RECENT ADVANCEMENTS IN MECHANICAL EARTH MODELING AT FARNSWORTH WEST UNIT

NEW MEXICO TECH
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Presentation Outline

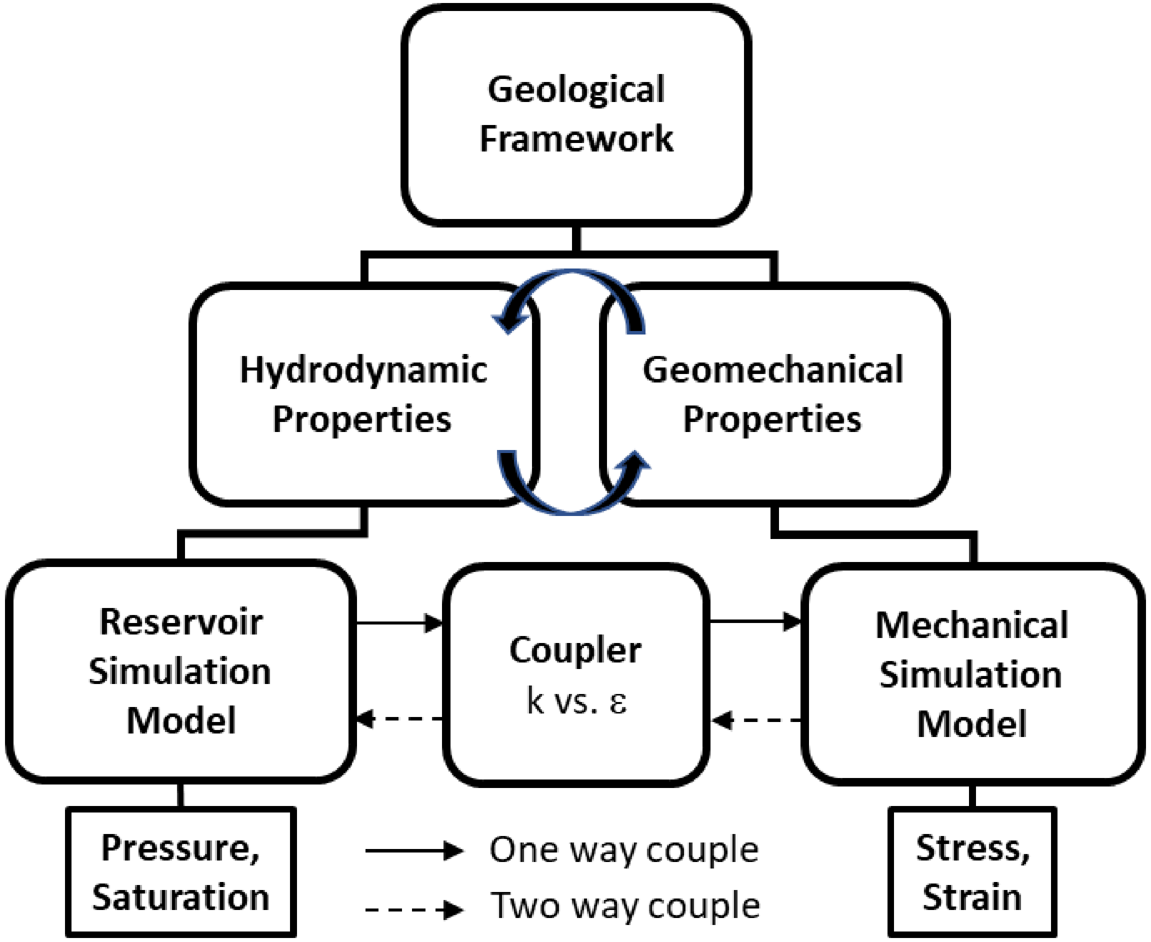
- SWP Overview
- Coupled Hydrodynamic/Geomechanical Modeling Workflow Overview
- Petrophysical-Mechanical Modeling
- FWU Life-of-Field Coupled Modeling
- Integrated Stress Model Calibration Workflow
- Stress-Strain-Velocity Evidence in Log and Core

Southwest Regional Partnership - Farnsworth

- Farnsworth Unit was discovered in 1955. Over 100 wells were completed by the year 1960.
  - Water injection for secondary recovery started in 1964.
  - CO_2 first injected in 2010.

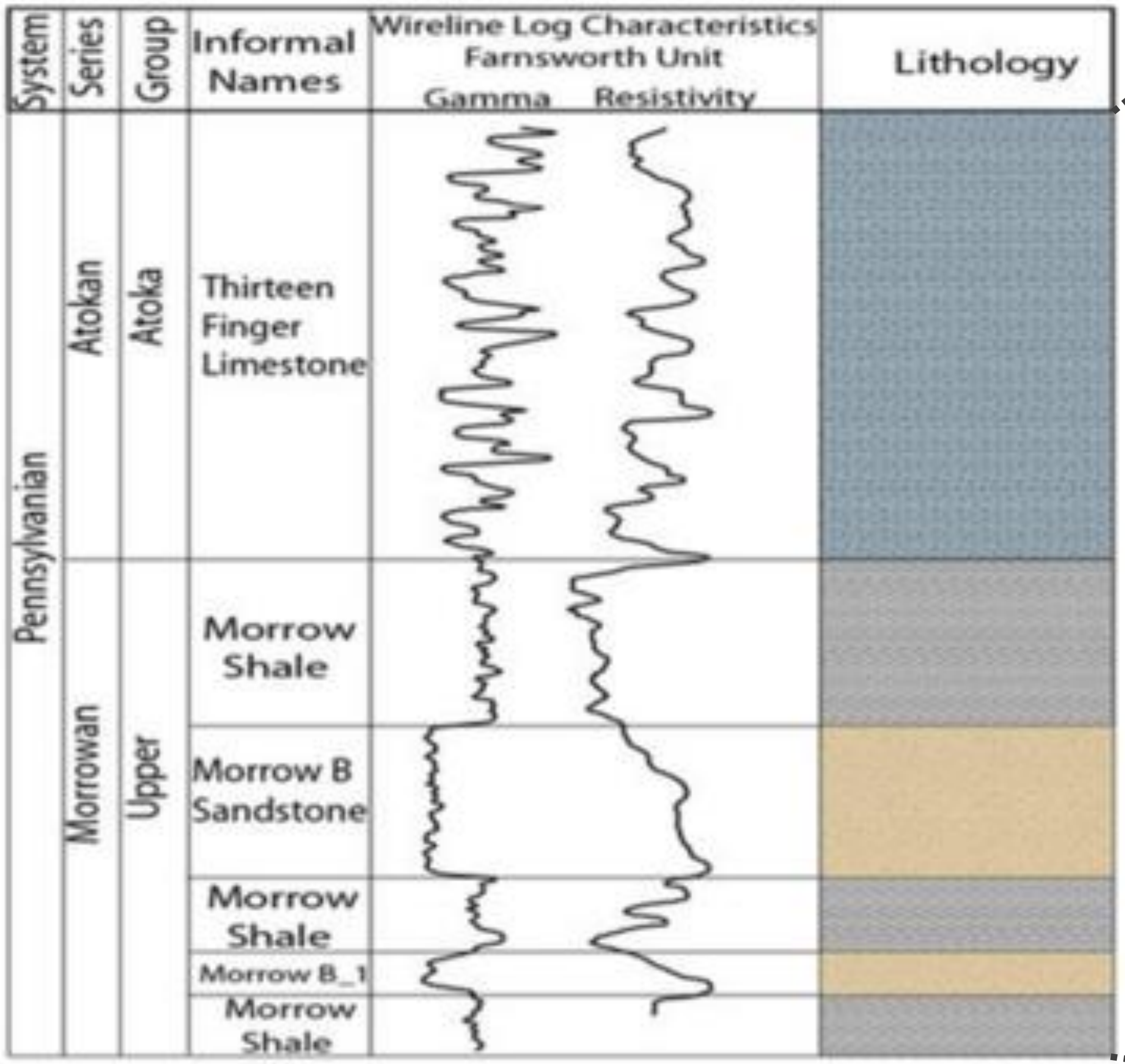
- Anthropogenic Supply: 500-600,000 Metric tons CO_2/year supply

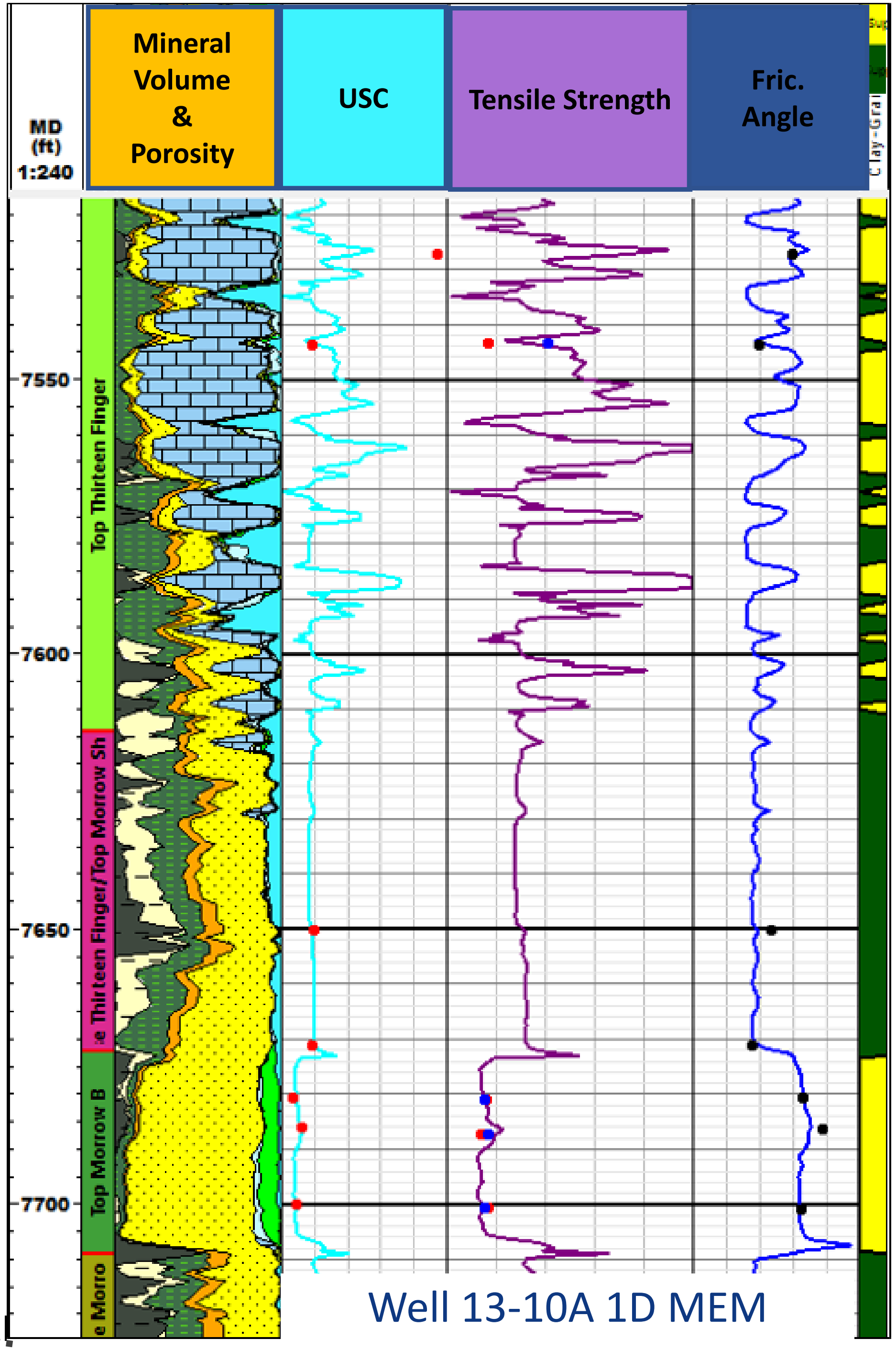
Coupled Geomechanical Modeling Workflow



- Geologic model captures structure and stratigraphy and also integrates well logs and 3D seismic
- 13-10A 1D MEM elastic properties is correlated with the 3D seismic to populate geomechanical properties of the 3D MEM.
- Existing compositional hydrodynamic simulation is coupled with geomechanical computations.
- Volumetric strain reflects porosity changes and impacts permeability
  - → One Way
  - → Two Way

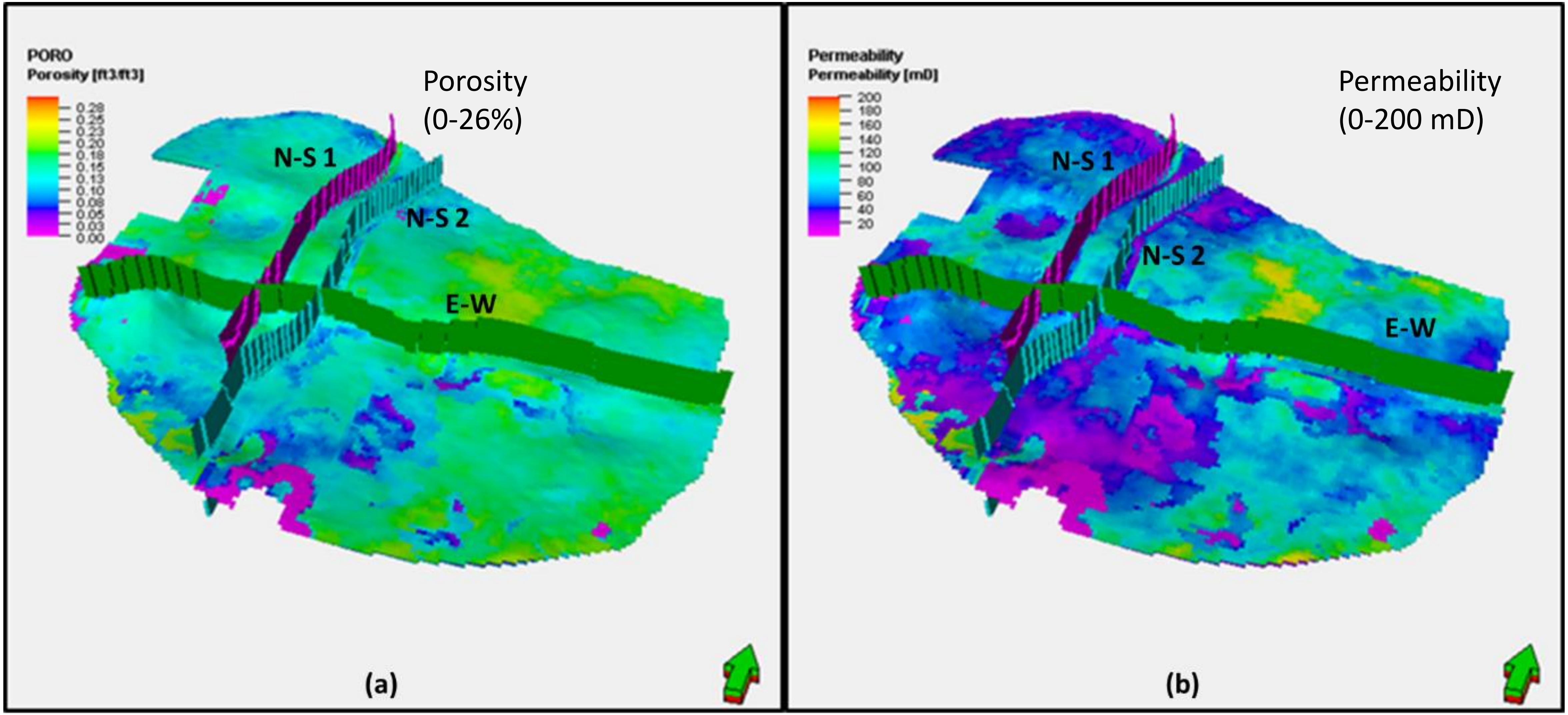
Stratigraphy and 1D MEM Mechanical Properties



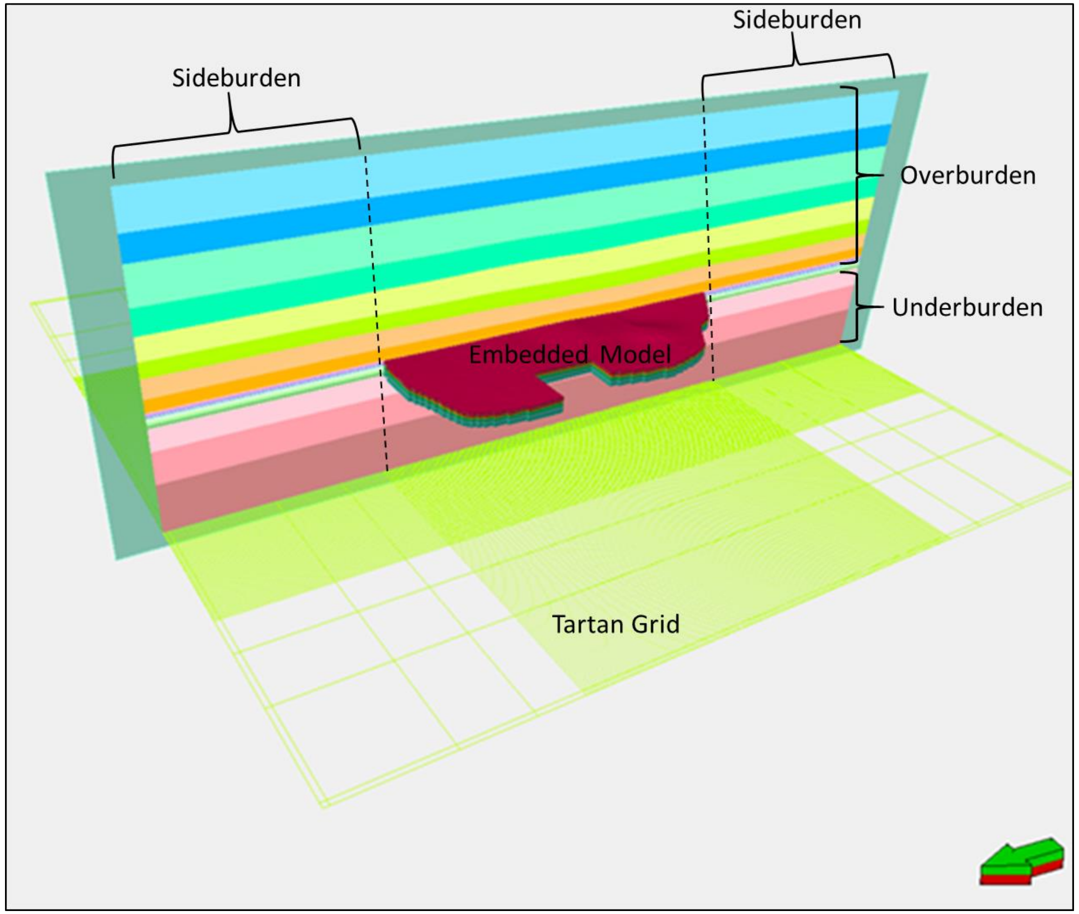


Well 13-10A 1D MEM

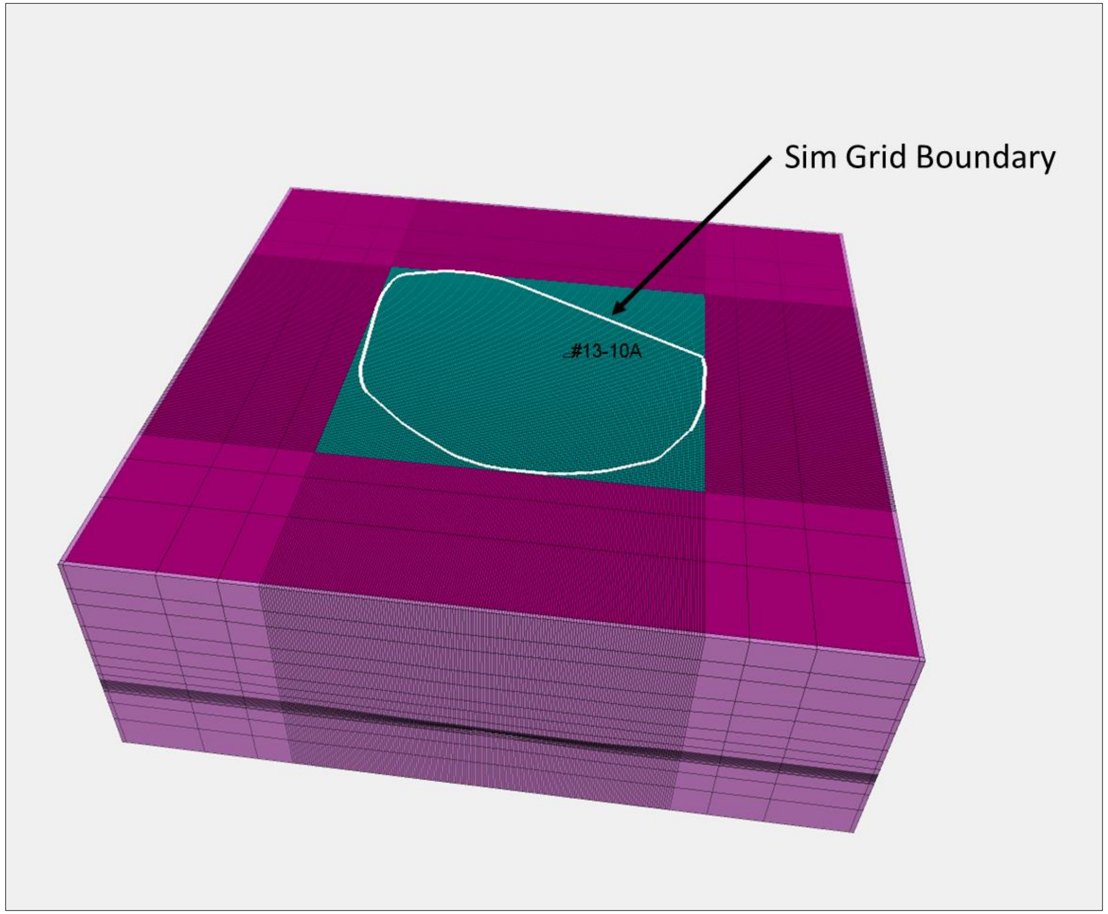
Reservoir Simulation Model Poro-Perm and Faults



Sim Model Embedding for Mechanical Boundaries



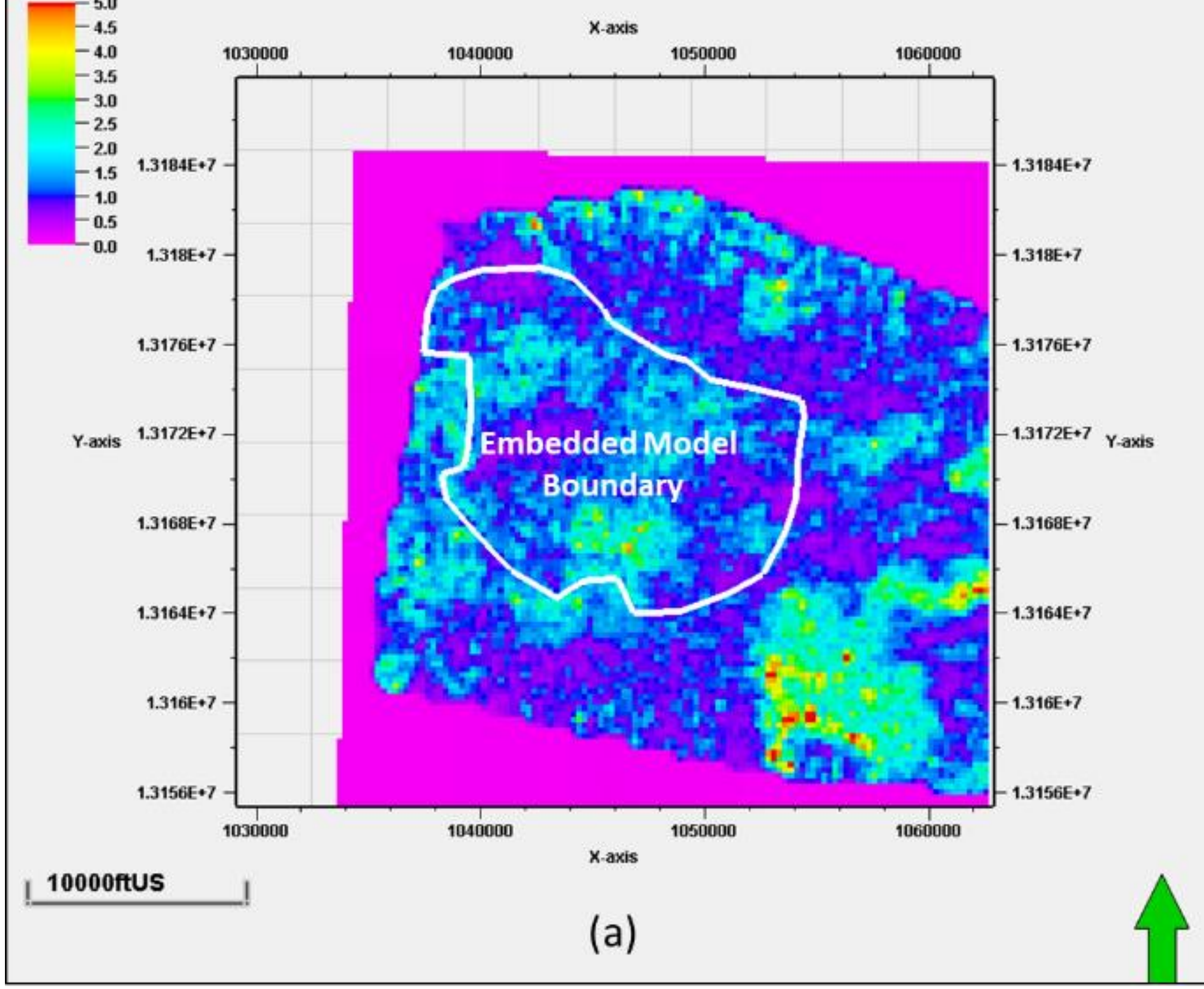
Vertical slice showing grid Z-Y skeleton, layering, and over/under/side burden



3D MEM Grid

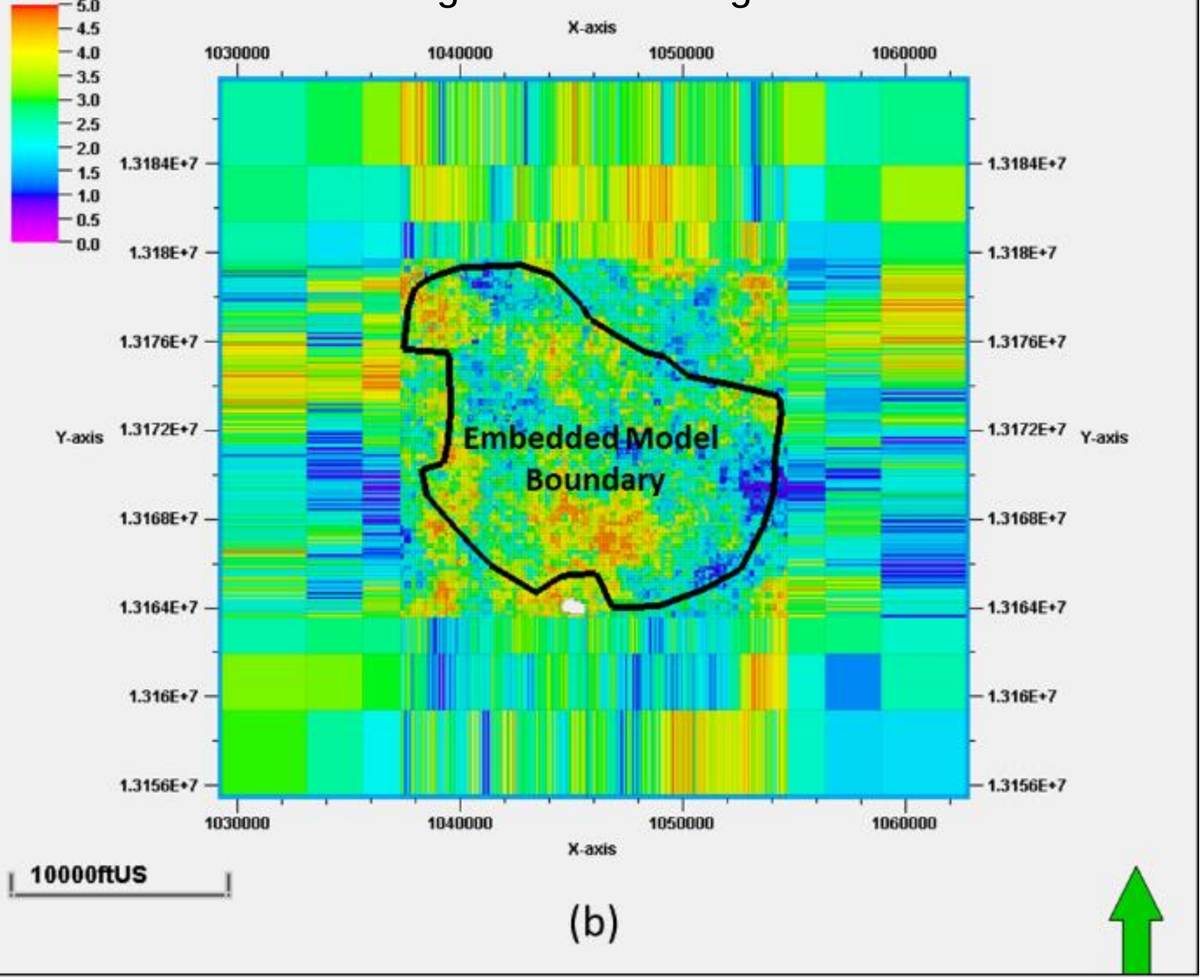
Mechanical Property Interpolation with Elastic Inversion

Seismic inversion derived estimate of Young's Modulus



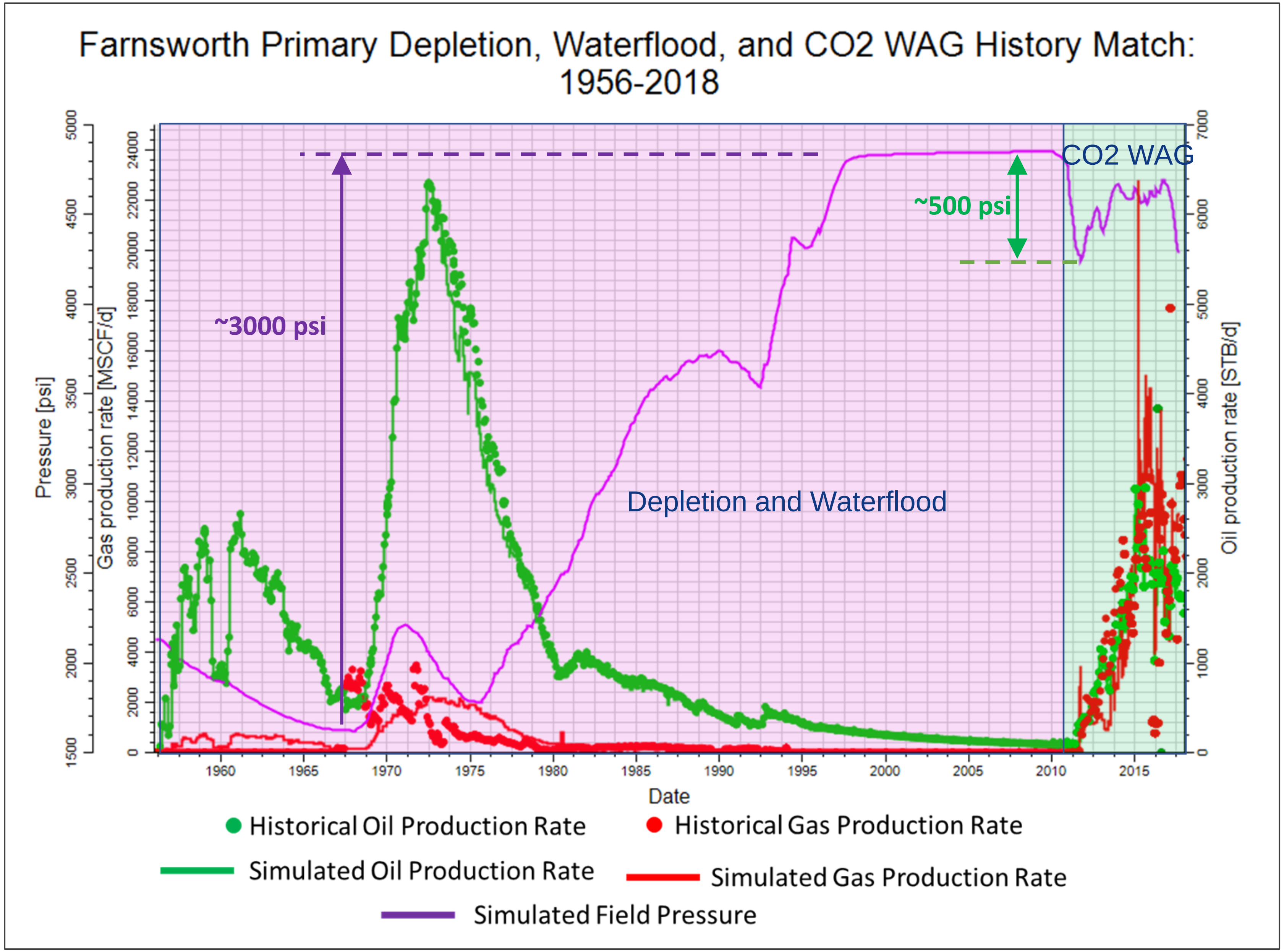
(a)

Distribution-adjusted and co-kriged Young's Modulus in geomechanical grid



(b)

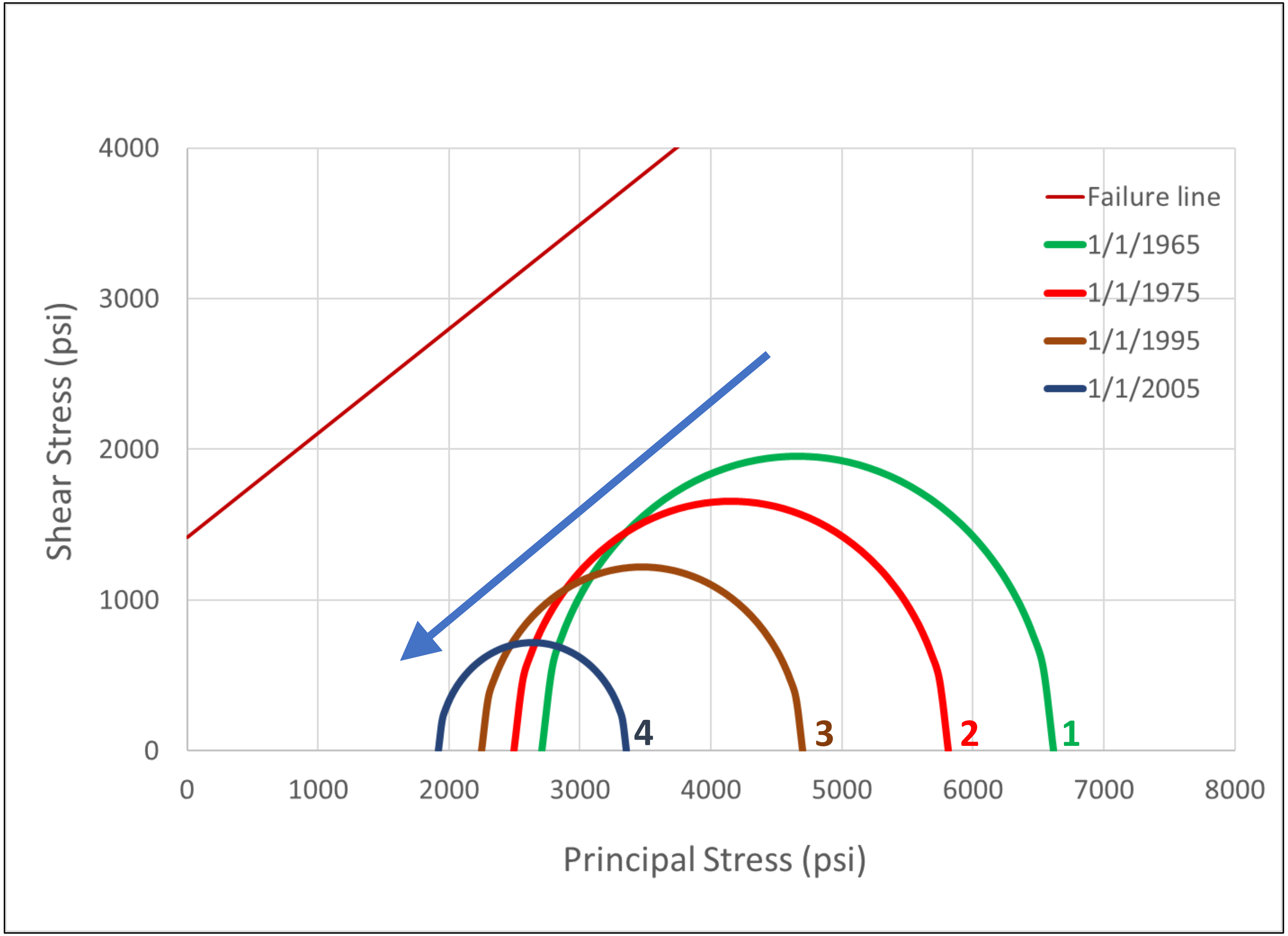
Oil/Gas Production History Match and Pressure History



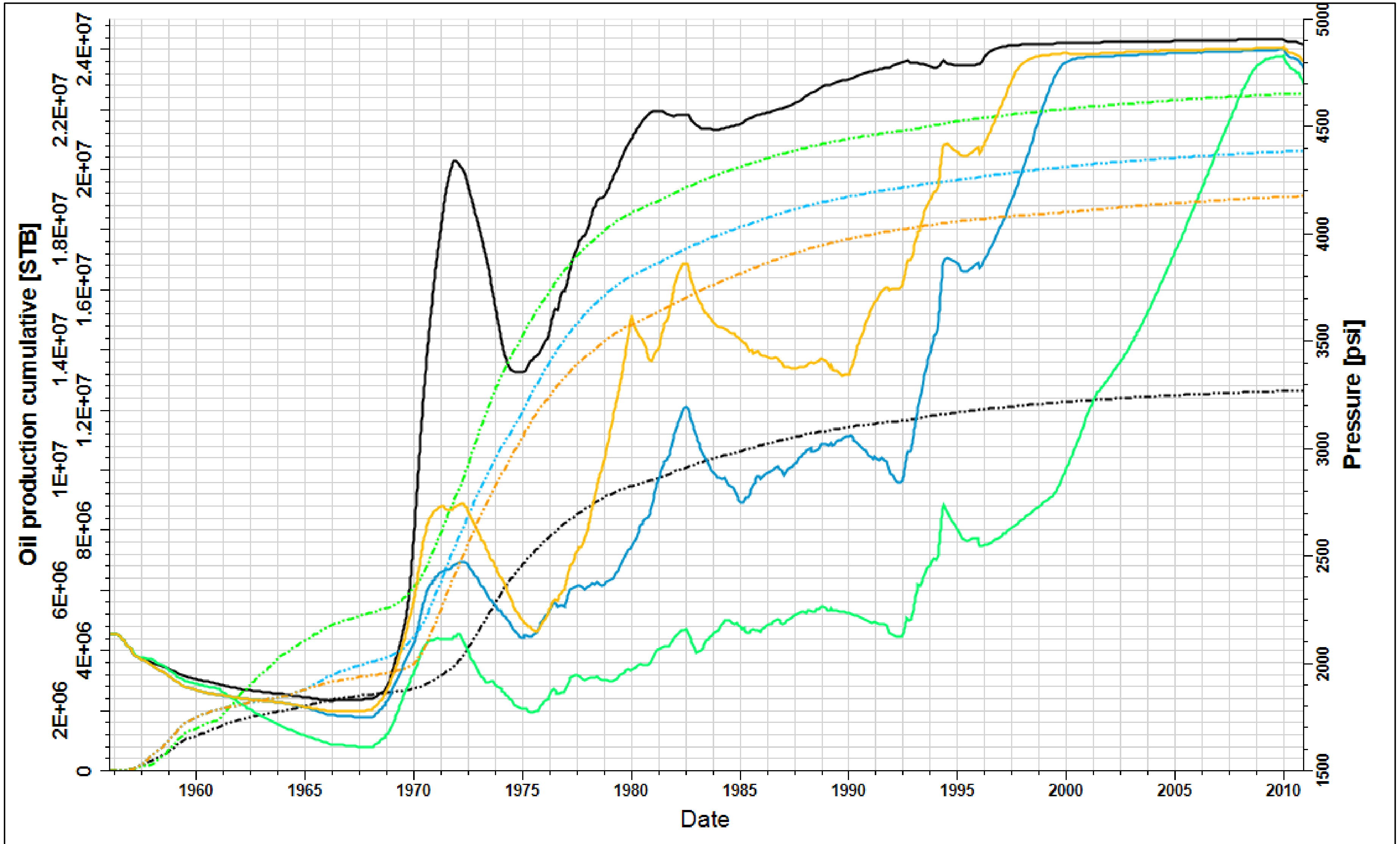
Coupled Simulations

- Coupled simulations were run for depletion-waterflood and CO_2 WAG periods to investigate importance of stress dependent permeability on reservoir performance and geomechanical state.
- Permeability is updated at selected pressure steps using Kozeny-Carman relationship where porosity change is a function of total volumetric strain from initial condition.
- Stress dependent permeability measurements on core are under way at NMT.

Primary and Secondary (Waterflood) Mohr Circle Analysis



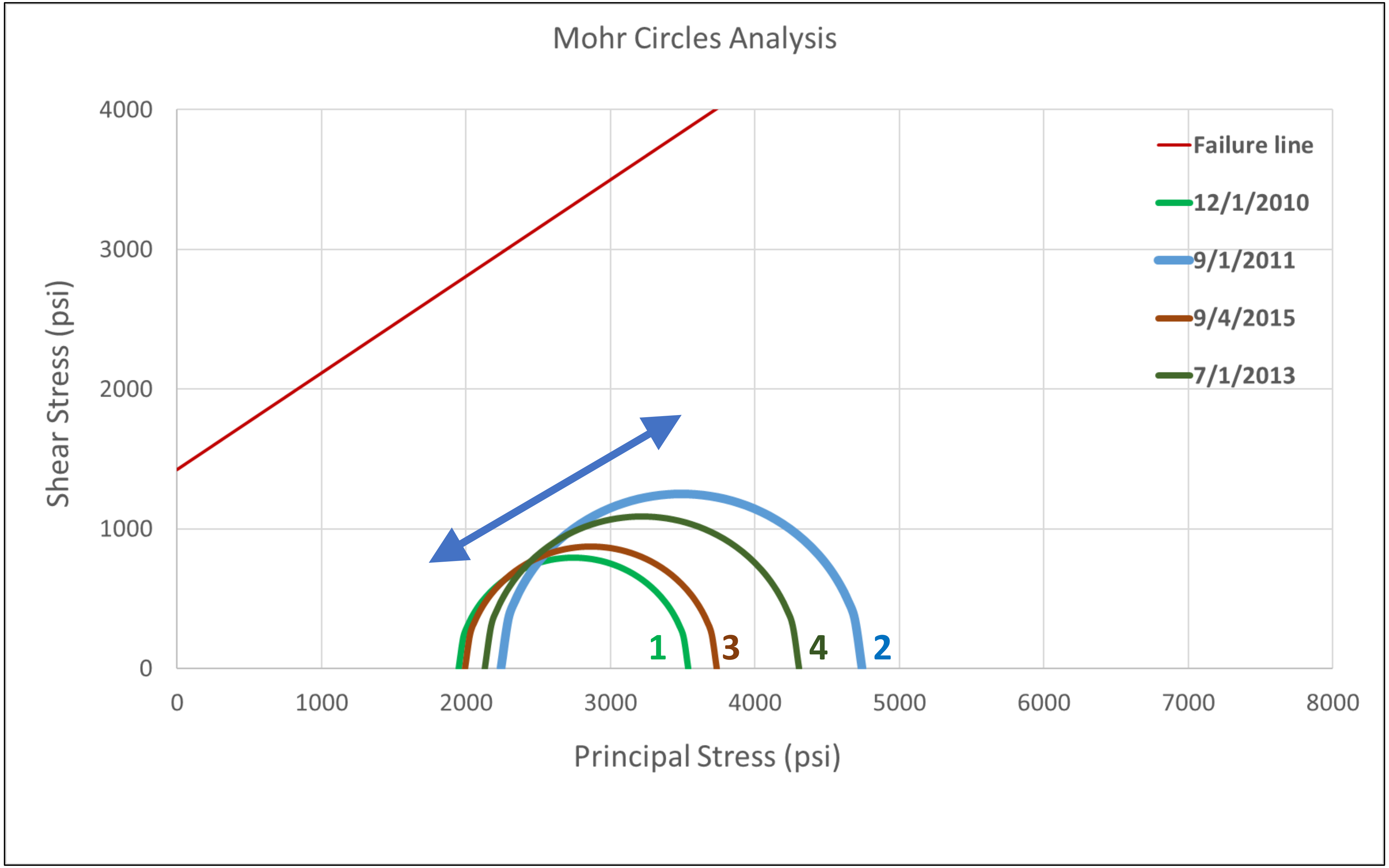
Impact of Permeability Updating: Primary-Waterflood Period



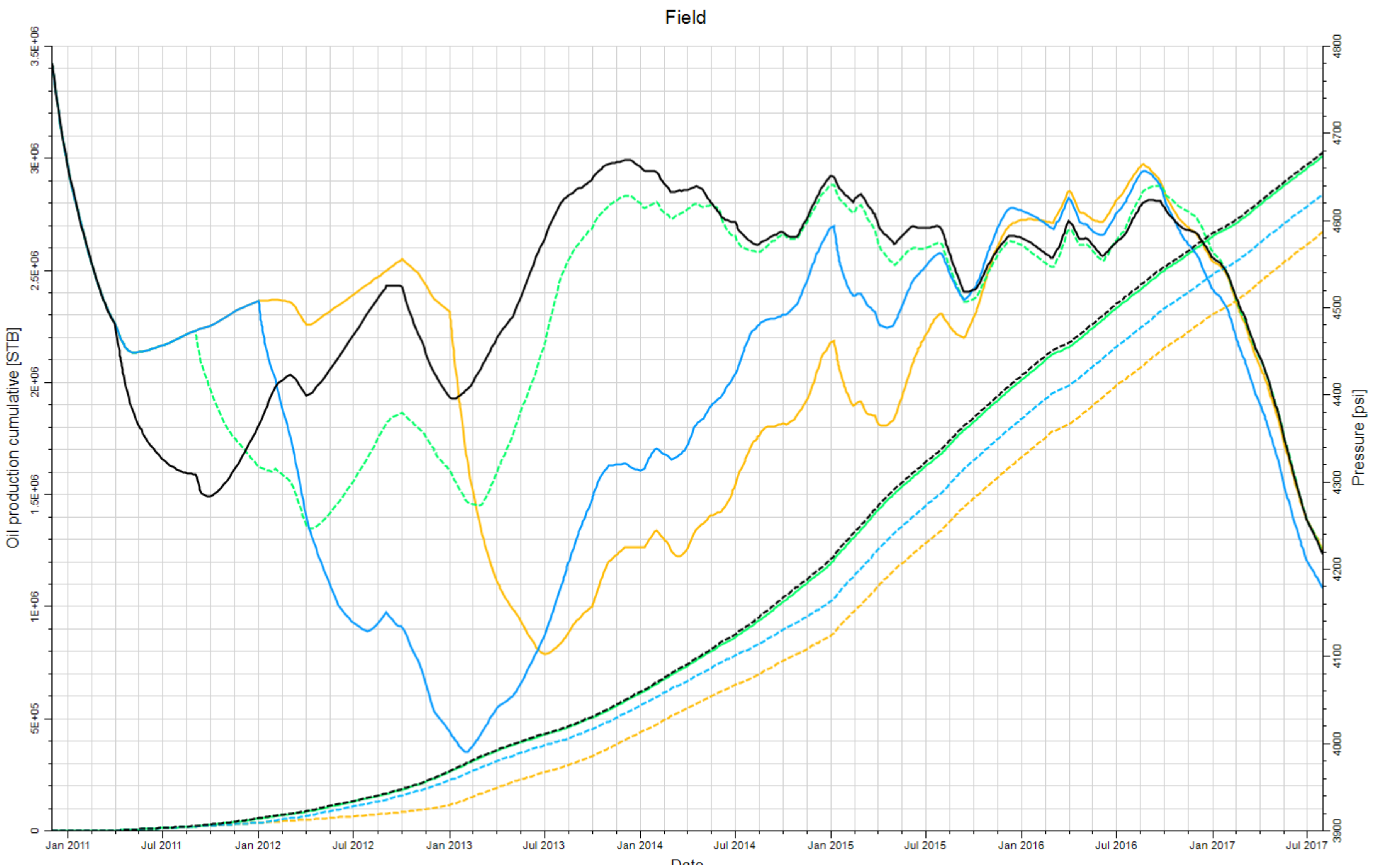
Prim-Sec 10 Year Update : Prim-Sec 5 Year Update : Prim-Sec 1 Year Update : No Update

Field Pressure (Solid Line) Field Cumulative Oil Production (Dashed Line)

Farnsworth CO_2-WAG Mohr Circle Analysis



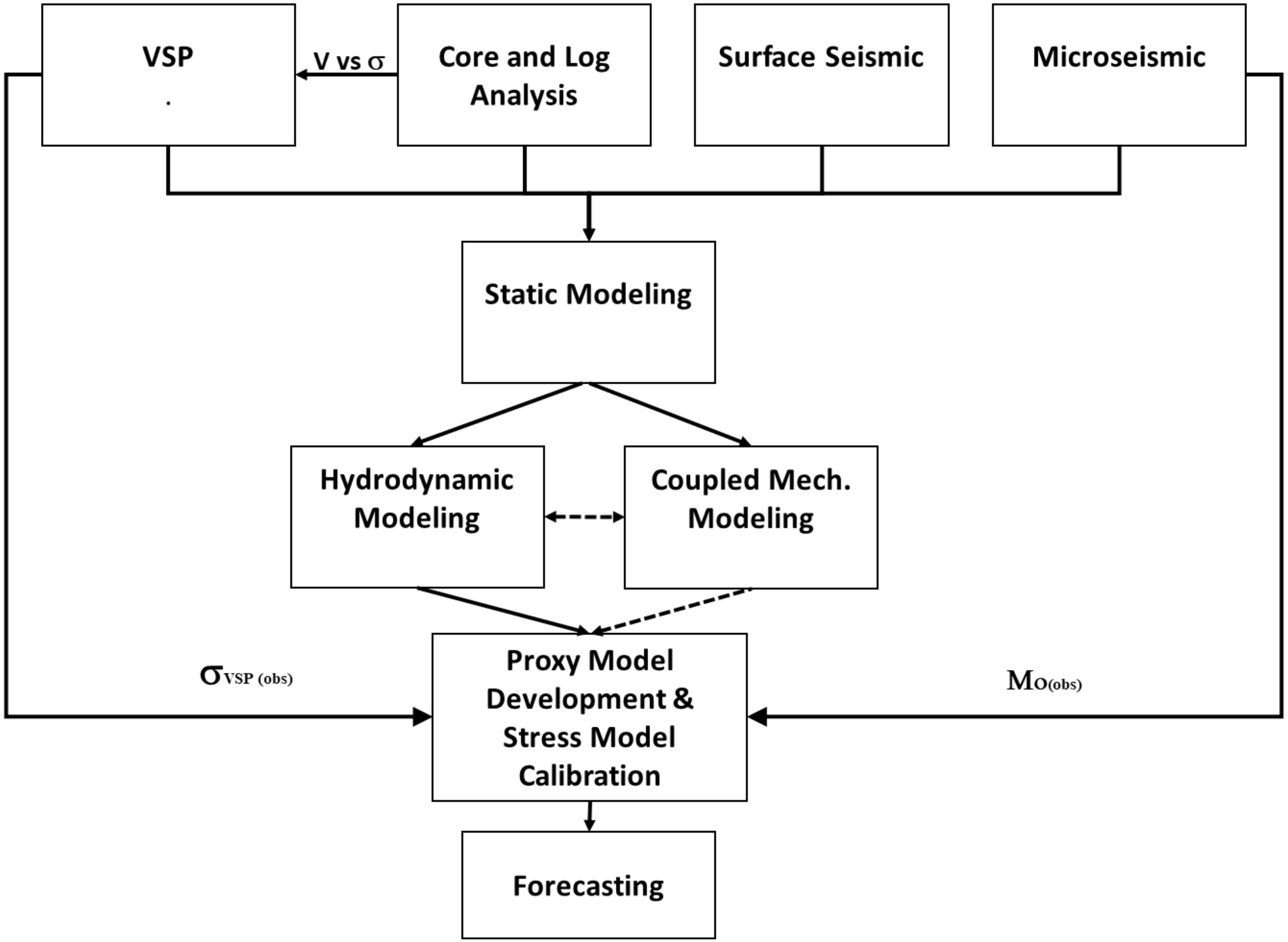
Impact of Permeability Updating: WAG Period



CO2 WAG 2 Year Update : CO_2 WAG 1 Year Update : CO_2 WAG 3-6 Month Update : No Update

Field Pressure (Solid Lines) Field Cumulative Oil Production (Dashed Lines)

Coupled Stress Model Calibration Workflow



Machine Learning Calibration Strategy

Our workflow uses machine learning at the highest level for solving the complex inversion problem

Reservoir Characteristic Data (Class *A* data)

Characterization
- Seismic data
- VSP data
- Well logs
- Core data
- Mechanical data
- Microseismic
- etc.

Fluid properties
- PVT data
- Fluid composition
- etc.

Rock/fluid interaction
- Relative permeability
- Capillary pressure
- etc.

Engineering Design Parameters (Class *B* data)

- Injection/production well specification
- Pattern design
- Well spacing
- Injection timeline
- Injection fluid
- Other project-specific design parameters
- etc.

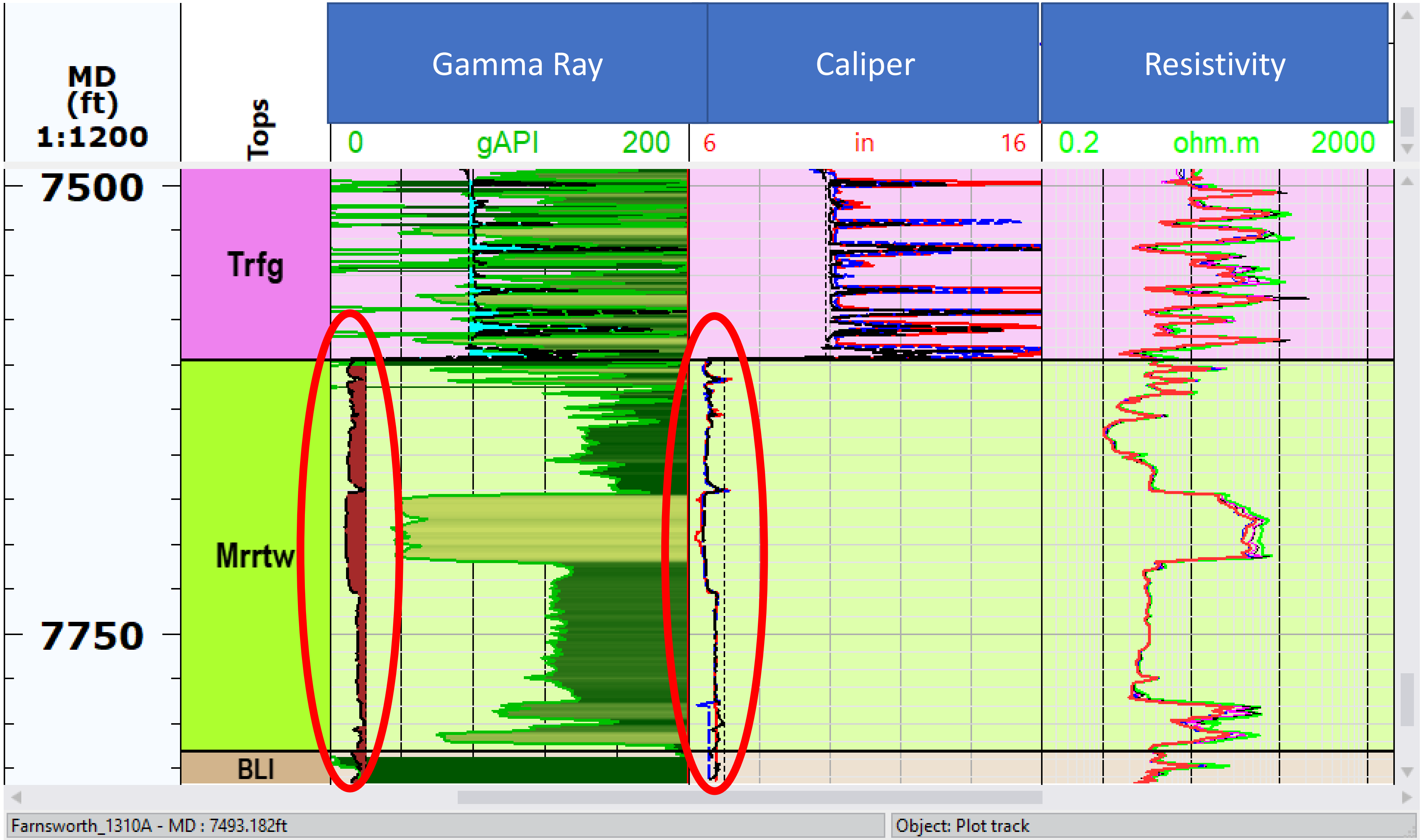
Project Response Data (Class *C* data)

- Oil production data
- Gas production data
- Water production data
- Pressure data
- Stress from VSP
- Moment Magnitude
- etc

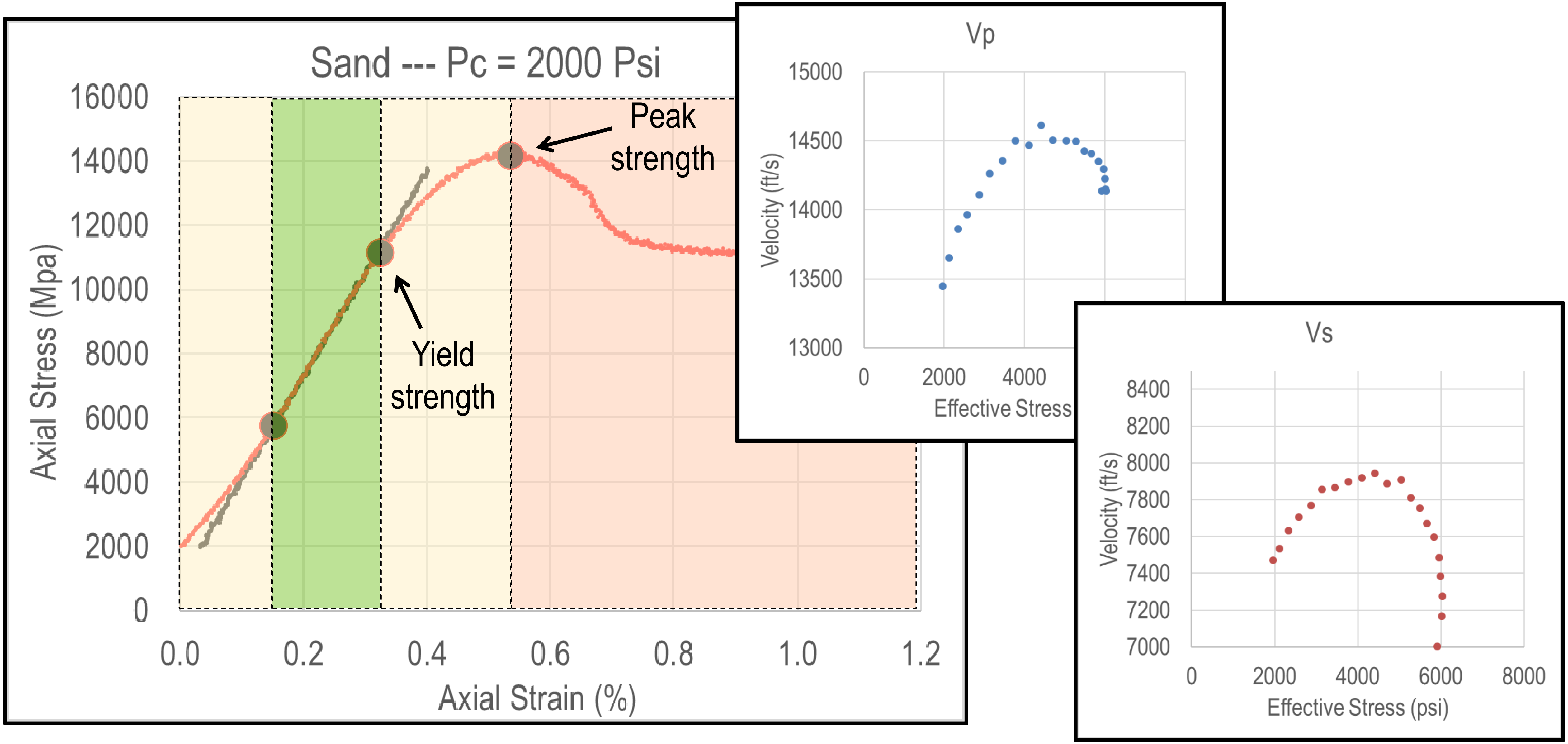
In this project we will train two different version of proxies to assist the history matching:

1. Forward-looking *Proxy*: $A \times B \rightarrow C$
2. Inverse History matching *Proxy*: $C \,/\, B \rightarrow A$

Stress Indicators: Borehole Deformation

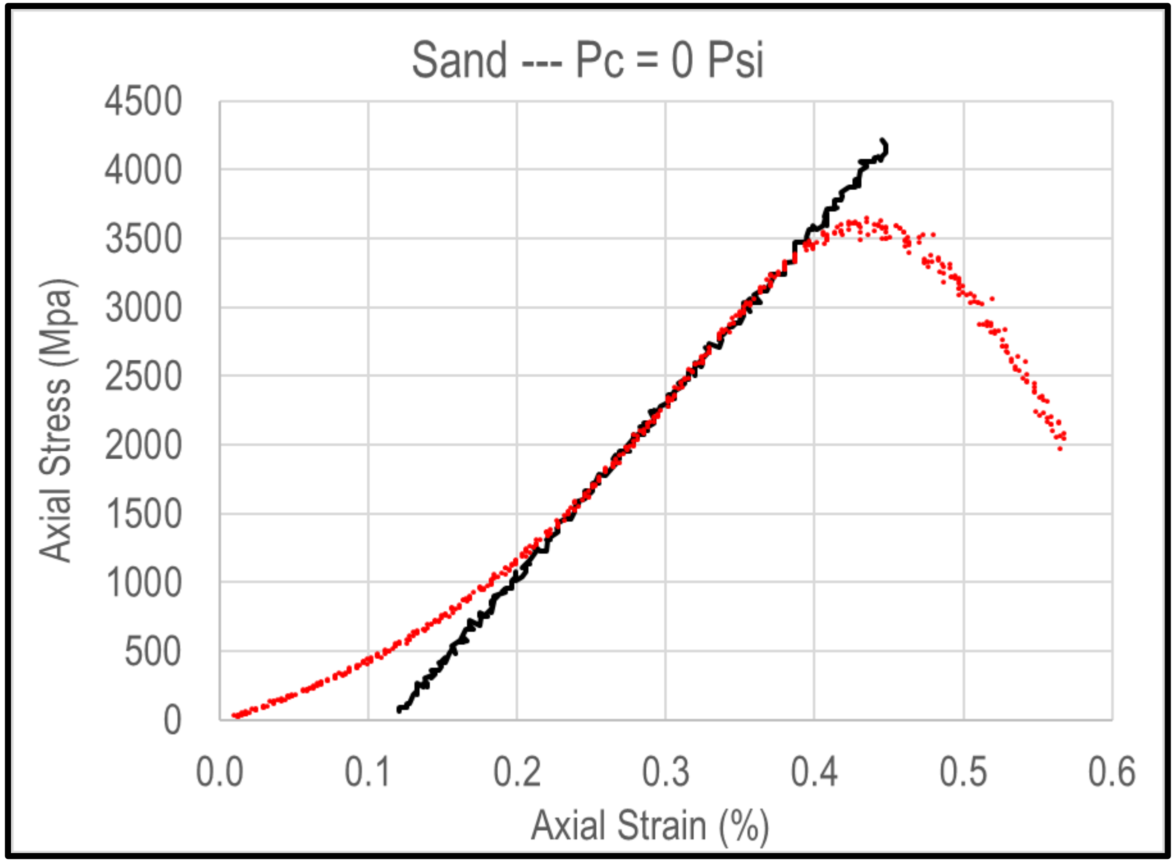


Stress Sensitive Velocity in Core

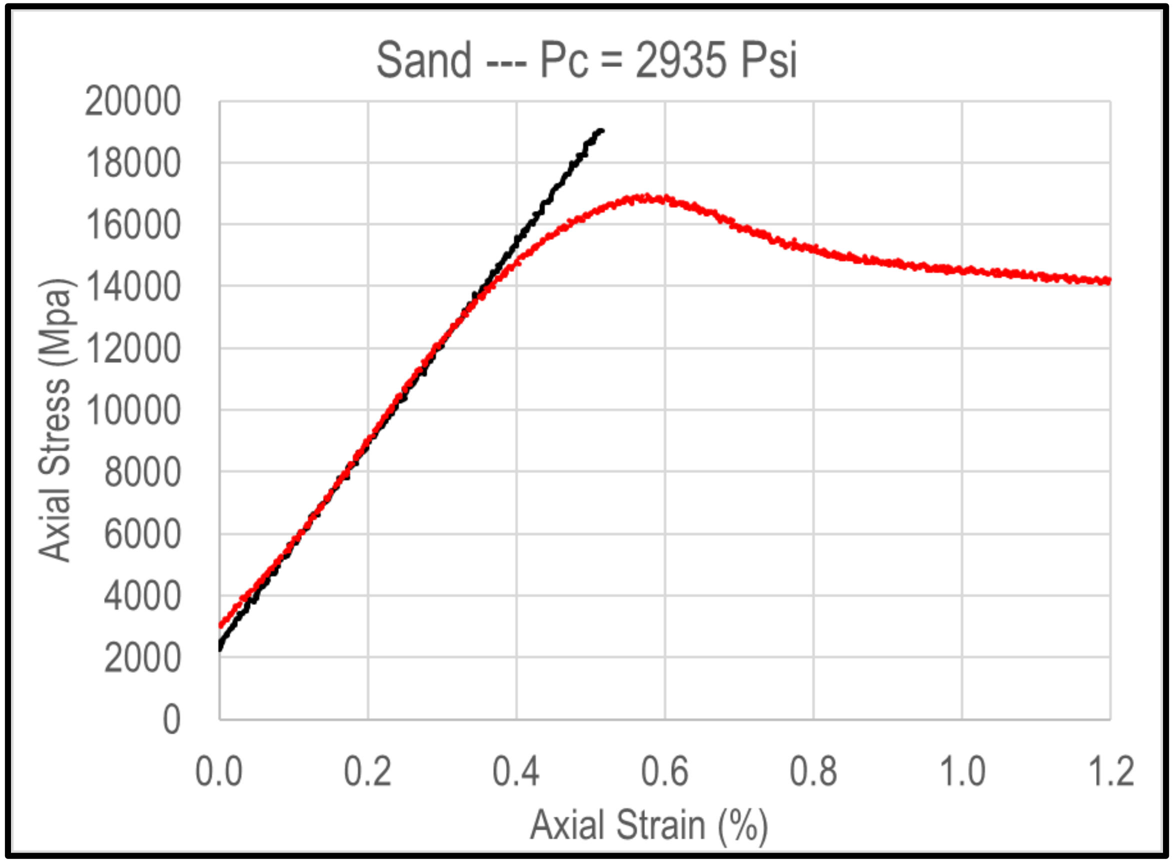


Stress Evidence of Microcracks in Core Analysis

Unconfined



Confined



Summary

Ongoing geomechanical studies at PRRC enjoy the benefits of:

- An excellent field dataset for “life-of-field” reservoir engineering studies
- Highly developed geological and calibrated compositional reservoir simulation models
- A rich core, log, and geophysical dataset for geomechanical characterization

PRRC has leveraged these to receive award of a challenging Stress Modeling project which is funding:

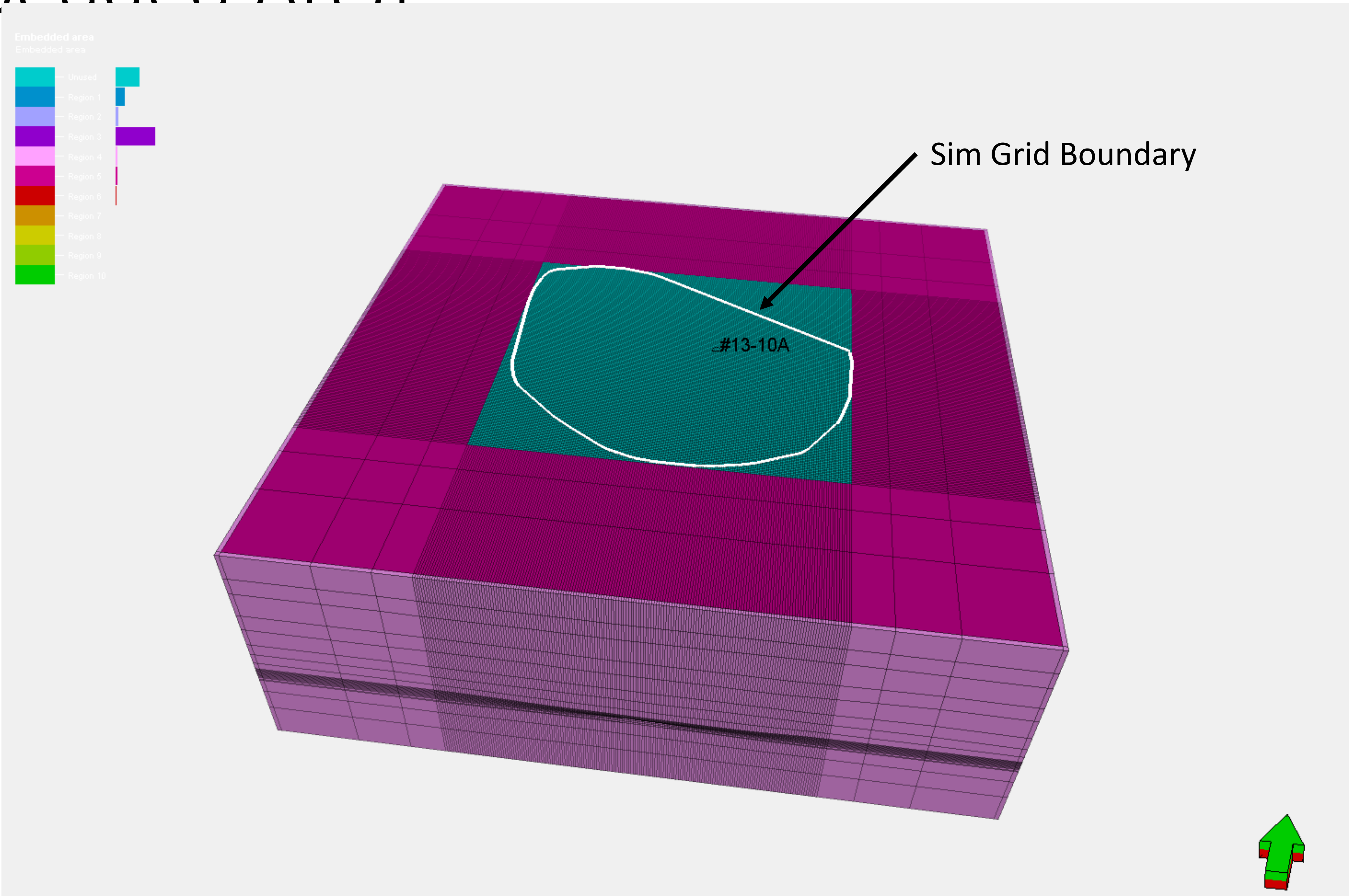
- Studies into characterization of induced microseismicity
- Development of machine learning methods for model optimization
- Advanced geophysical and log analysis for geomechanical characterization
- Collaboration with national laboratories on advanced seismic analyses

Acknowledgement

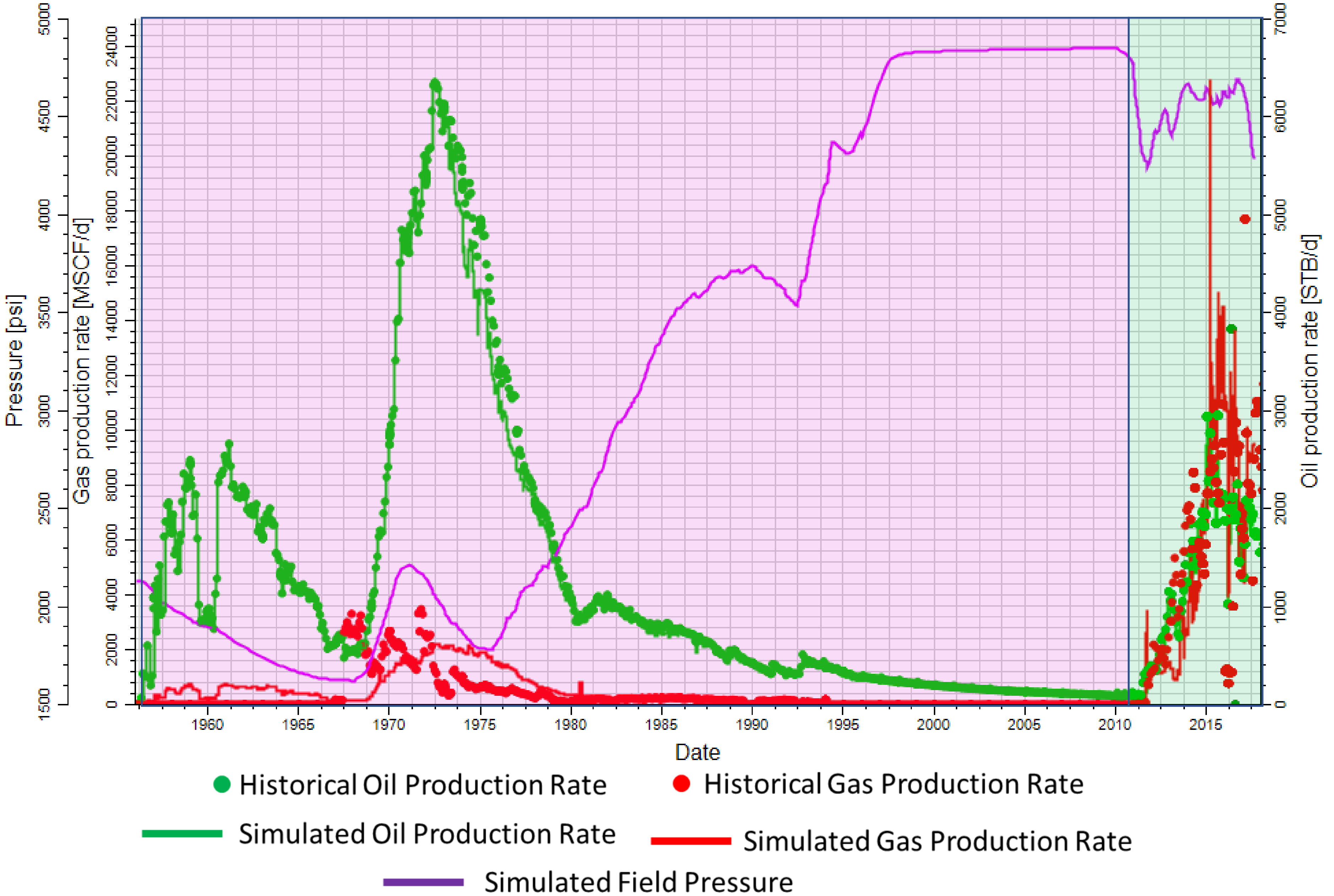
- Funding for this project is provided by the U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL) DOE Award No. DE-FE31684 and through the Southwest Regional Partnership on Carbon Sequestration (SWP) under and under DOE Award No. DE- FC26-05NT42591.
- The presenter thanks Bob Will, Tom Bratton, William Ampomah, Don Lee, and Marcia McMillan for their contributions to the work presented here.
- Additional support has been provided by the site operator and Schlumberger.

Questions

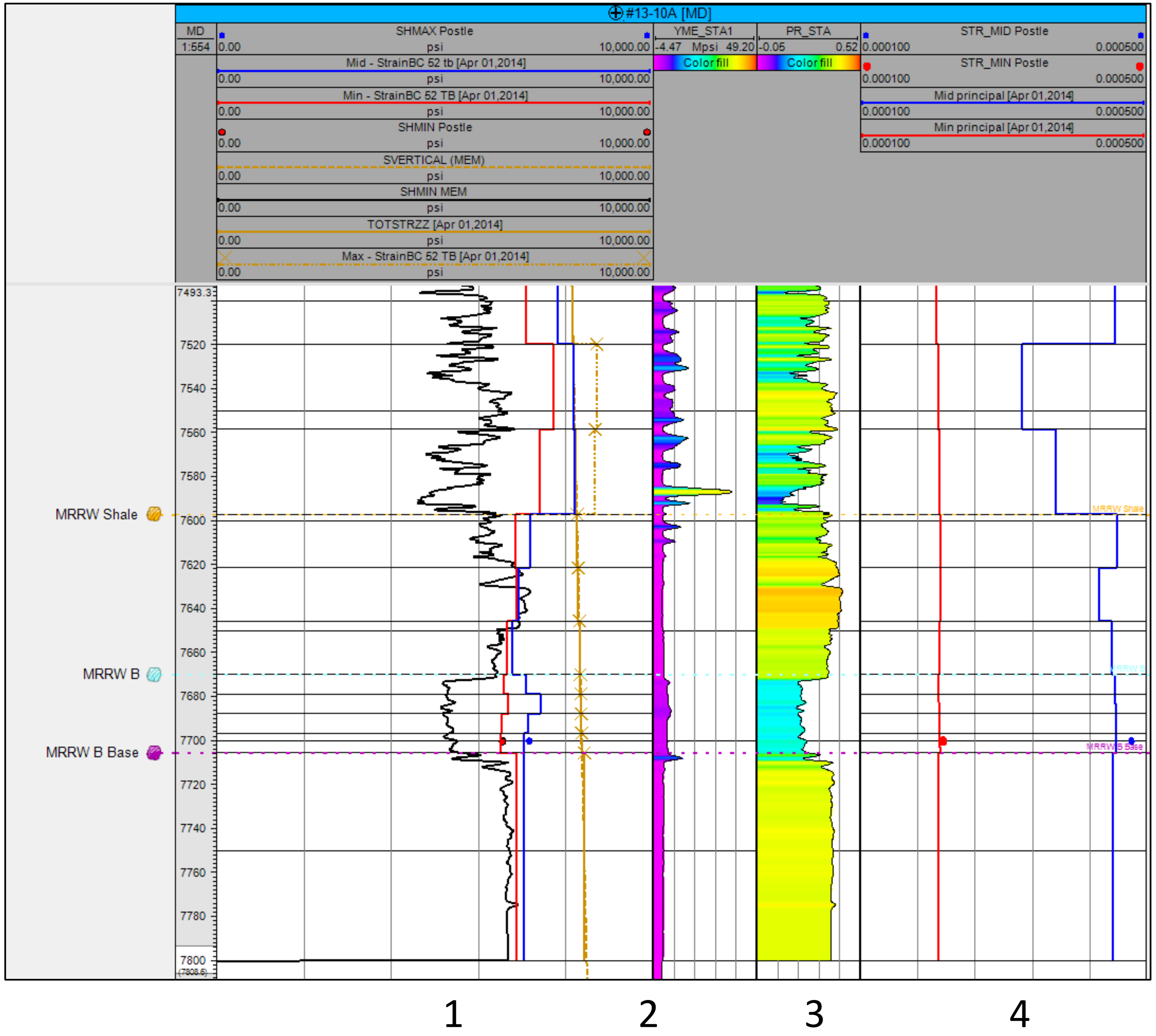
Embedded Area



Farnsworth Primary Depletion, Waterflood, and CO2 WAG History Match: 1956-2018



Strain Boundary Condition - Model Initialization



Track 1

Shmin (MEM)

Model Min Principal Stress

Model Mid Principal Stress

Model Max Principal Stress

Model ZZ

Analytical Shmin (x)

Analytical SHMax (y)

Track 2/3

Young Modulus

Poisson ratio

Track 4

Model Min Principal Strain

Model Mid Principal Strain

Analytical Eps_x

Analytical Eps_y