RECENT ADVANCEMENTS IN MECHANICAL EARTH MODELING AT FARNSWORTH WEST UNIT

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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.
  - CO₂ first injected in 2010.

- Anthropogenic Supply: 500-600,000 Metric tons CO₂/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

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<tr>
<th>System</th>
<th>Series</th>
<th>Group</th>
<th>Informal Names</th>
<th>Wireline Log Characteristics</th>
<th>Farnsworth Unit</th>
<th>Gamma</th>
<th>Resistivity</th>
<th>Lithology</th>
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Well 13-10A 1D MEM

Mineral Volume & Porosity
USC
Tensile Strength
Friction Angle
Reservoir Simulation Model Poro-Perm and Faults

Porosity (0-26%)

Permeability (0-200 mD)
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

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

![Mohr Circle Analysis Diagram](image-url)
Impact of Permeability Updating: Primary-Waterflood Period
Farnsworth CO$_2$-WAG Mohr Circle Analysis

Mohr Circles Analysis

- Failure line
- 12/1/2010
- 9/1/2011
- 9/4/2015
- 7/1/2013

Shear Stress (psi) vs. Principal Stress (psi)
Impact of Permeability Updating: WAG Period

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

CO2 WAG 2 Year Update : CO2 WAG 1 Year Update : CO2 WAG 3-6 Month Update : No Update
Our workflow uses machine learning at the highest level for solving the complex inversion problem.

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:  \[ C \div B \rightarrow A \]
Stress Evidence of Microcracks in Core Analysis

Unconfined

Confined

Sand --- Pc = 0 Psi

Sand --- Pc = 2935 Psi
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

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• 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

Sim Grid Boundary

#13-10A
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