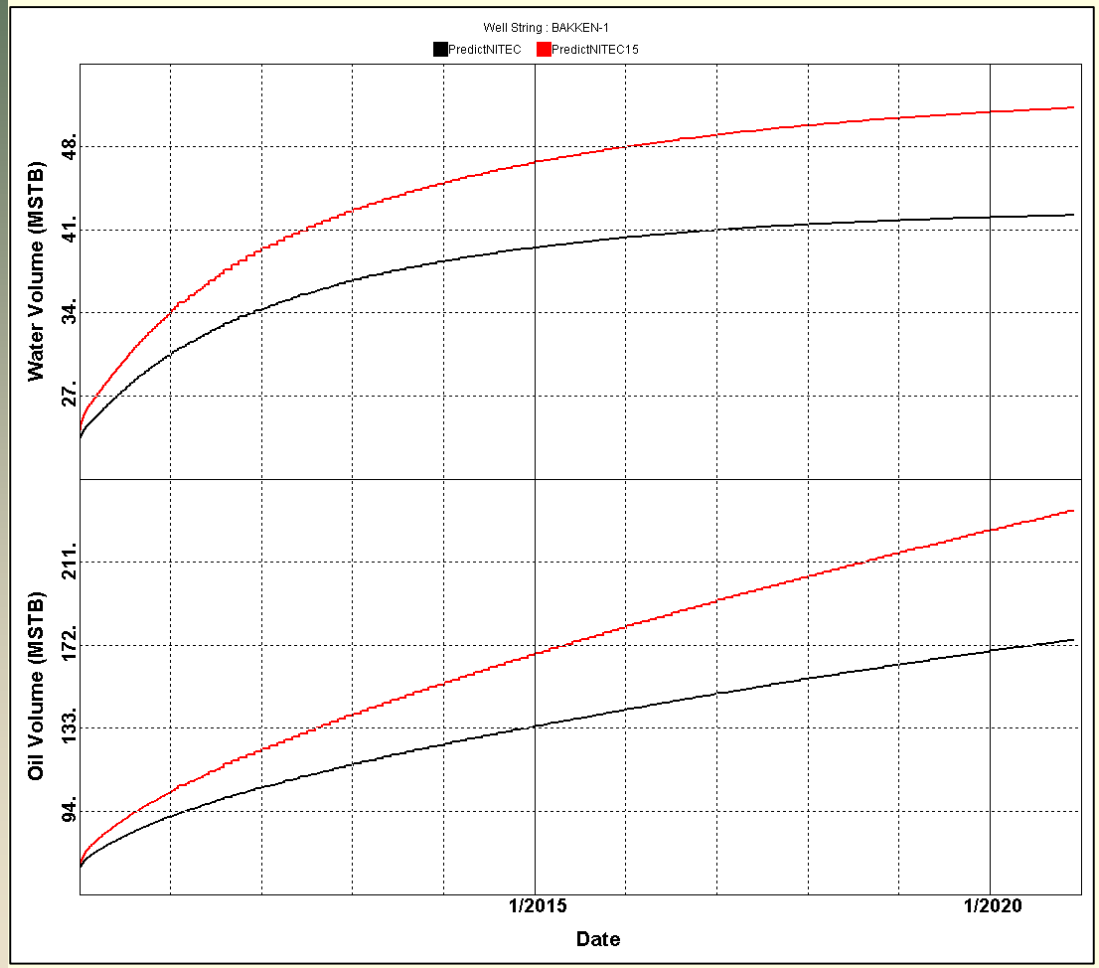
- Doubling of Frac Injection Rate

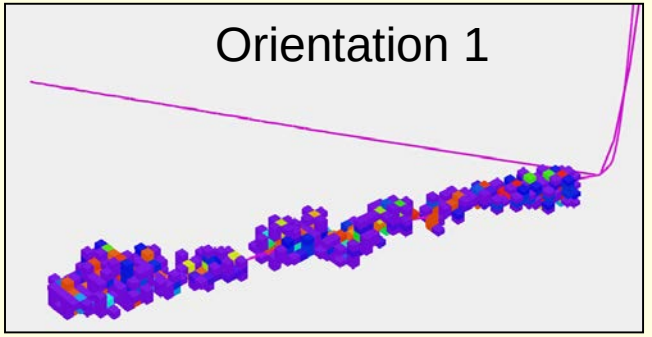


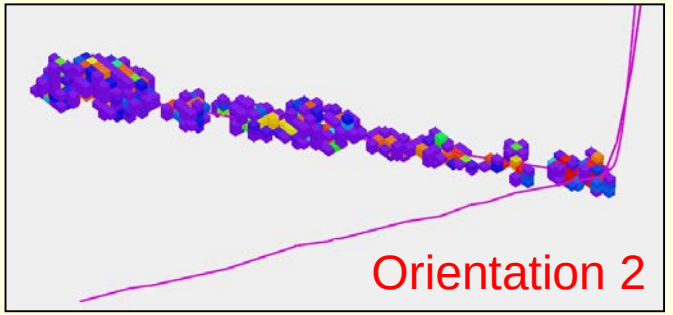




Optimize Well Orientation







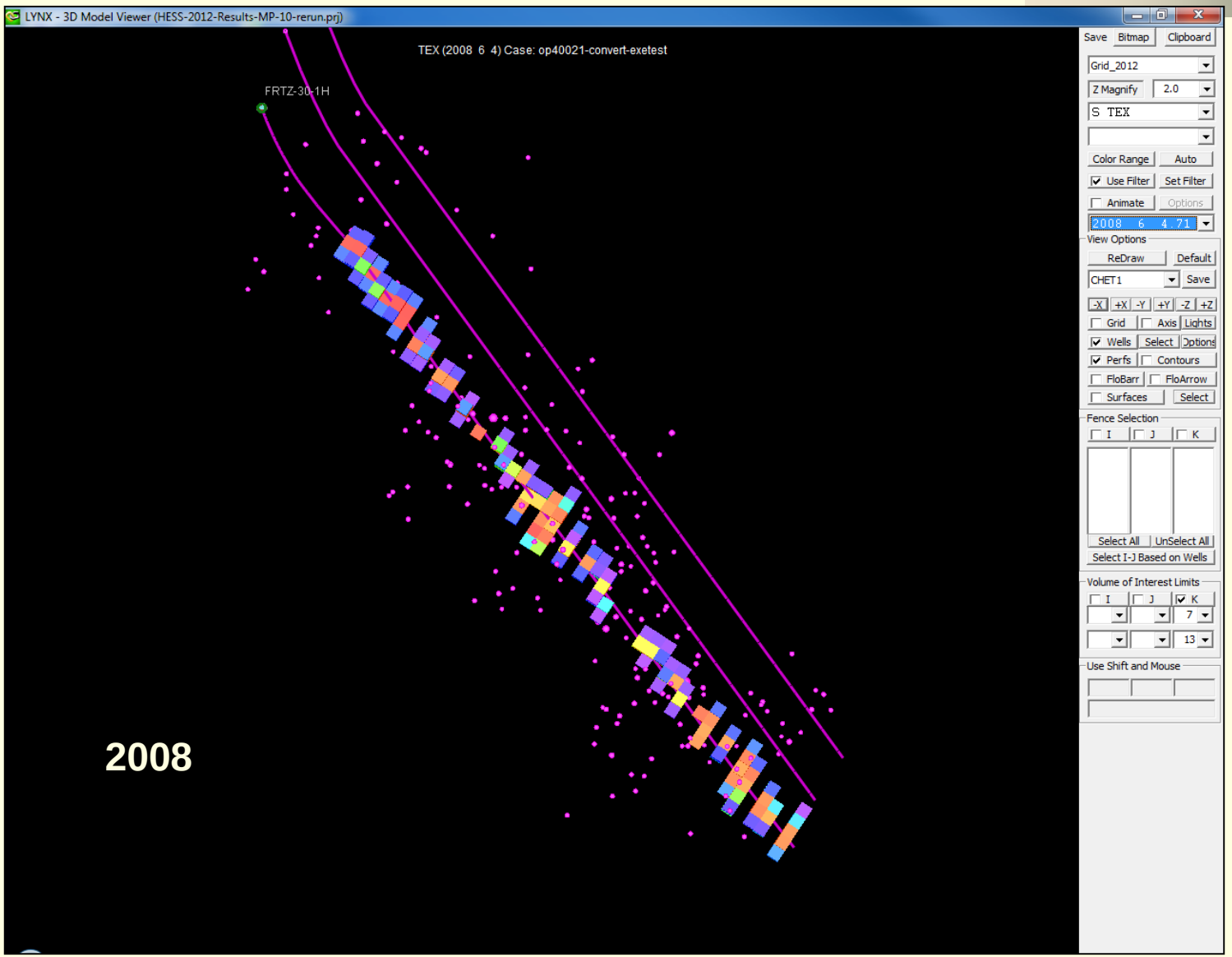
Multiple Wells

Project Description:

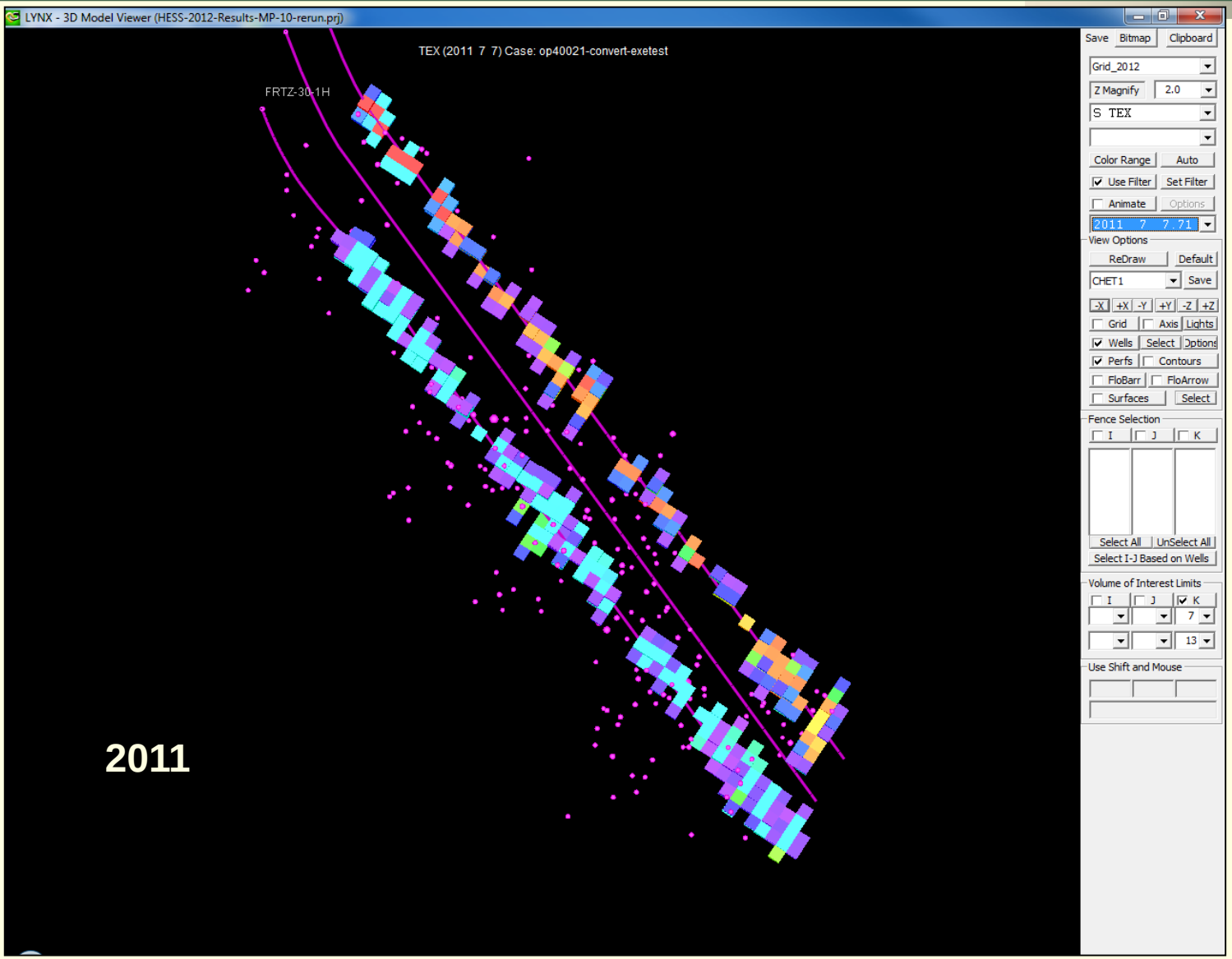
- All wells use the same drilling and completion strategy
  - First well drilled in 2008 and produces
  - Second well drilled in 2011 and produces
  - Third well to be drilled in 2013

- Automatically accounts for affect of stress level changes from one well fracture area to another over time

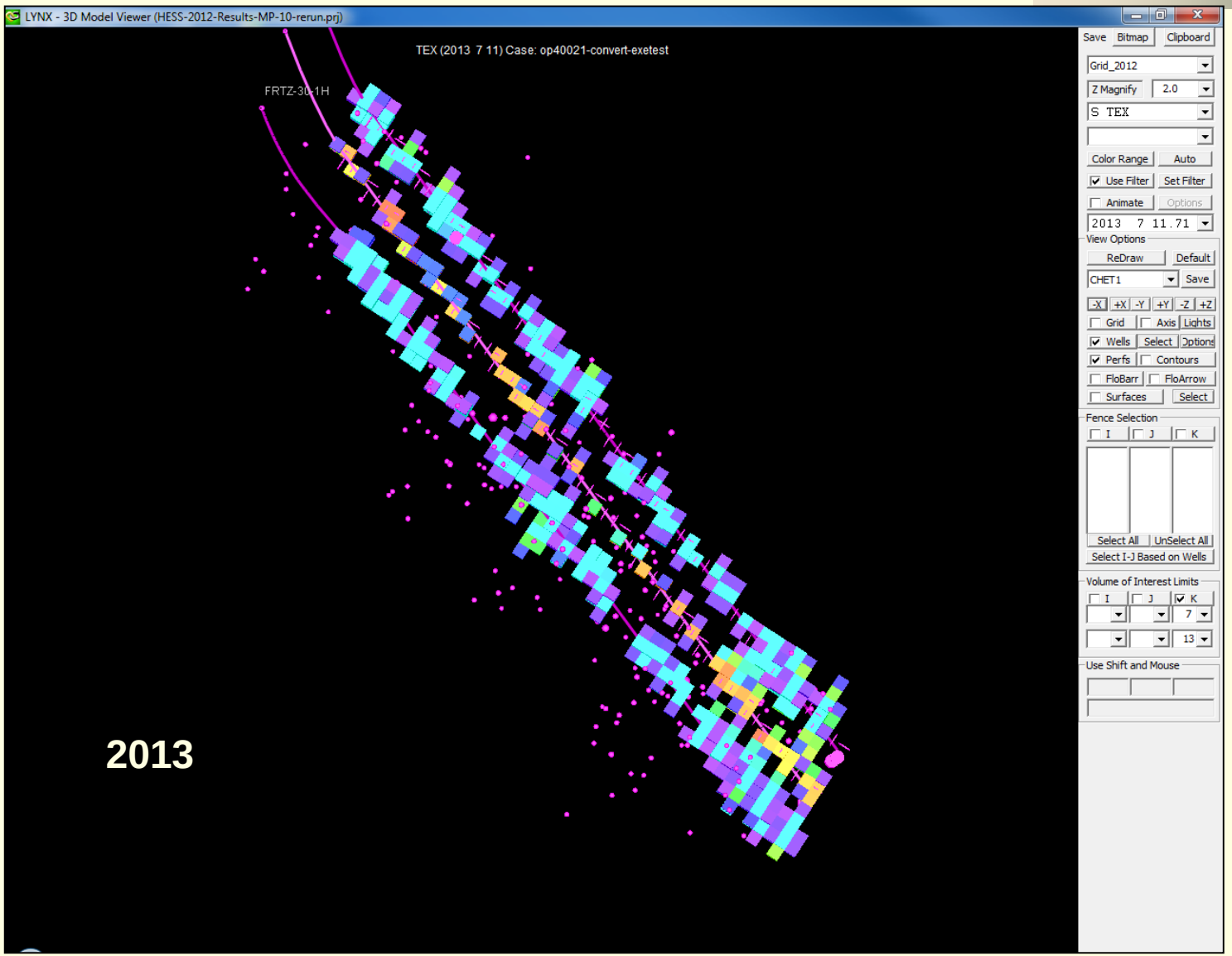
Multiple Wells



Multiple Wells



Multiple Wells



How are we using this technology today?

Analyze multiple wells in the same field
- Different hydraulic fracture treatments

Understand the performance differences based on
- Reservoir quality
- Completion type
- Treatment volumes
- Treatment stages

Optimize treatment practices and well spacing

Supplemental recovery mechanisms

Questions?

Thank You!

Bill Savage
NITEC LLC
475 17th Street, Suite 1400
Denver, CO 80202
www.nitecllc.com