Improving Production in the Emerging Paradox Oil Play

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National Energy Technology Laboratory
Resource Sustainability Annual Project Review Meeting
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Acknowledgements

Presentation Outline

- Improving Production in the Emerging Paradox Oil Play
  - Project Overview
  - Technology Background
  - Technical Approach and Scope
  - Progress and Current Status of Project
    - Core/Fracture Analyses
    - Petrophysics & Machine Learning
    - Model Development and Simulation
    - Stimulation Approach
    - Other Activities and Issues
  - Plans for Future Testing/Development/Commercialization
  - Summary

Project Overview

– Funding (DOE and Cost Share)

- $8M Federal, $3M+ Cost-Share, $11M+ Total

– Overall Project Performance Dates

- January, 2020 – September, 2024 (NCTE into 2025)

U.S. DEPARTMENT OF ENERGY

Project Participants:

THE UNIVERSITY OF UTAH

UTAH DNR UTAH GEOLOGICAL SURVEY

ZEPHYR ENERGY

ROCKIES STANDARD OIL COMPANY

KIRKWOOD Oil & Gas LLC

NATIONAL ENERGY TECHNOLOGY LABORATORY

Rose Petroleum plc

BYU

Schlumberger

Statistical Petrophysics LLC

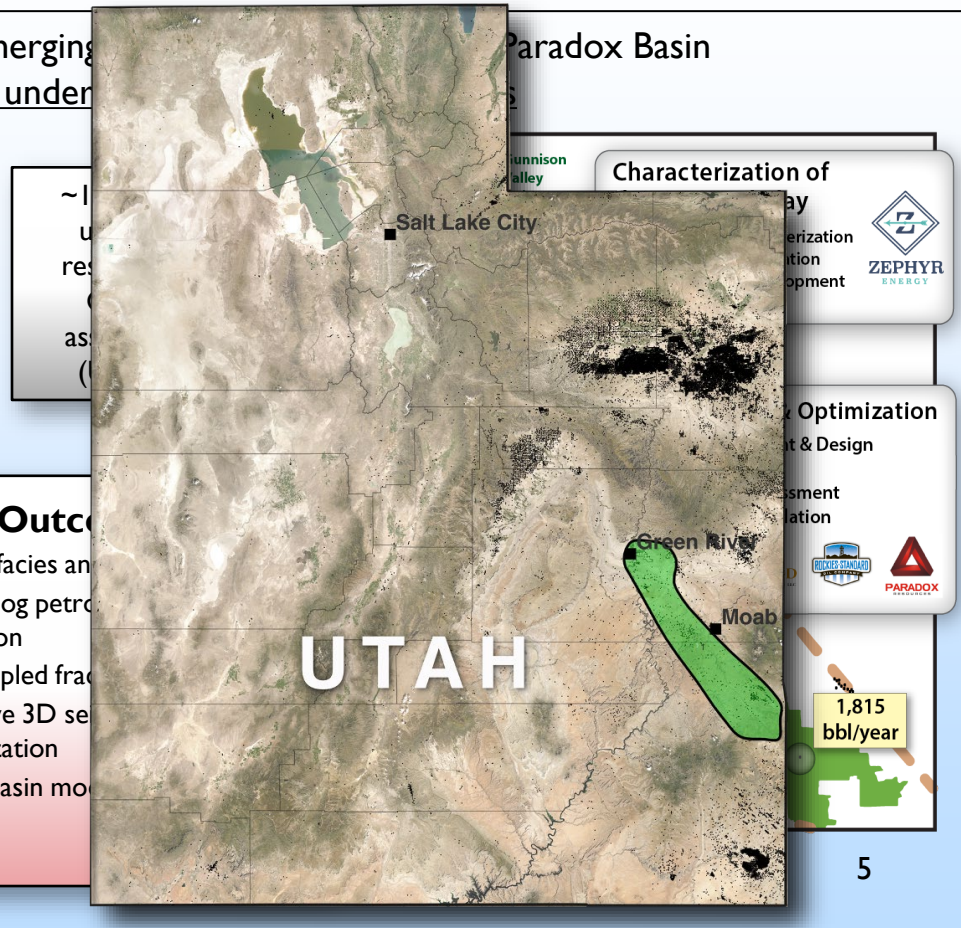
Project Overview: Overall Project Objectives

- **Objective**: determine / test best strategy to drill emerging … Paradox Basin Play - maximize production, minimize impact by better under…

- **Key Tasks**: characterize, quantify, and interpret natural fractures in the Paradox Play

Experimental Design and Work Plan:

- Fundamental THMC characterization
- Forecast location, extent and mechanisms of natural fractures
- Develop drilling strategy to maximize intersection with natural fractures
- develop a tactical stimulation strategy
- Test the best approach



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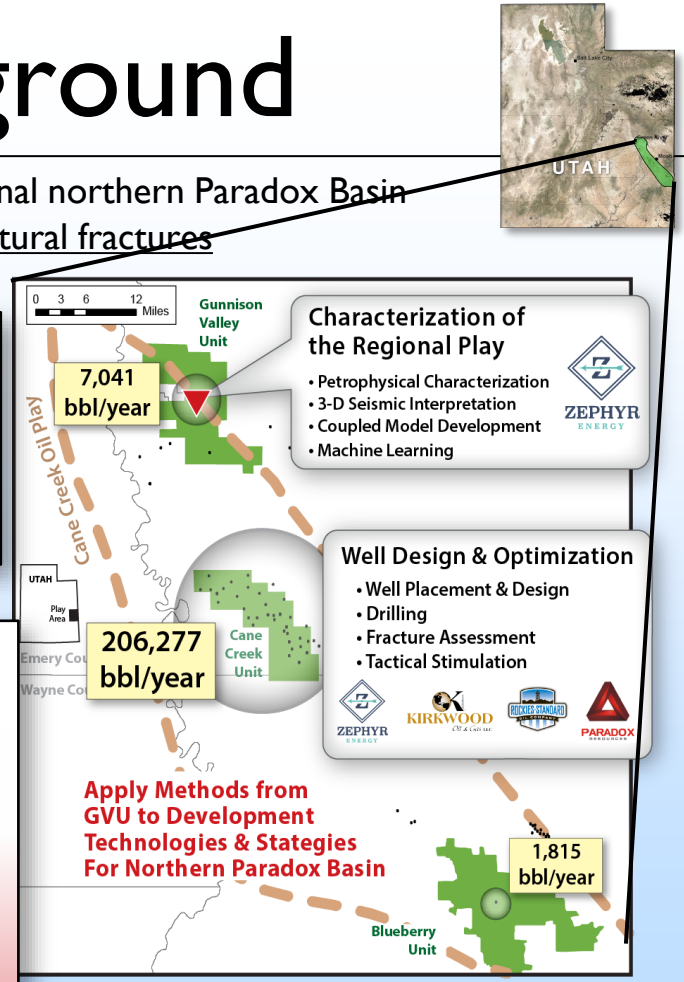
Technology Background

- **Objective**: determine / test best strategy to drill emerging unconventional northern Paradox Basin Play - maximize production, minimize impact by better understanding of natural fractures

- **Key Tasks**: characterize, quantify, and interpret natural fractures in the Paradox Play

~1.2 billion BOE undiscovered resources in the Cane Creek assessment unit (USGS, 2012)



Experimental Design and Work Plan:

- Fundamental THMC characterization
- Forecast location, extent and mechanisms of natural fractures
- Develop drilling strategy to maximize intersection with natural fractures
- develop a tactical stimulation strategy
- Test the best approach

Major Outcomes:

- detailed facies analysis of core
- core-to-log petrophysical integration
- Fully coupled fracture model
- innovative 3D seismic interpretation
- THMC basin model for forecasting

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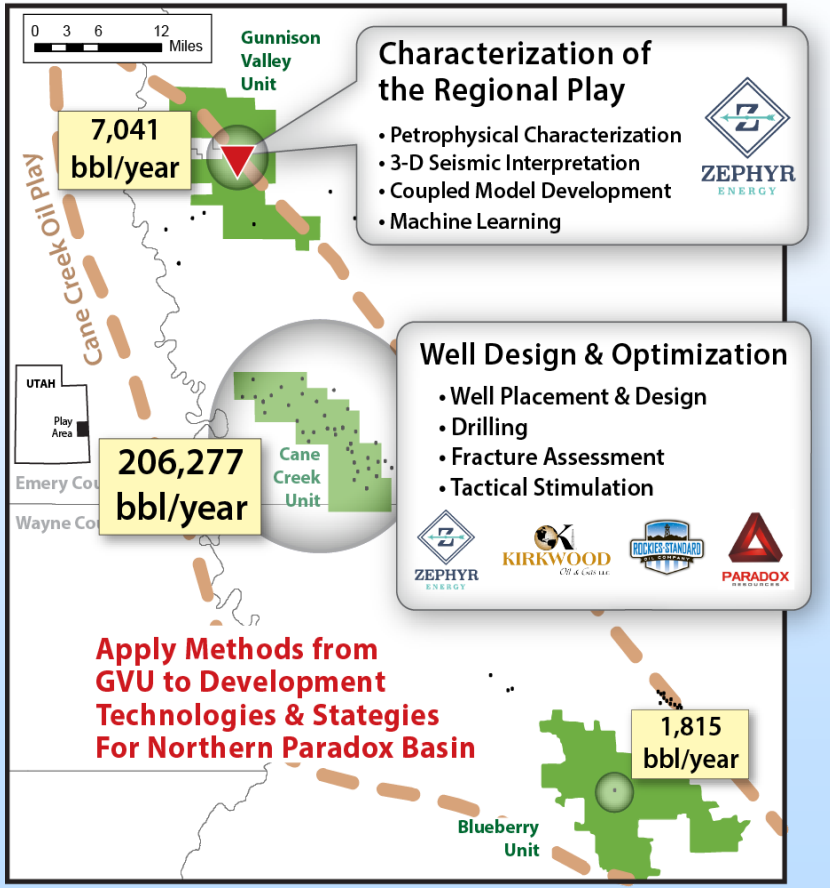
Technical Approach and Scope

Experimental Design and Work Plan

1. Characterize fundamental geology, hydrology, and geomechanics
2. Forecast location, extent and mechanisms of natural fractures throughout the play (all years);
3. Develop drilling strategy to maximize intersection with (dominant) natural fractures (this year)
4. Use high-resolution characterization data to develop and employ a tactical stimulation strategy (now)
5. Test the best approach
   (with the operator, determine whether (3) new drilling design or (4) the new tactical stimulation design will be more effective, and test in the field in new well(s) with strategic drilling and tactical stimulation (years 3 and 4).



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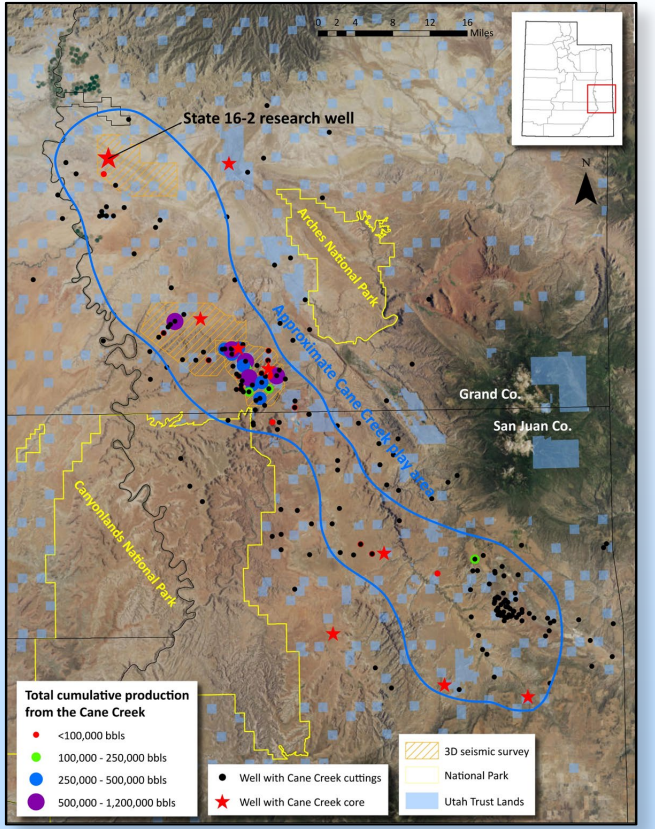
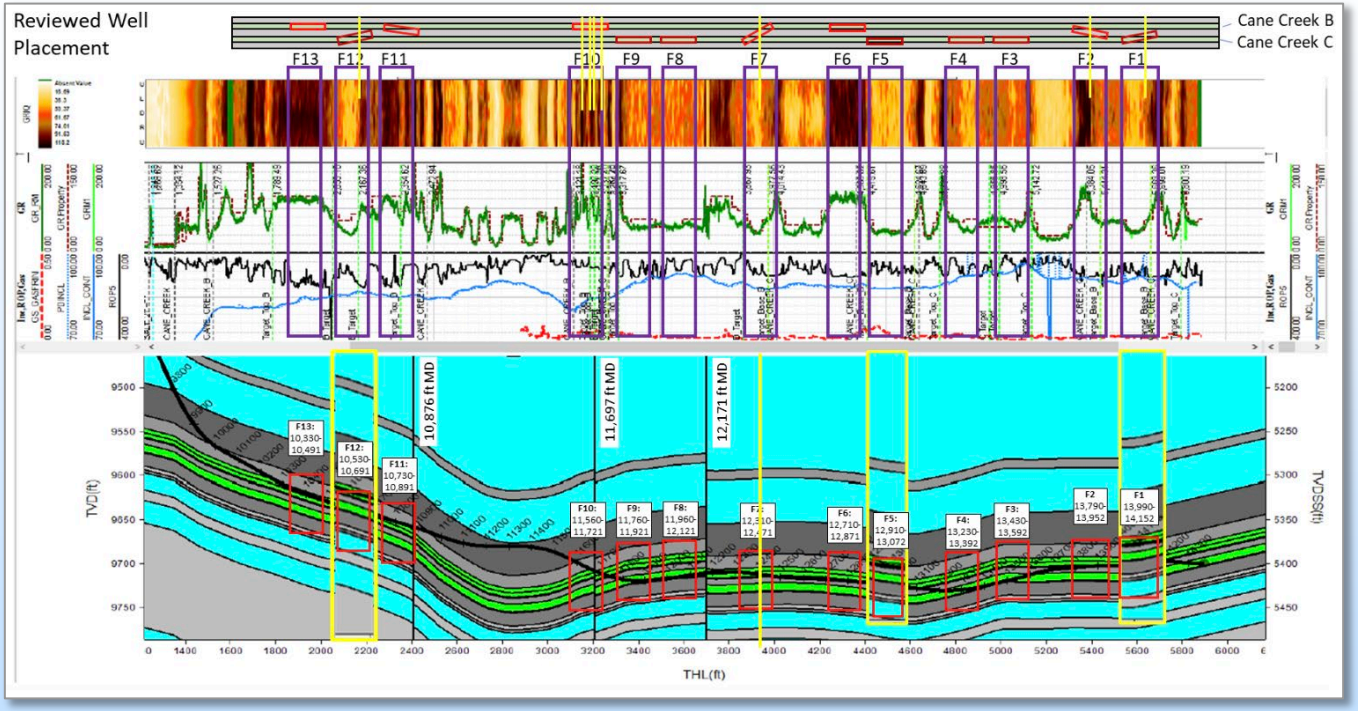
The Field Laboratory

- **Zephyr State 16-2 and State 16-2-LN-CC, White Sands Unit, Utah**
  - **Vertical Strat Well: December 2020 to January 2021**
  - **Horizontal Well: July 2021**



State 16-2L: Lateral Well Placement

Geologic evaluation of the State 16-2L wellbore's lateral cross-section using Formation Micro-Imager (FMI), gamma logs, cuttings, and fault analysis, in relation to 13 hydraulic fracture stages.



The mudstone Cane Creek sample contains a 7 mm thick natural fracture filled with migrated salt.

State 16-2 Micro-facies Characterization

Laboratory testing was performed to understand the role of rock type on porosity and permeability, as well as the influence of sample size on geomechanical properties within the Cane Creek.

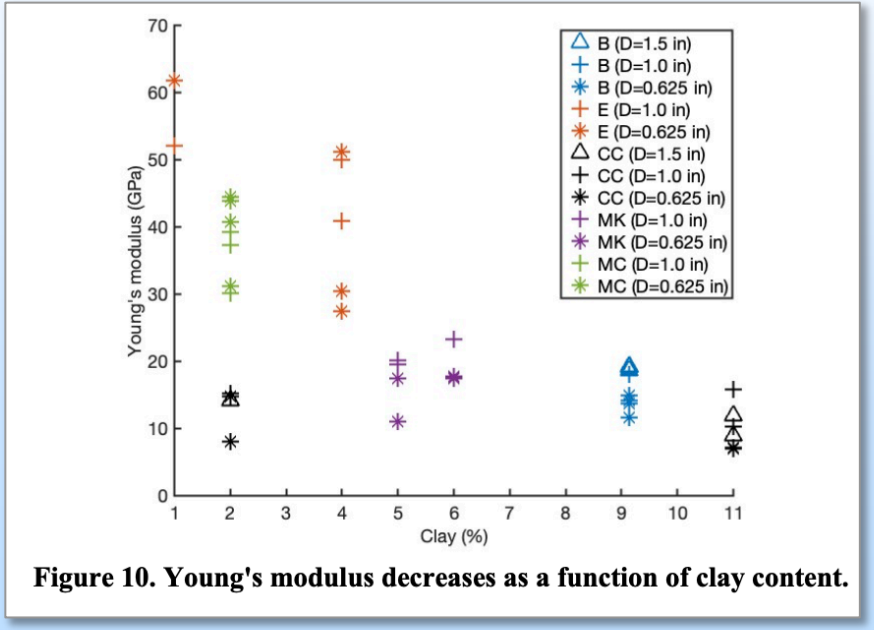
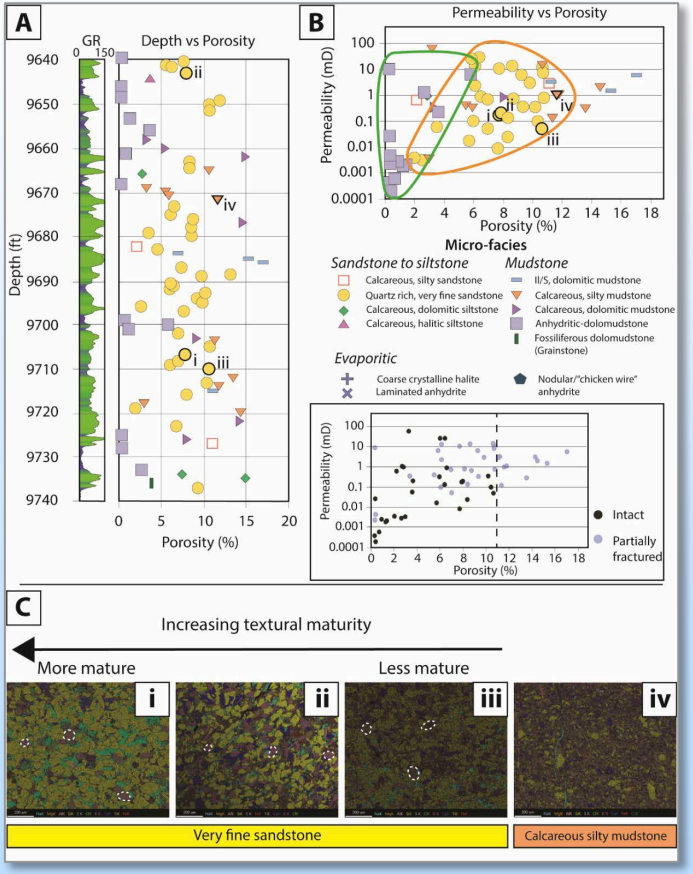


Figure 10. Young's modulus decreases as a function of clay content.



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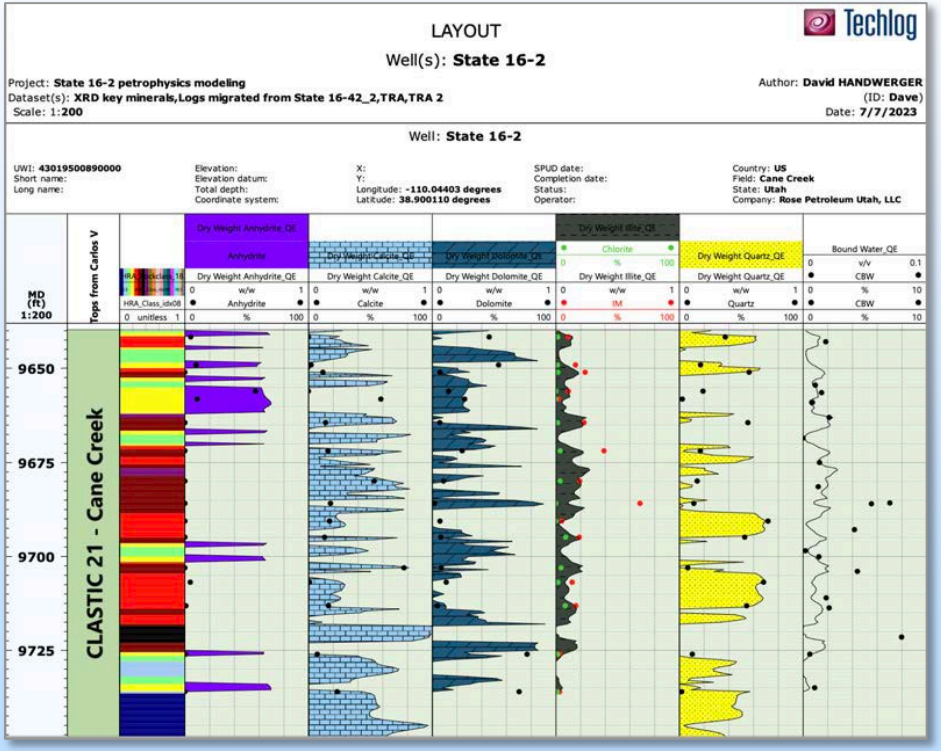
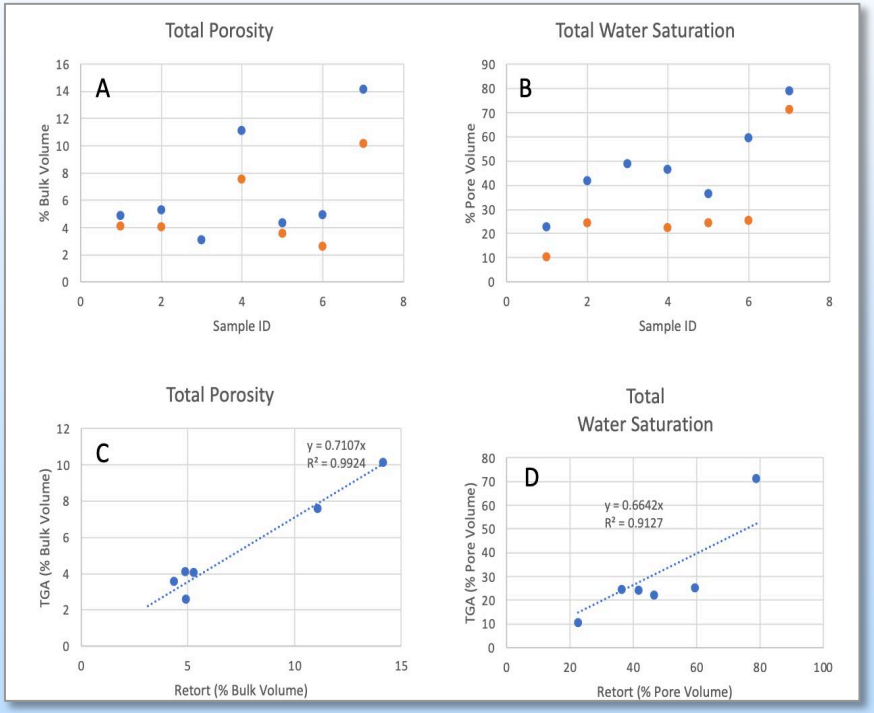
Petrophysics: Porosity and Water Saturation Assessment

Preliminary petrophysical work was conducted for just the State 16-2L to define the Cane Creek subfacies. Discrepancies in the water saturation lab measurements were identified and addressed with new measurements.





Petrophysics + Machine Learning

Machine Learning (ML) model…

…for propagating sonics

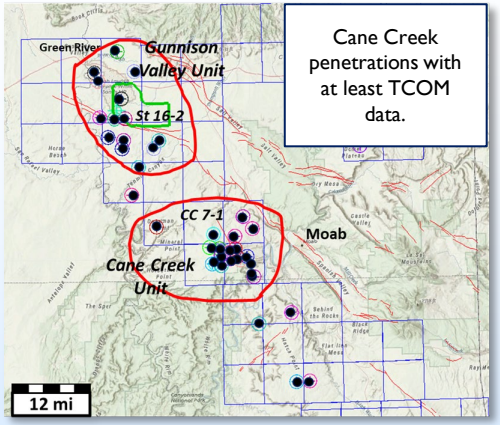
- Trained in State 16-2 clastics, validated in shifted State 16-42 Cane Creek section
- Input: Triple combo + Platform Express data. Output: P-, S-wave sonic travel times

…for propagating elemental abundances

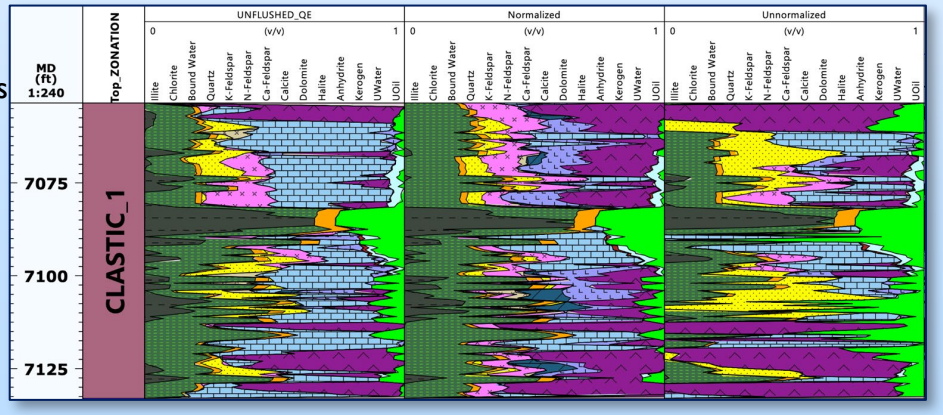
- Trained across State 16-2 and Cane Creek 7-1 high-tier data
- Validated in randomized held-out sections of State 16-2, Cane Creek 7-1
- Provide element-by-element performance of ML model

Assessment of ML-informed petrophysical model

- Created pseudo-Lithoscanner logs from Triple combo logs in State 16-2 well to validate against recorded logs.
- Ran identical petrophysical model on recorded logs (Triple combo+Lithoscanner) and pseudo-logs (recorded Triple combo+pseudo-Listhoscanner) for comparison.
- Quantifying uncertainty of petrophysical model given uncertainty of inputs

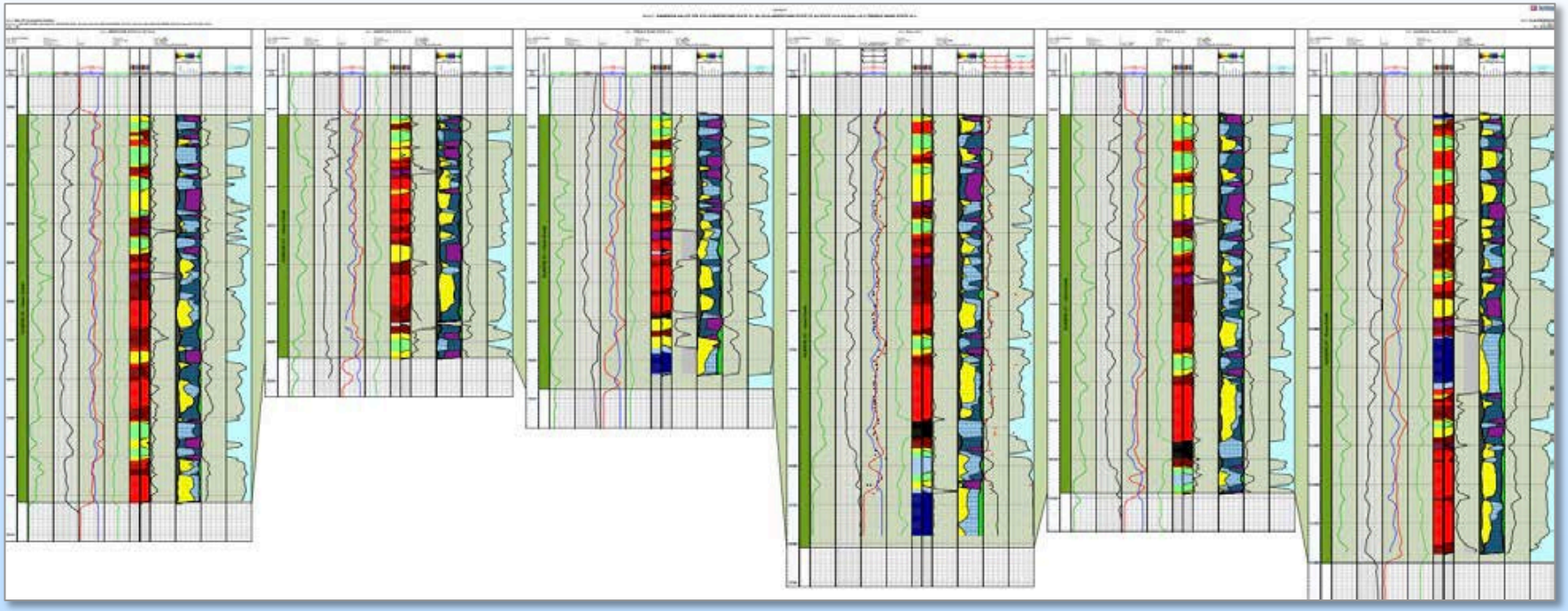


Recorded logs | ML model (normalized inputs) | ML model (unnormalized inputs)



Northern Paradox: Petrophysical Analysis

The wells used to construct the petrophysical model arranged from shallowest to deepest occurrence of the Cane Creek Unit.



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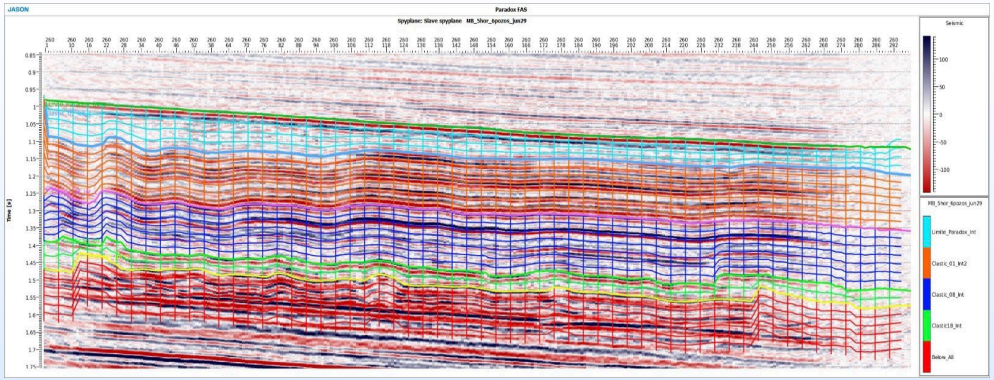
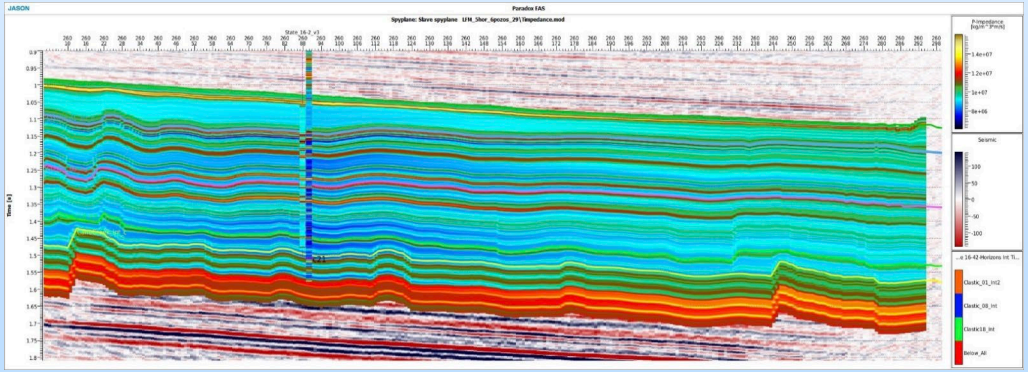
Geophysics: Initial 3D Geologic Model Construction

Due to the structural complexity of the Cane Creek formation, a localized geological model was initially constructed in the area surrounding the State 16-2L well. Geophysical measurements and attributes were tied to the well to validate the location and improve the accuracy of the attributes.



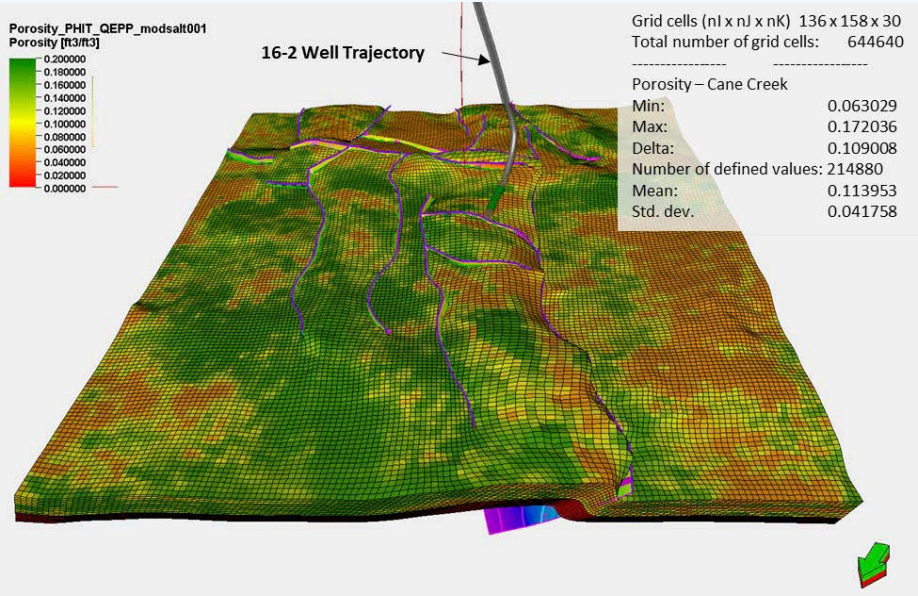
Initial processing

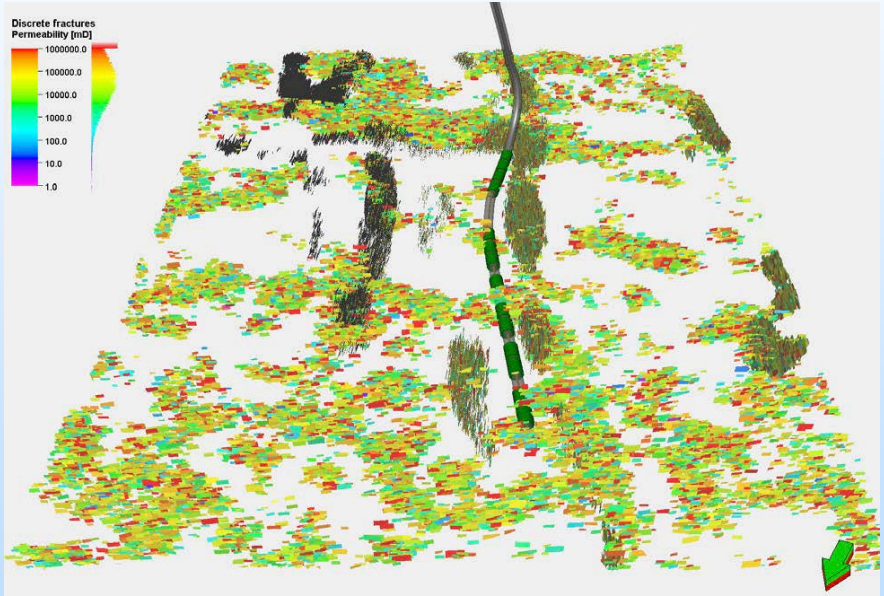


State 16-2L well tie

Localize 3D Seismic Processing

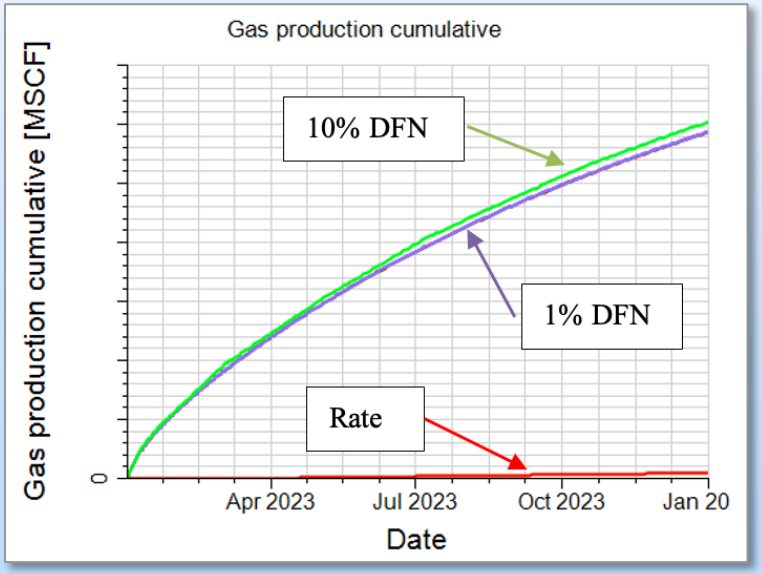
State 16-2L features localized high-resolution geophysical processing and mesh for well simulation work, displaying porosity (left) and DFN (right).

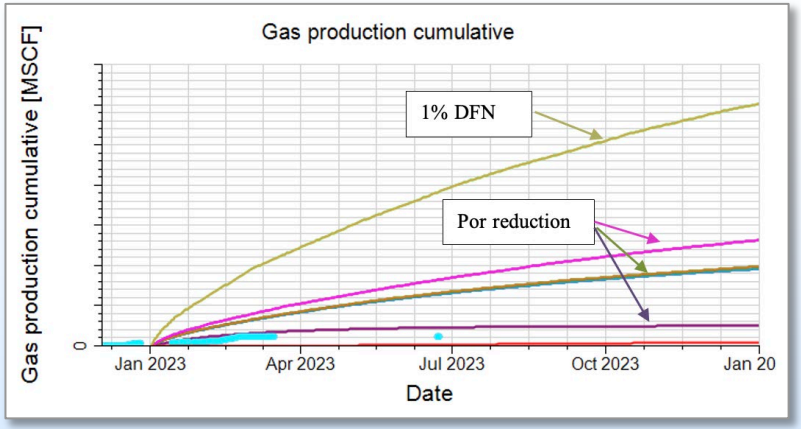


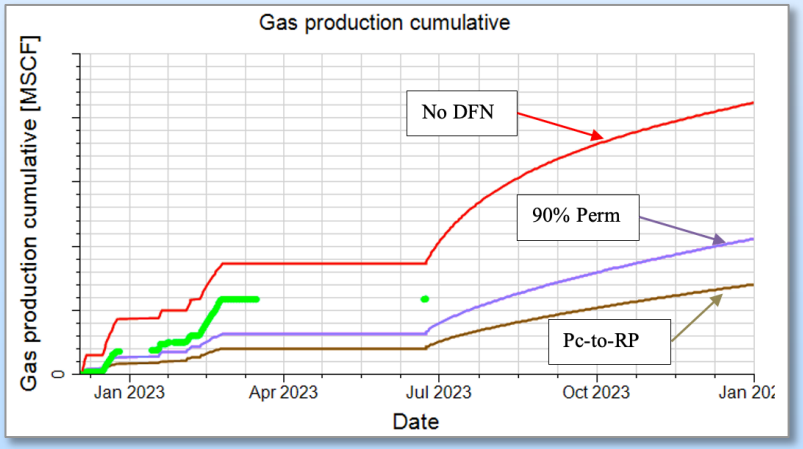


Simulation: Production Matching

Production history matching is being performed for the State 16-2L well using Eclipse and Petrel.



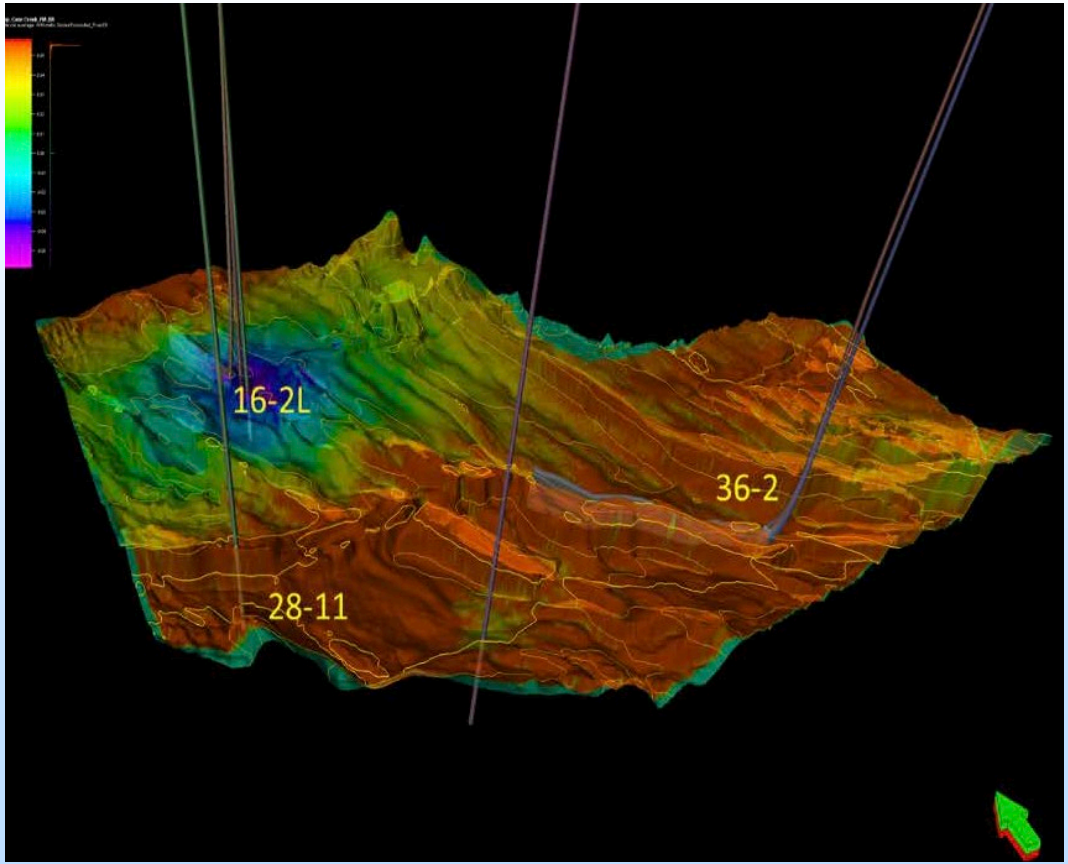




Full 3D Seismic Body Processing

The entire seismic area has been processed for use in completing the field development plan for the Northern Paradox Basin's seismic area.

The image on the right displays the porosity attribute using data (logs, core, cuttings) from wells drilled into the Cane Creek.



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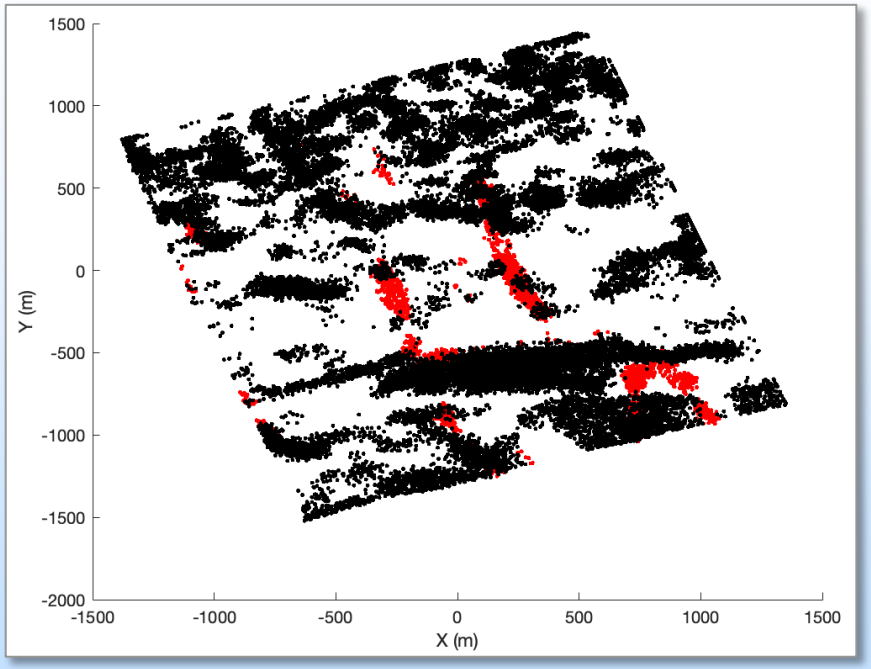
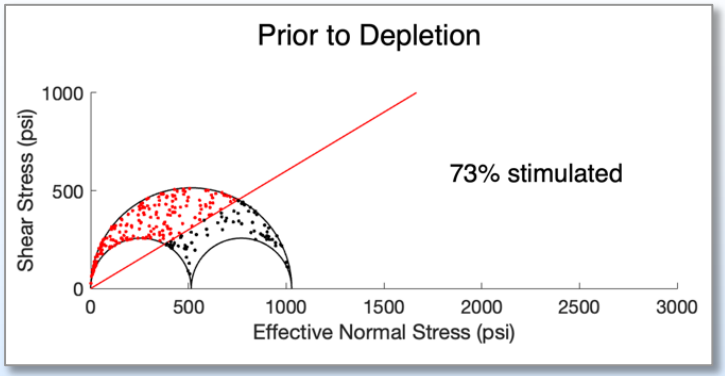
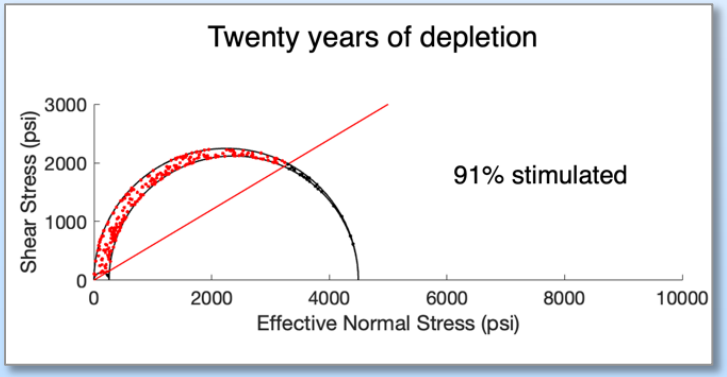
Poroelastic Impact of Depletion



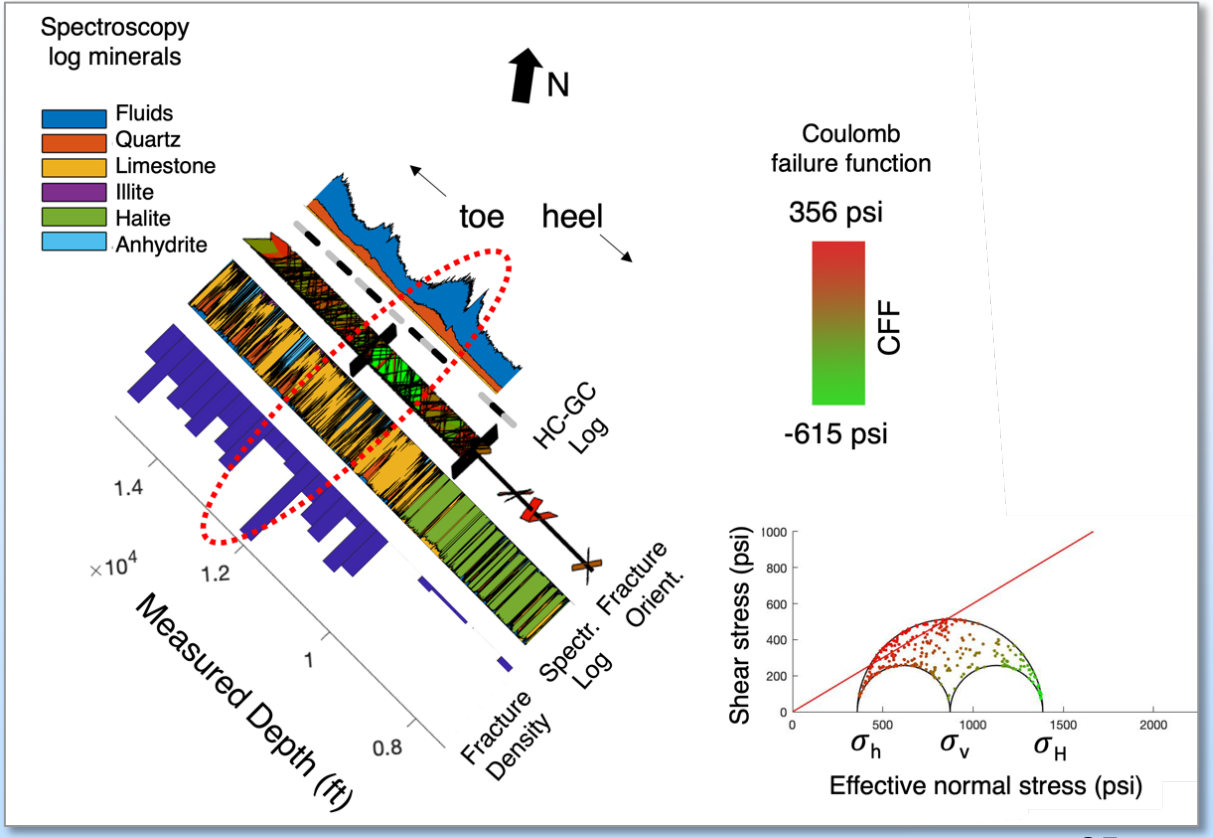




Fracture trends are determined based on the geomechanical stability of the Discrete Fracture Network (DFN).

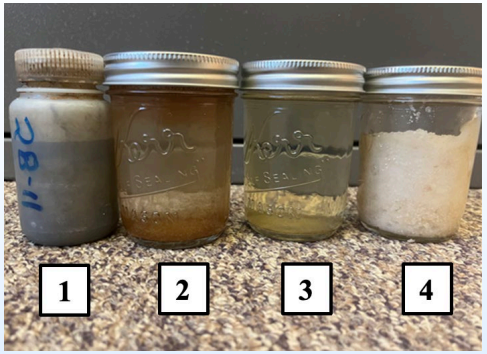
Correlation Plot of Fractures in the State 16-2L

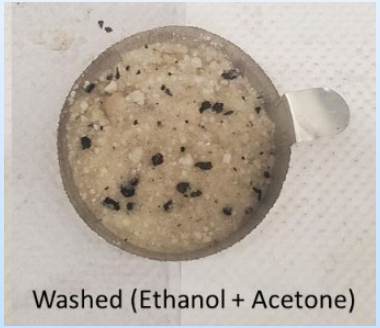
- Fracture density varies throughout the lateral section.
- The orientation of fractures varies depending on the composition and location.
- The highest hydrocarbon production comes from a limestone-rich region with fewer natural fractures than other regions.



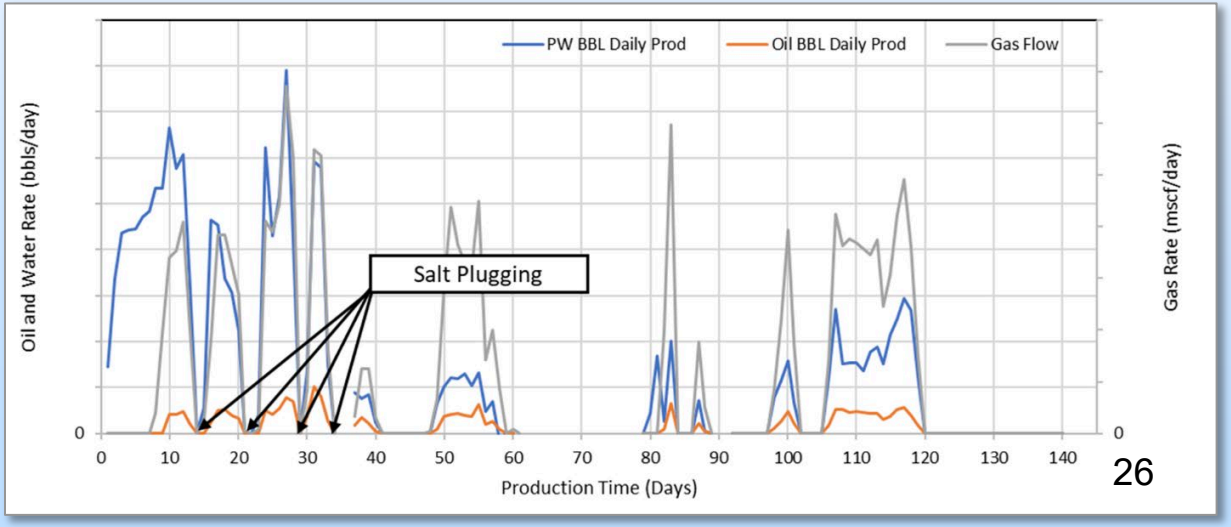
Salt (Halite) Plugging and Management

1: Solid sample from the separator at Federal 28-11
2: Water sample from the water tank at Federal 28-11
3: Water sample from oil tank on Federal 28-11
4: Solid sample from sand catcher at State 16-2





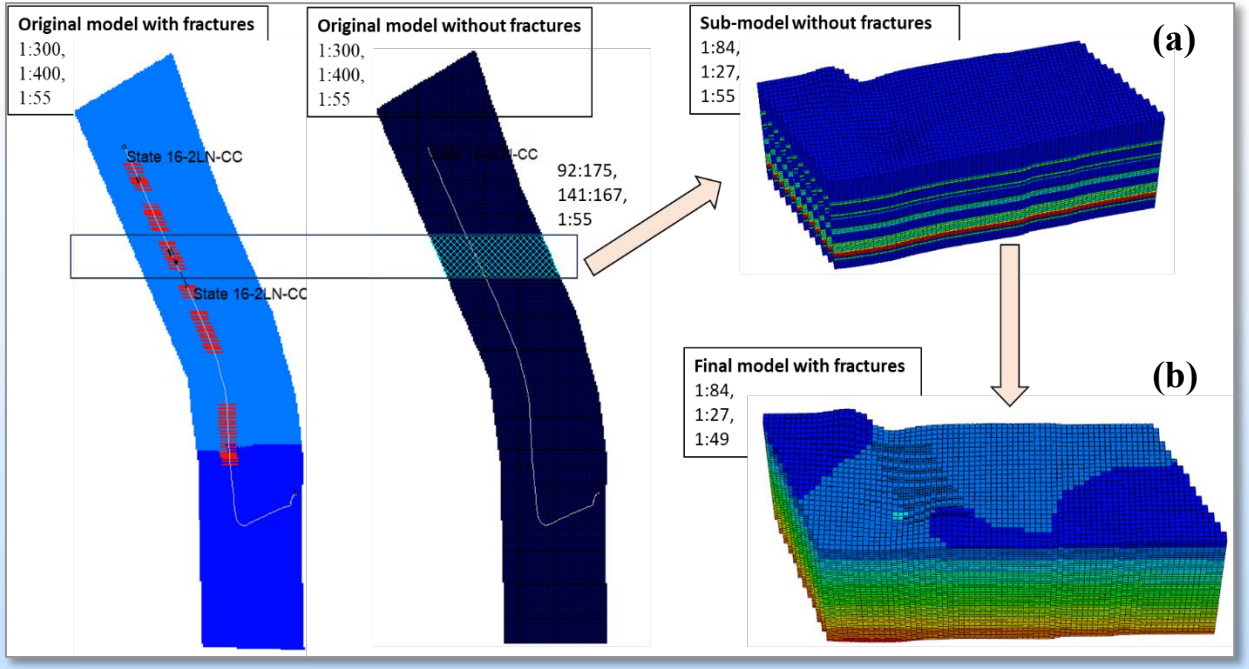
Scaling Sample Characterization using plasma mass spectrometry (ICP-MS), ion chromatography (IC), and colorimetric



Near-Wellbore PVT Modeling

Paradox basin Cane Creek reservoir with 16-2LN-CC well (a) a full model with 6.6 million grid (400, 300, 55) (b) A sub-model with 124,740 grids (84,27,55).

Hydraulic fracture stages coupled with production of in-situ hydrocarbon compositions.



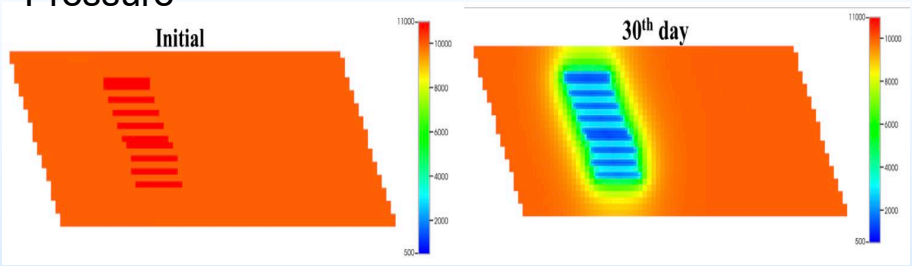
Simulation CMG-GEM Attributes:

- Convective and Dispersive Flow in Porous Media
- Phase Equilibrium Between Hydrocarbon and Aqueous Brine Phase
- Chemical Equilibrium for Mineral Reactions Between Solid Phase and Aqueous Components
- Mineral Dissolution and Precipitation Kinetics

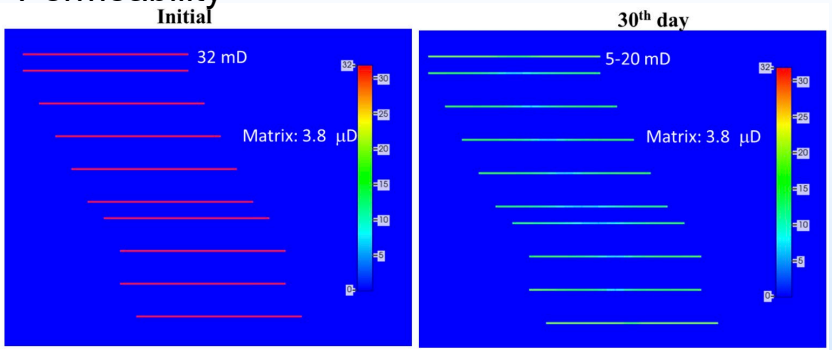
Near-Wellbore Simulation Results

State 16-2L CMG-GEM simulation results for 30 days of production.

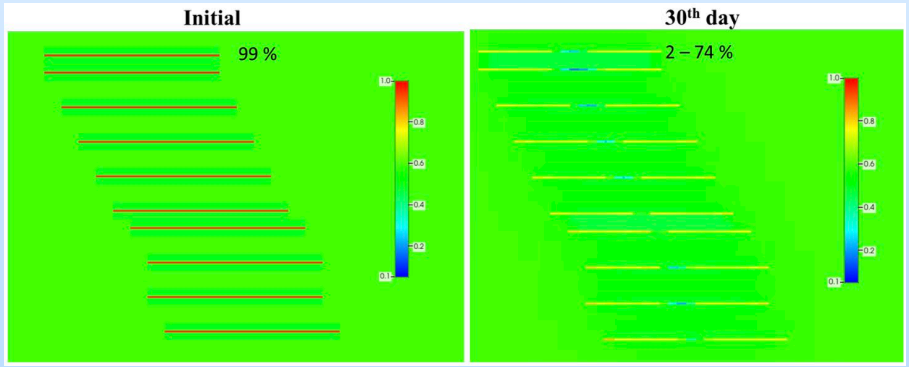
Pressure



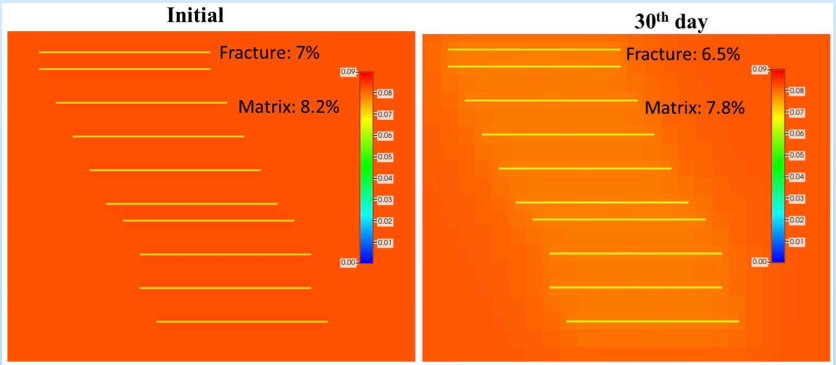
Permeability



Percent Produced Water



Porosity



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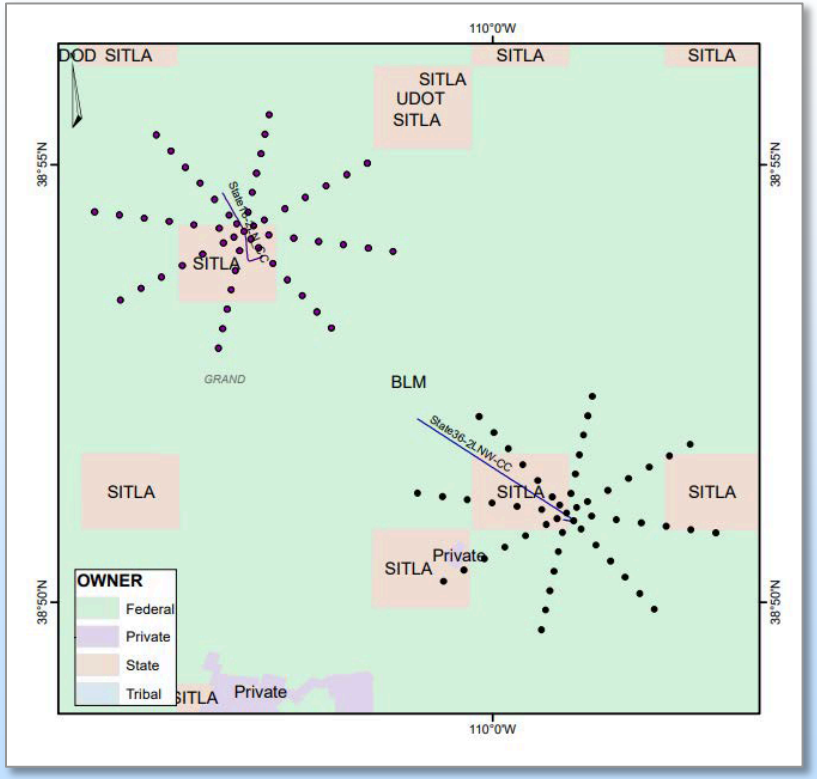
State 16-2: Passive Seismic Evaluation

A passive geophone array was recently placed on the surface above the State 16-2L well to conduct preliminary event assessment prior to implementing the scaling mitigation plan.



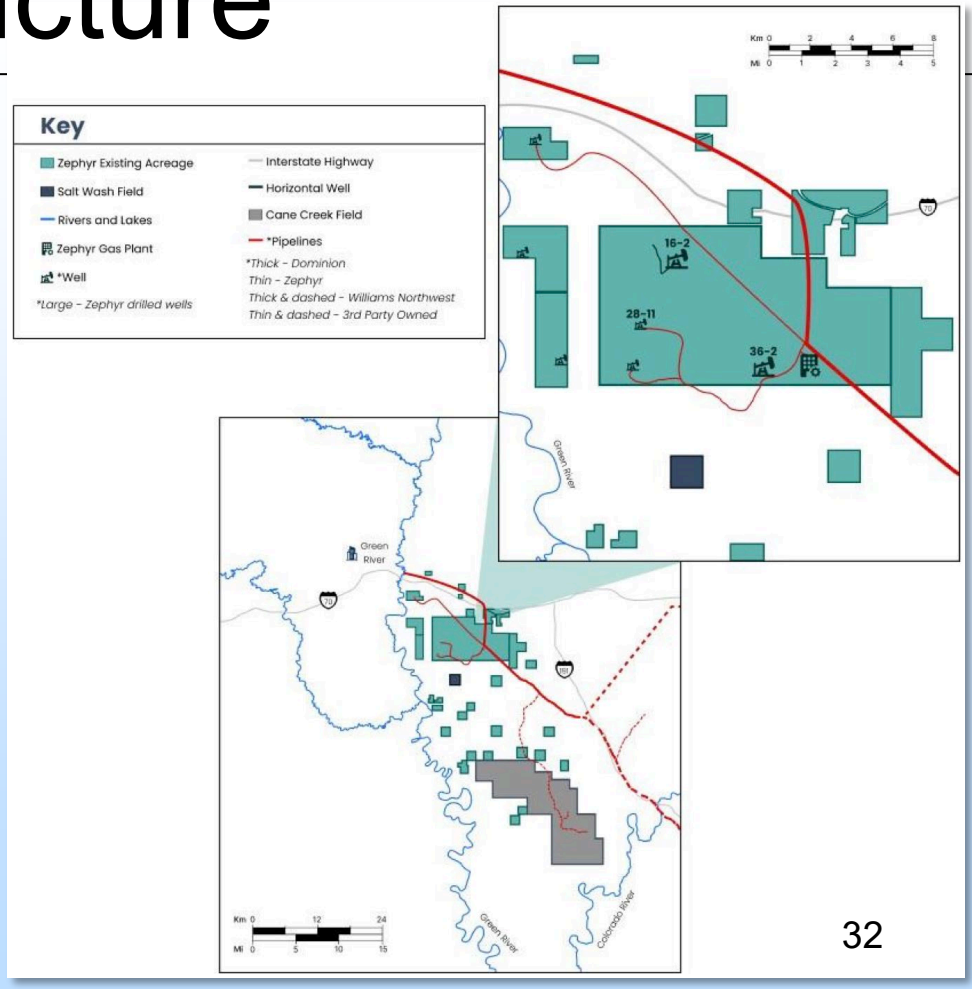
36-2 LNW-CC Well Damage

Twisted 2 7/8” tubing recently removed from the hole

Replacement tubing to be inserted

Zephyr Infrastructure

- More than 46,000 acres supported by advanced 3D seismic technology.
- The Dominion natural gas infrastructure became operational in October 2023.
- Successful drilling of two wells, each discovering substantial hydrocarbon deposits in the primary Cane Creek reservoir.
- Evidence of hydrocarbons in several additional reservoir layers.
- Opportunities for extraction through hydraulic fracturing or exploiting natural fractures.
- Involvement in the emerging regional market for helium.



Paradox Challenges and Potential Solutions

Challenge	Resolution
Overlooked basin with minimal recent drilling	Seismic and early drilling data enabled acquiring significant acreage cost-effectively before other competitors.
16-2 well teething issues on second production test (salt issues)	Third-party studies identified a straightforward mitigation solution.
36-2 well drilling challenges	Adopt learnings and revert to drilling methods used for the 16-2 well.
36-2 well blowout	Strong evidence of significant hydrocarbons for targeting in a redrill. Enhancements in team, well design, and procedures planned to effectively "twin" the well.
Delays from extended 36-2 well work	Exploring solutions to expedite the production of wells 16-2 and 28-11.

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Plans for Future Testing/Development/Commercialization

State 16-2 Horizontal Well Scaling Mitigation Plan Implementation

- Strategic Implementation: State 16-2 will implement a scaling mitigation plan for horizontal wells, conceptualized from the laboratory testing and simulations.
- Advanced Stimulation Monitoring: Utilization of Distributed Acoustic Sensors (DAS) or Distributed Temperature Sensing (DTS) in the horizontal well will facilitate the evaluation of the scaling reduction plan's effectiveness and the production contributions from individual hydraulic fracturing stages.

Data Integration and Production Insights

- Data Synthesis: State 36-2R production data will be integrated with data from State 16-2 and additional wells to enhance the understanding of various production scenarios within the basin.
- Stacked Pay Potential: Exploration of multiple stacked pay zones has revealed the presence of hydrocarbons, indicating promising drilling opportunities that extend beyond the primary Cane Creek reservoir.

Expansion and Collaboration Opportunities

- Paradox Basin Expansion: Potential for broadening activities within the Paradox Basin, including collaborations with other operators and partners.
- Intensified Horizontal Drilling: Envisioning a cluster of horizontal wells in a confined area targeting the natural fracture network, with extensive opportunities beyond the 3D seismic coverage.

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Summary Accomplishments

Geophysical 3D Geological Model and Reservoir Simulation

- 3D geophysical analysis has been utilized to enhance our understanding of drilling challenges posed by numerous salt intervals, leading to better mitigation strategies.

Well Drilling

- Enhanced understanding of well drilling optimization techniques gained

Production

- Production and completion designs have been tailored to accommodate the varying states of stress and the presence of natural fracture networks.

Geologic Characterization of Cane Creek and Development of Facies Model

- A comprehensive geologic characterization of Cane Creek has been conducted, encompassing porosity, permeability, fluid saturations, and source rock analysis, including detailed studies of the Cane Creek core and associated clastic zones.

Specialty Core Analyses and Geomechanics

- Specialty core analyses have been completed, covering water saturation, mercury intrusion capillary pressure (MICP), wettability, and relative permeability, along with a full suite of geomechanical studies.

Fracture Analysis

- Petrophysical log analyses and correlations have been refined. Models utilizing machine learning have been developed to correlate the logs from State 16-42 Paradox Formation with those from State 16-2.

Project Summary

- $11,000,000 project over 5 years ($8M Federal, $3M cost-share by local operators)
- Project drilled and characterized data from a 9,748 ft stratigraphic well (110 ft of core, cuttings, sidewall core, geophysical logs)
- Additional legacy wells brough into project by Zephyr Energy
- Lessons from initial State 36-2 well and spud of 36-2 redrill well
- Multiple operators in/around Paradox Basin to benefit from optimized drilling strategies and reduced environmental impacts
- Coordination with educational institutions and company-led training to transfer tech skills for development of play

THE UNIVERSITY OF UTAH

ZEPHYR ENERGY

UTAH DNR UTAH GEOLOGICAL SURVEY

THE UNIVERSITY OF ARIZONA

Statistical Petrophysics LLC

NATIONAL ENERGY TECHNOLOGY LABORATORY

BYU

Drilling of project stratigraphic well – Jan 2021,

Synergy Opportunities

- Oil & Gas Program
  - Core from State 16-2 well stored at Utah Geologic Survey available for public review
  - Seismic monitoring using fiber optics
  - Machine Learning – Full-waveform inversion in seismic imaging
- Other NETL-funded Partner Initiatives
  - CarbonSAFE San Juan Basin – investigations into induced seismicity using mechanical Earth Models
  - CUSP and SWP – knowledge base & detailed analyses on geomechanics in the region
  - DE-FOA-0002401 - detection and characterization of faults and quantification of fluid migration through the caprock layer
  - Hydrogen storage initiatives – utilization of findings on state of stress, geomechanics, and interplay of clastic and salt layers

Benefit to the Program

Objective: To advance the characterization of the Cane Creek play and formulate innovative strategies and technologies that expedite its development.

Strategic Approaches:

Economic Assessment: Conduct a thorough analysis of economic viability to ensure profitable exploitation.

Completion Engineering: Design optimal well completions to enhance production efficiency.

Fracture Optimization: Develop fracture treatment designs tailored to the unique geology of the play.

Development Planning: Make informed field development choices to achieve the highest possible recovery.

Key Focus Areas:

Leveraging Natural Fractures: Utilize natural fractures as a sustainable approach to maximize production and minimize environmental impact.

Innovative Stimulation Techniques: Explore alternative well stimulation methods that avoid issues associated with fracking near salt formations.

Technological Edge:

3D Seismic Integration: Access to high-quality 3D seismic data to accurately determine fracture density and orientation.

Data-Driven Decisions: Utilize insights from the recently drilled State 16-2LN CC lateral well to refine development strategies.

Benefit to the Program

- The primary project objective is to characterize the emerging Cane Creek play and develop technologies and strategies that can accelerate the development the play, including the evaluation of:
  - Economic viability
  - Optimal well completion design
  - Fracture treatment design
  - Field development choices that can lead to maximum ultimate recovery
- Cane Creek Play
  - Natural fractures = key to maximizing production and minimizing environmental impact
  - It will also be evaluated as a resource play (not just a fracture play)
  - Well stimulation will be considered (How do you stimulate wells without fracking into salt?)
  - The project has access to a quality 3D seismic critical to fracture density and orientation and follow up data from the recently drilled State 16-2LN CC lateral well

Project Overview - Goals and Objectives

Task/Subtask	Description	Date	Success Criteria
2.0	Workforce Readiness Plan	First continuation application	A detailed plan ready after reviewing the required skill sets and training/certifications (if any), and identifying the appropriate source or personnel for the workforce.
3.1	Geologic Characterization	Q4 2022	A geologically characterized basin model integrating 3D seismic data, well logs, core data, and production histories using machine learning algorithms.
3.2	Coupled Model Development	Q3 2024	A multi-continuum dynamic reservoir model, that combines the geological and discrete fracture network models, ready for simulating multiphase flow in the play.
4.3	Well Drilling	Q2 2024	New well drilled into the Cane Creek formation taking logs and other production evaluation measurements to characterize well production.
4.3	Well Characterization	Q2 2023	Fracture characterization and assessment of productive potential, reservoir properties, and stimulation treatment effectiveness.
5	Development Strategy Plan	Q4 2024	Develop a plan to effectively assess the technical and economic viability of further development of emerging UOG plays in the area and others across the US.

Appendix

- Organization Chart
- Gantt Chart

Organization Chart

Organizational Chart

Improving Production in the Emerging Paradox Oil Play

US DOE/NETL
Project Manager

PI: Brian McPherson
EGI, University of Utah

Partners

The University of Utah
Kirkwood Oil & Gas LLC
Zephyr Energy
Utah Geological Survey
BYU
Statistical Petrophysics LLC

Task 1
Project Management
Brian McPherson
Eric Edelman
The University of Utah

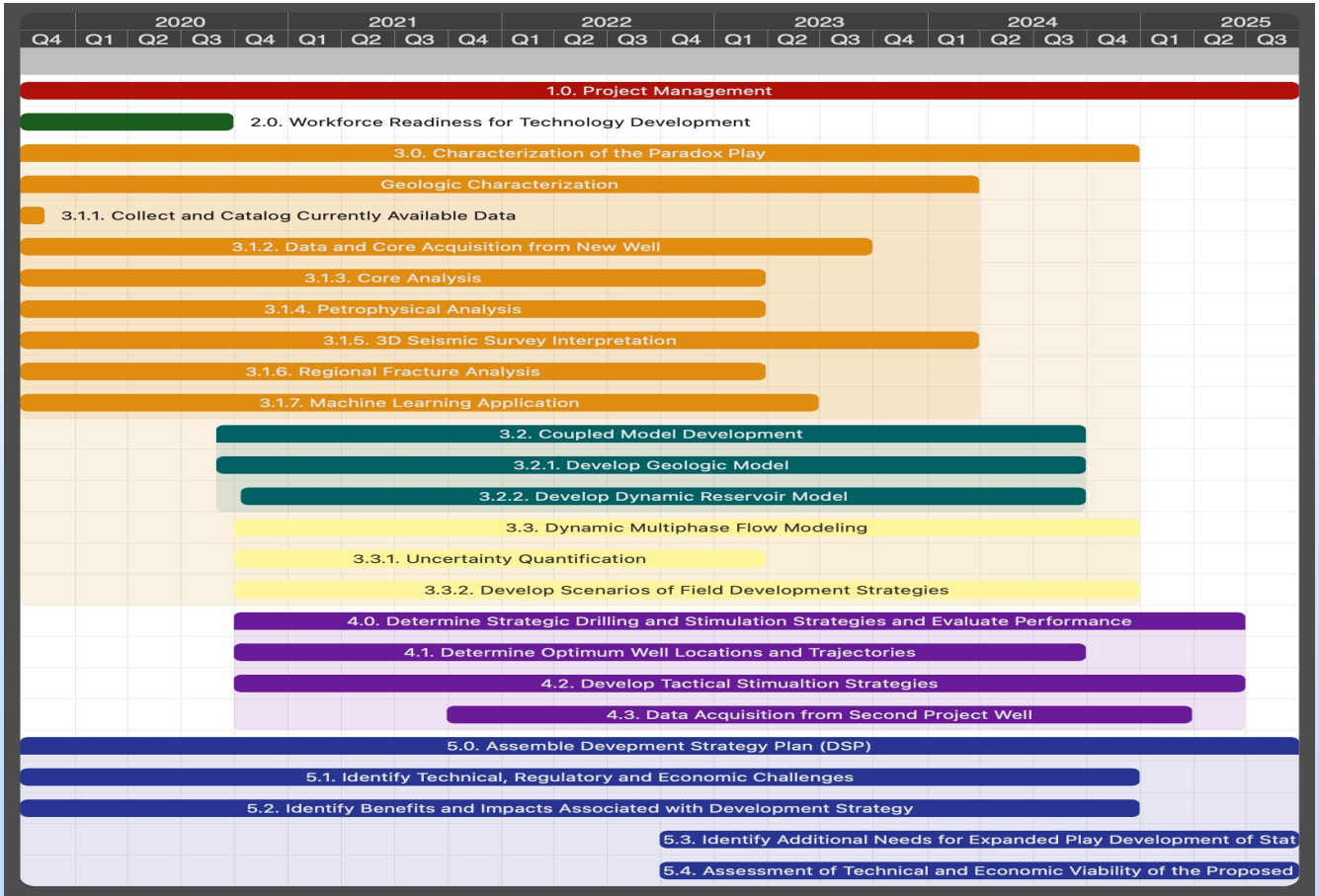
Task 2
Workforce Readiness for Technology Deployment
Brian McPherson
Eric Edelman
The University of Utah

Task 3
Site Characterization
Michael Vanden Berg
Bill Keach
Lauren Bergenheier
David Handwerger
Carlos Oroza
Pania Newell
Utah Geological Survey
Zephyr Energy
Kirkwood Oil & Gas LLC

Task 4
Field Development Strategy and Well Design and Completion
John McLennan
Gregor Maxwell
Zephyr Energy
Kirkwood Oil & Gas LLC

Task 5
Development Strategy Plan
Brian McPherson
John McLennan
Zephyr Energy
Kirkwood Oil & Gas LLC

Gantt Chart


2020
2021
2022
2023
2024
2025
Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3 Q4 Q1 Q2 Q3
1.0. Project Management
2.0. Workforce Readiness for Technology Development
3.0. Characterization of the Paradox Play
Geologic Characterization
3.1.1. Collect and Catalog Currently Available Data
3.1.2. Data and Core Acquisition from New Well
3.1.3. Core Analysis
3.1.4. Petrophysical Analysis
3.1.5. 3D Seismic Survey Interpretation
3.1.6. Regional Fracture Analysis
3.1.7. Machine Learning Application
3.2. Coupled Model Development
3.2.1. Develop Geologic Model
3.2.2. Develop Dynamic Reservoir Model
3.3. Dynamic Multiphase Flow Modeling
3.3.1. Uncertainty Quantification
3.3.2. Develop Scenarios of Field Development Strategies
4.0. Determine Strategic Drilling and Stimulation Strategies and Evaluate Performance
4.1. Determine Optimum Well Locations and Trajectories
4.2. Develop Tactical Stimualtion Strategies
4.3. Data Acquisition from Second Project Well
5.0. Assemble Devepment Strategy Plan (DSP)
5.1. Identify Technical, Regulatory and Economic Challenges
5.2. Identify Benefits and Impacts Associated with Development Strategy
5.3. Identify Additional Needs for Expanded Play Development of Stat
5.4. Assessment of Technical and Economic Viability of the Proposed