Field Evaluation of the Caney Shale as an Emerging Unconventional Play, Southern Oklahoma

DE-FE0031776

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U.S. Department of Energy

National Energy Technology Laboratory

Resource Sustainability Project Review Meeting

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DOE Award DE-FE0031776 from the Office of Fossil Energy in Partnership with industry partner, OGS, OSU Geology, OSU Chem. Engineering, University of Pittsburgh, Lawrence Berkeley National Lab and DOE NETL.

Project Overview

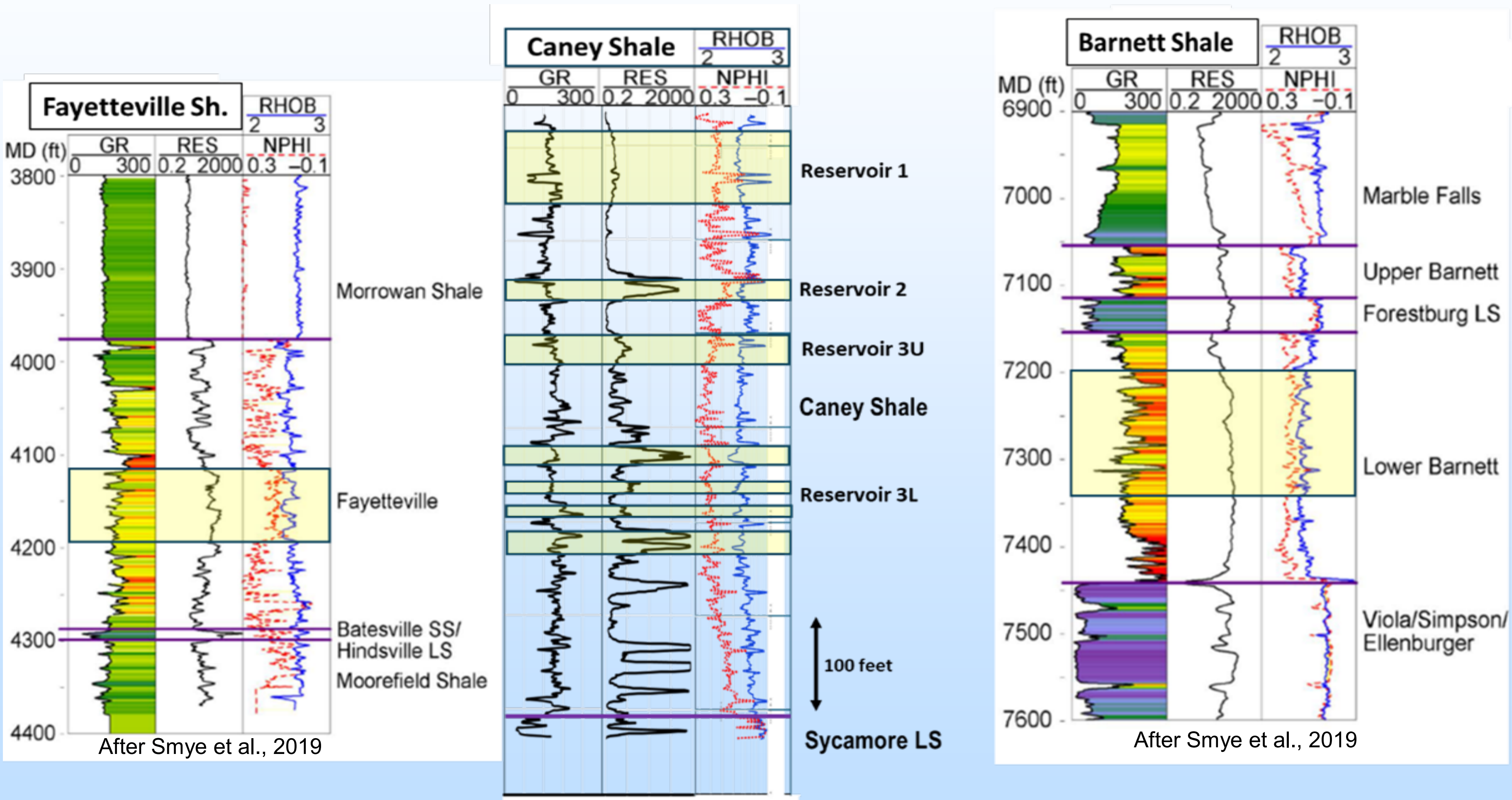
- **Funding** - DOE: 7.8 million dollars; Industry share: 12.1 million dollars.
- **Date**: October 1, 2019 to September 31, 2023 with 1-year no-cost extension.
- **Objective**: Evaluate relatively unknown and unstudied reservoir in southern Oklahoma called the Caney Shale as a potential emerging unconventional oil and gas play.
  - Characterize geologically including depositional facies, reservoirs and seals
  - Establish tectonic control of Caney Shale deposition
  - Complete comprehensive geomechanical and geochemical characterization
  - Calibrate core to petrophysical properties including wireline-log signatures and establish reservoir and seal distribution
  - Establish mechanical properties and rock-fluid interactions
  - Investigate rheology as pressure and fluid composition change
  - Generate field development strategy based on integrated results of characterization and drilling and production data from project well

Technical Approach/Project Scope

Task	Status
1.0 Planning	Complete
2.0 Workforce Readiness	Complete
3.0 Data Management Plan	Complete
4.0 Geological Characterization	Complete except biostratigraphy
5.0 Characterization of Mechanical Properties	Complete
6.0 Rock-Fluid Interactions	Complete
7.0 Fluid-Flow & Geomechanical Modeling	In-progress
8.0 Economic Field Baseline	Complete
9.0 Well Candidate Selection	Complete
10.0 Horizontal well drilled	Complete
11.0 Detailed Rock Analysis	Complete except for nano-scale pore characterization
12.0 Rock-Fluid Characterization	In-progress
13.0 Coupled Processes-Field Test	In-progress
14.0 Tech. Analysis Drilling, Stimulation and Production	Complete
15.0 Development Strategy Plan	In-progress
16.0 Final Report	

Progress -Task 11: Petrophysical Analysis

Caney Shale: Similar but more subtle log responses in reservoir and ductile beds as Fayetteville and Barnett shales

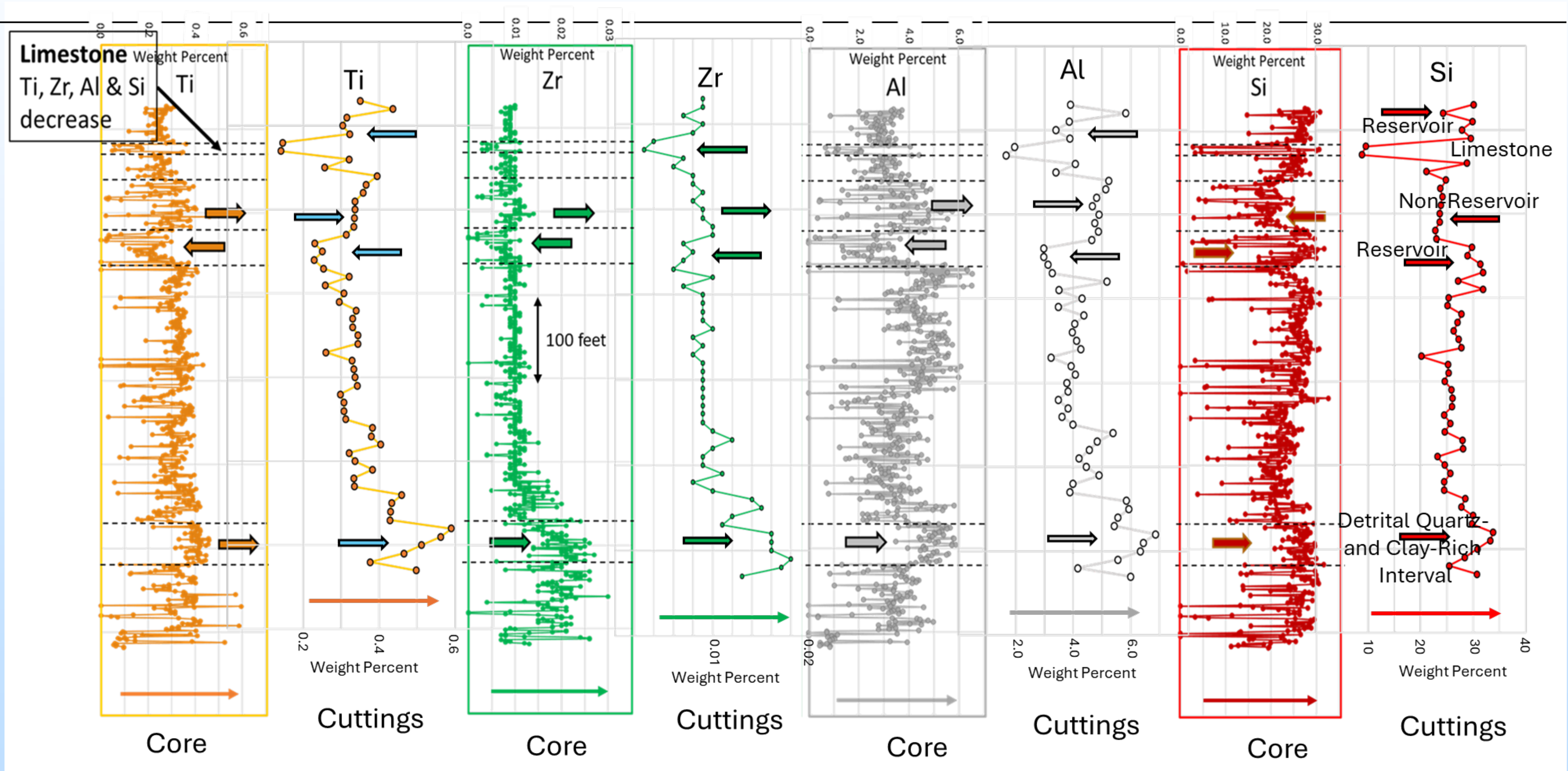


Reservoir: higher RES, lower NPHI and higher RHOB

Ductile: low RES, higher NPHI and higher RHOB

Progress - Task 11: Petrophysical Analysis

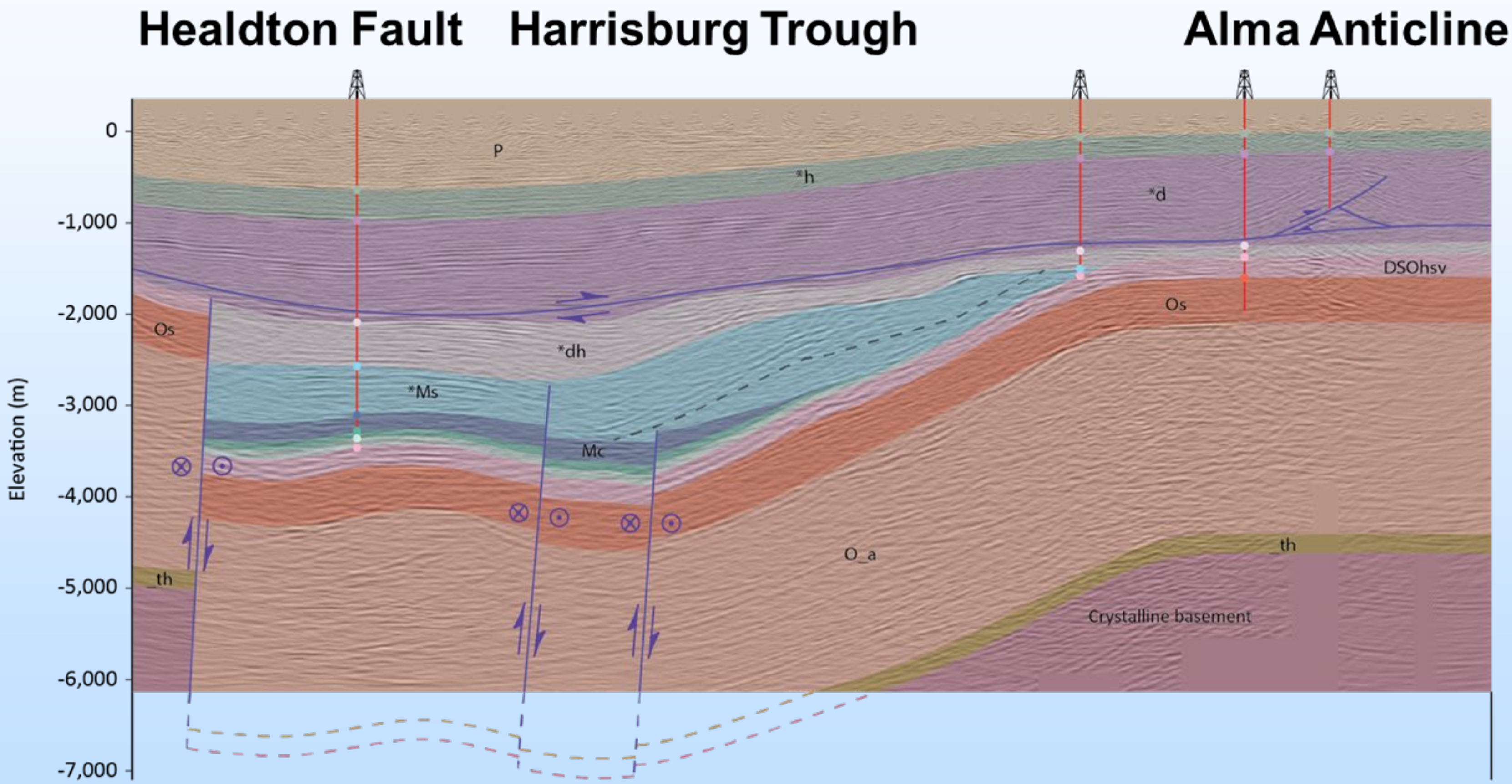
X-ray fluorescence (XRF)-derived concentration of Al increases with clay mineral content in ductile intervals and decreases in reservoirs



XRF of cuttings detects some changes in elemental concentrations observed in core

Progress - Task 11: Detailed Rock Analysis

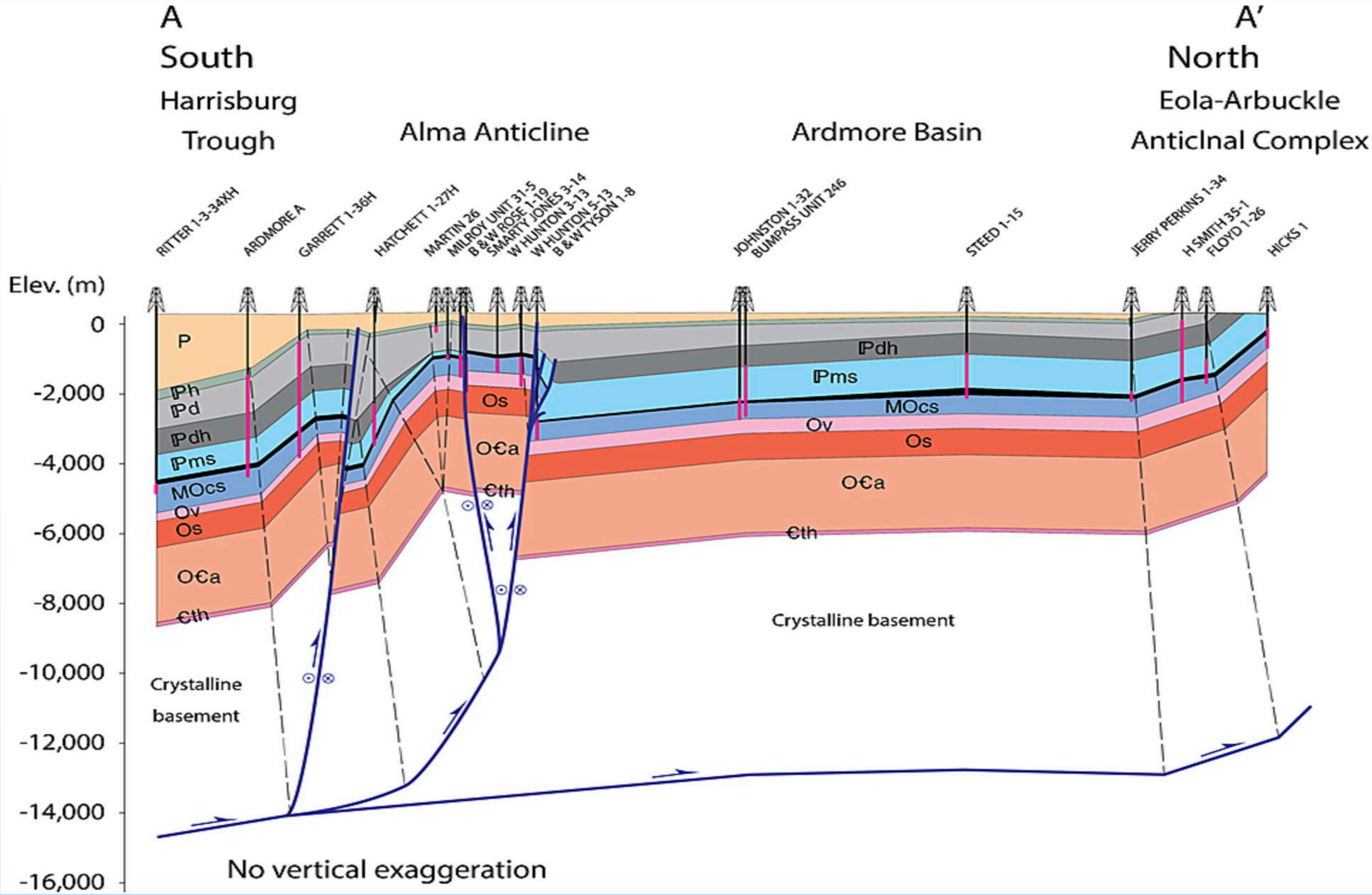
Insight into Architecture and Origin of the Ardmore Basin, Caney Shale Exploration Fairways



Reprocessed Seismic Profiles Depth-Converted and Interpreted
2D Basin Model Constructed based on Seismic and Well Control

Progress - Task 11: Detailed Rock Analysis

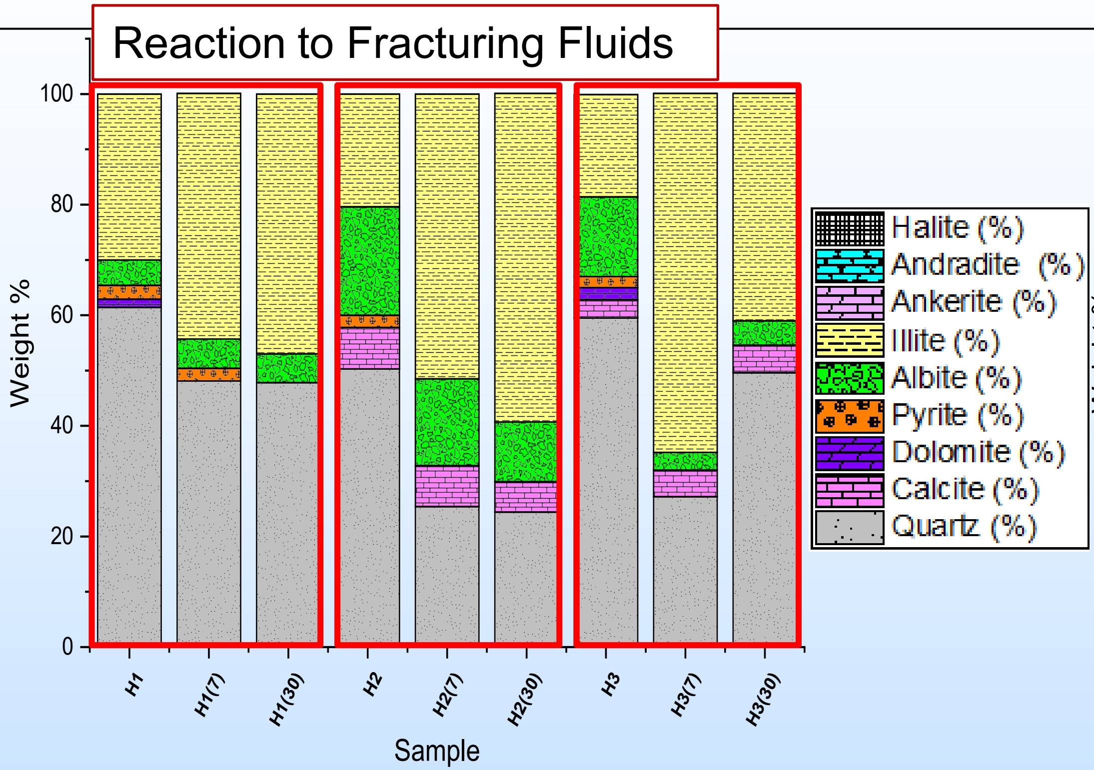
Caney Shale Reservoirs Developed in Compressive Oblique-Slip Tectonic System, Faults Broke Forward during and after Caney Deposition



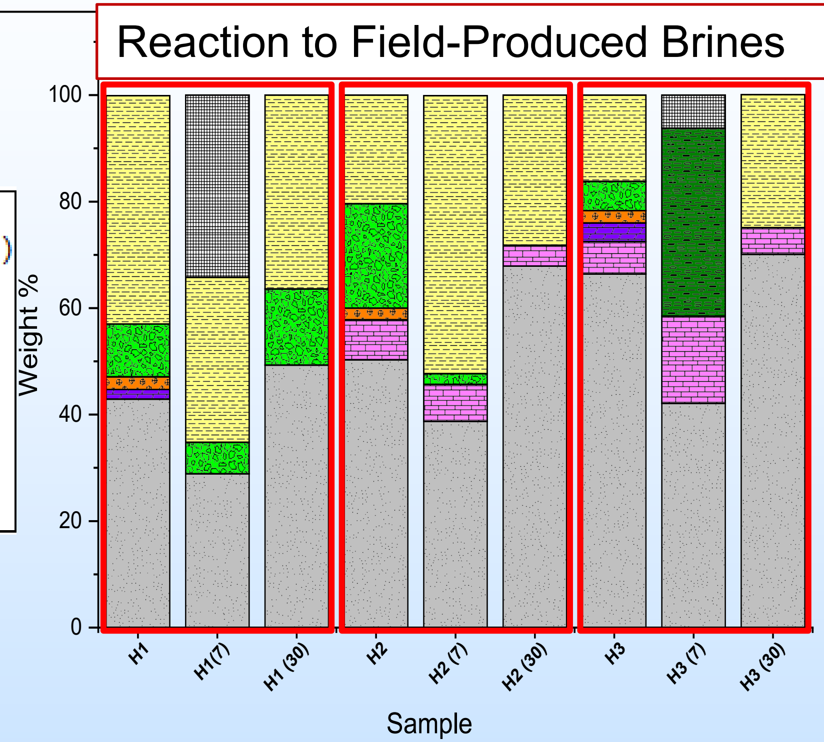
Structural Cross Section showing Relationship of Folds and Faults to Mid-Crustal Detachment

Progress - Task 12: Rock-Fluid Interactions

Geochemical Characterization: Mineralogical Changes



Mineralogical changes due to reaction with field fracturing fluids – Short-Term Changes



Mineralogical changes due to reaction with field produced brines – Long-Term Changes

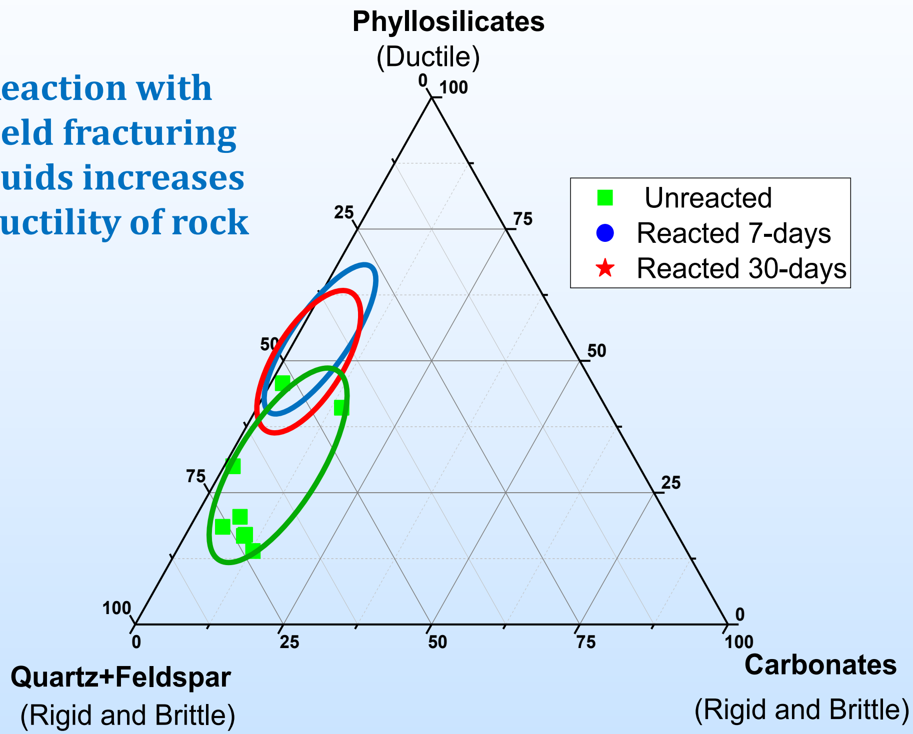
- ✓ Pyrite, carbonates, and feldspar breakdown is consistent for all samples
- ✓ Illite weight % increases and is attributed to:
    - Illitization (from breakdown of feldspar)
    - Faster breakdown of other minerals in the short-term

- ✓ Carbonate is relatively stable in produced brines
- ✓ Pyrite and feldspar breakdown is consistent
- ✓ Illite weight % fluctuates and generally declines after 30days reaction
- ✓ Long-term deflocculation of illite may be responsible for decline in weight % illite

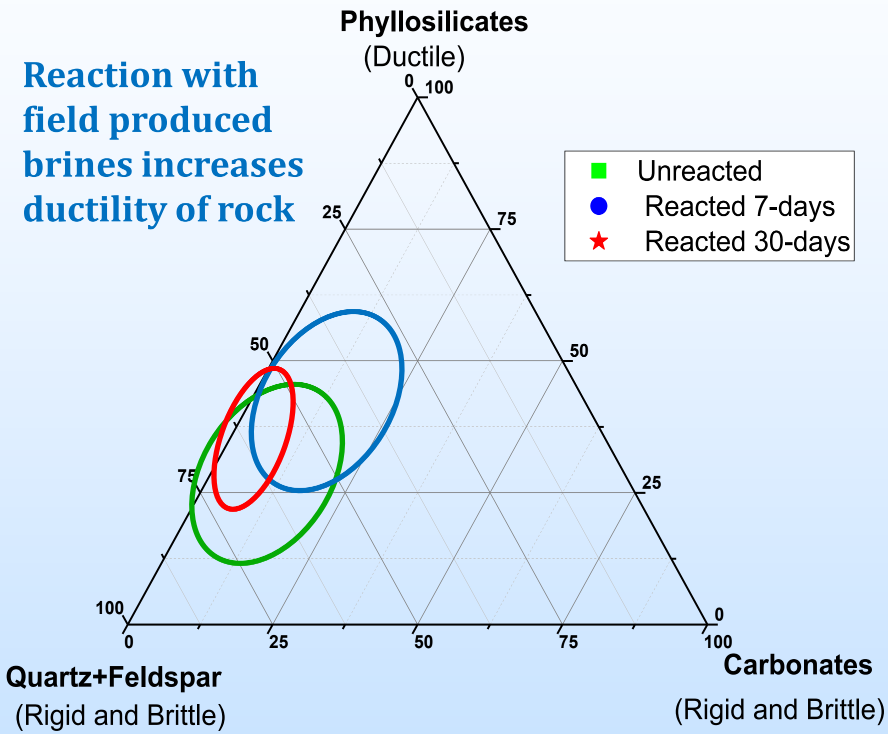
Progress - Task 12: Rock-Fluid Interactions

Geochemical Characterization: Rock Properties

Reaction with field fracturing fluids increases ductility of rock



Reaction with field produced brines increases ductility of rock



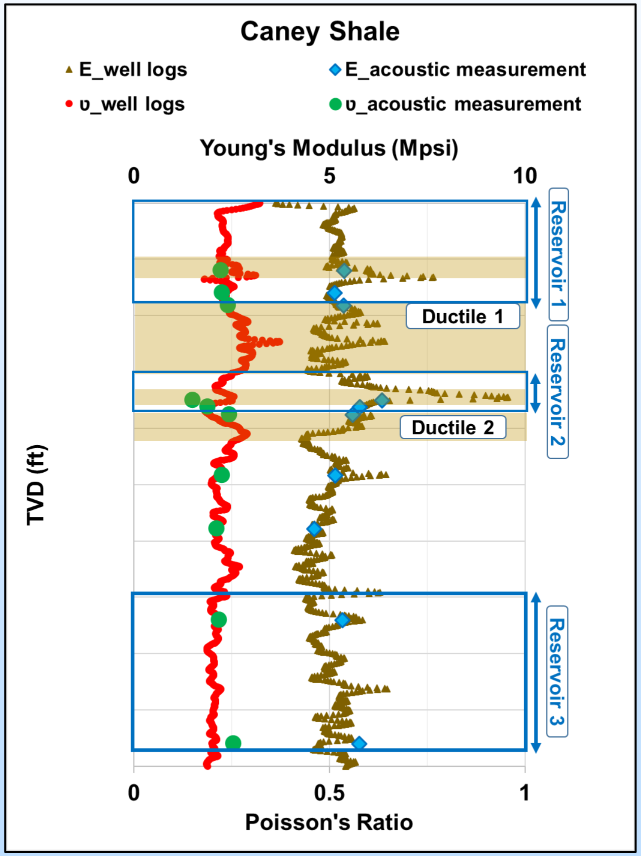
- ✓ Reaction with field fracturing fluid replicates the short-term transformations post-hydraulic fracturing
- ✓ Rock composition rapidly drifts towards phyllosilicate zone – ductile zone
- ✓ This induces fracture healing and adverse petrophysical properties
- ✓ This is responsible for rapid permeability decline

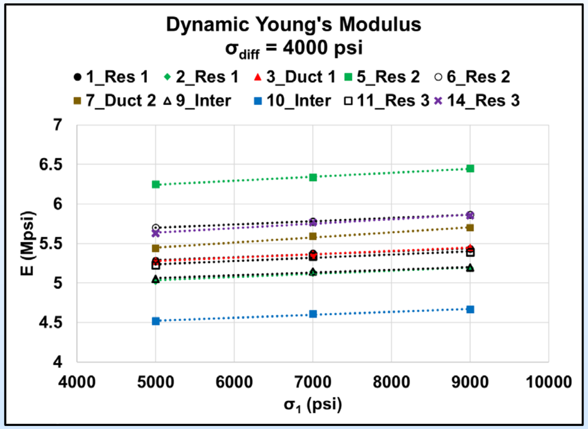
- ✓ Reaction with field produced brine replicates the long-term transformations post-hydraulic fracturing
- ✓ Rock composition initially drifts towards phyllosilicate and carbonate zone
- ✓ Later breakdown of phyllosilicates is an indication of clay fines migration the cause major fracture closures
- ✓ This is responsible for massive permeability losses

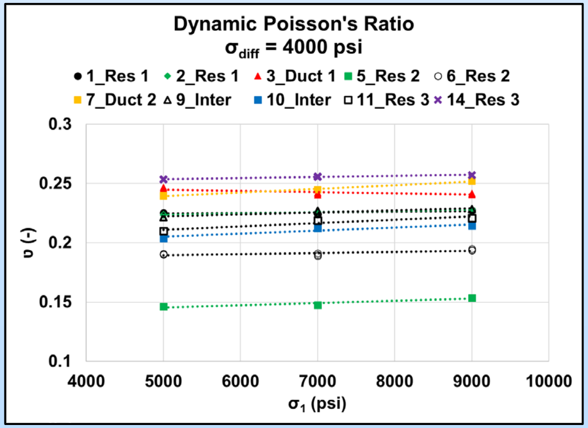
Progress - Task 12: Rock-Fluid Interaction

Evaluation of Dynamic and Static Mechanical Properties for Caney Shale: Effective Stress Impact on Dynamic Mechanical Properties

- A good match between the dynamic mechanical properties from the sonics logs (field) and the acoustic P and S wave velocities measurements (lab) for 10 Caney samples under :
  - Axial stress (σ_1) = 7000 psi
  - Confining stress (σ_3) = 3000 psi
  - Temperature = 240 ^oF
  - Saturation impact was considered from the measurements of saturated Gray Berea sandstone samples
- Additional measurements were conducted at σ_1 of 5000 and 9000 psi.
- Increase in σ_1 yielded an increase in Young's modulus (*E*), while there was no clear impact on Poisson's Ratio (*υ*).



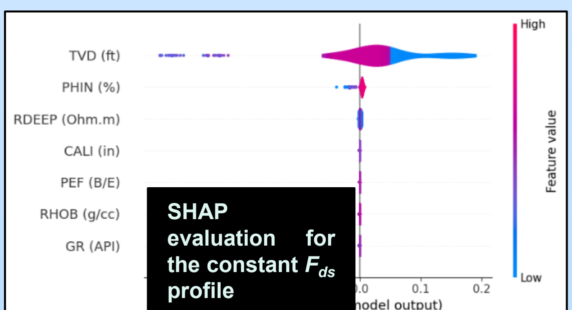




Progress - Task 12: Rock-Fluid Interaction

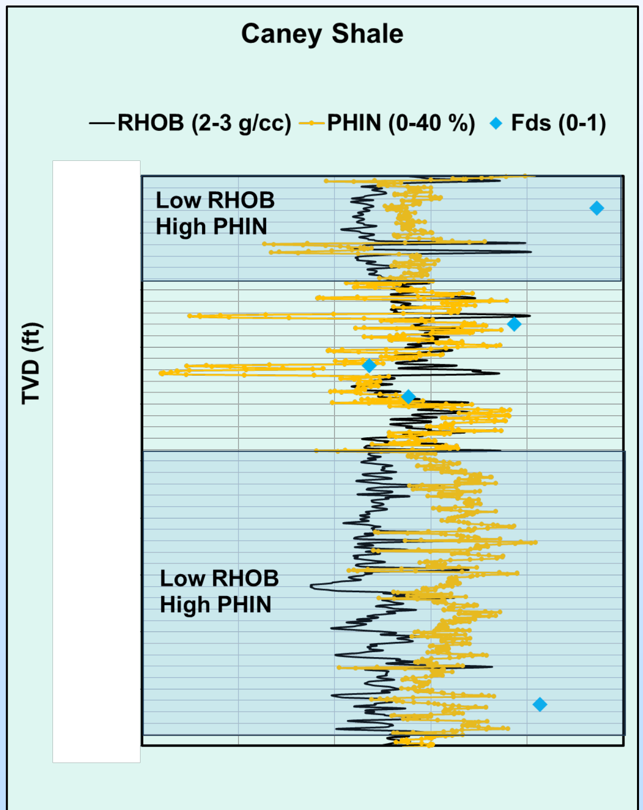
Evaluation of Dynamic and Static Mechanical Properties for Caney Shale: Static Mechanical Properties Derivation

- **Dynamic to static correction factor (*F_{ds}*) was estimated for the 5 depths with known Static Young's modulus (Benge et al., 2021).**
- ***F_{ds}* is higher for zones with high neutron porosity (PHIN) and low bulk density (RHOB).**
- **The XGBoost SHAP evaluation showed that the constant *F_{ds}* profile has the strongest correlation with TVD and PHIN.**

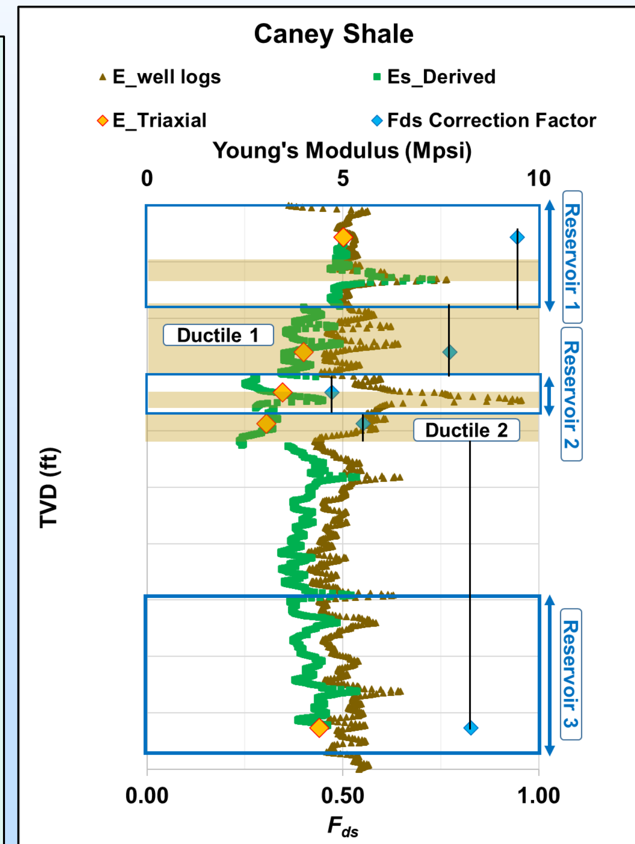


SHAP evaluation for the constant F_{ds} profile

Relation between F_{ds}, PHIN, and RHOB



Derived E_s from the constant F_{ds} profile

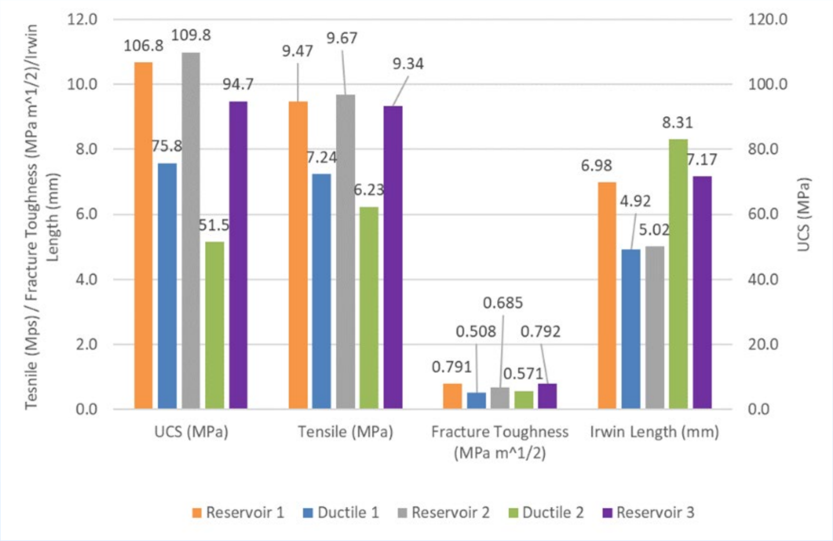


Positive (SHapley Additive exPlanations (SHAP) value explains contributions to machine learning model outcome

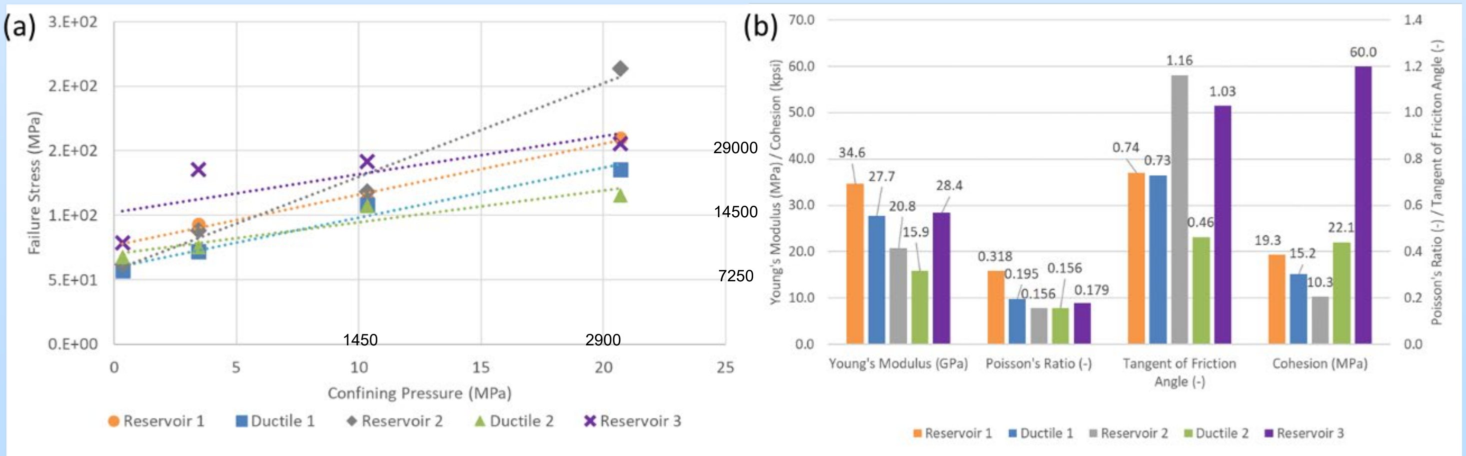
Progress - Task 12: Rock-Fluid Interaction

Geomechanical Characterization: Strength and Elastic Properties

- Completed laboratory characterization of static mechanical properties
- Zones identified as nominally "ductile" were weaker than "brittle" zones
- No significant difference in mechanical properties other than compressive strength



Summary of Unconfined Testing Results (from Benge et al, 2021a)

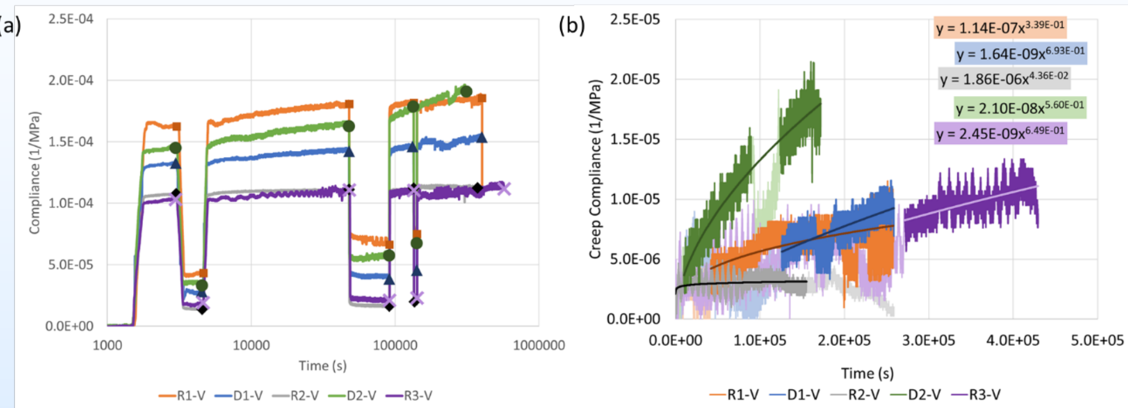


Summary of Unconfined Testing Re(a) Failure envelopes from triaxial testing and (b) Properties obtained from triaxial testing at 3000 psi confining pressure (from Benge et al, 2021a) results (from Benge et al, 2021a)

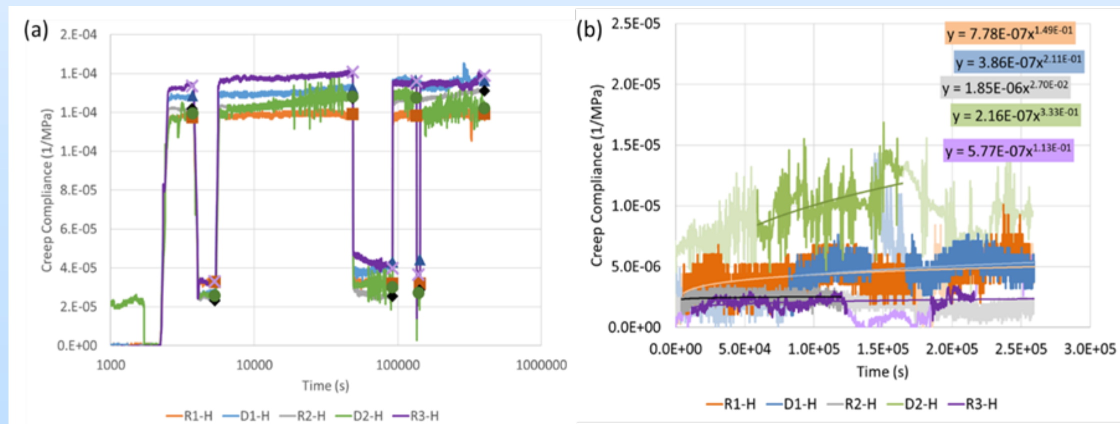
Progress - Task 12: Rock-Fluid Interaction

Geomechanical Characterization: Creep Properties

- Creep testing conducted on samples drilled at multiple orientations
  - Vertical (perpendicular to bedding)
  - Horizontal (parallel to bedding)
  - 45°
- Nominally "ductile" zones significantly more prone to creep than nominally "brittle" zones.
- Bedding planes allow for more creep and more deformation
  - Vertical samples have more creep, lower Young's modulus
  - 45° between behavior of vertical and horizontal samples



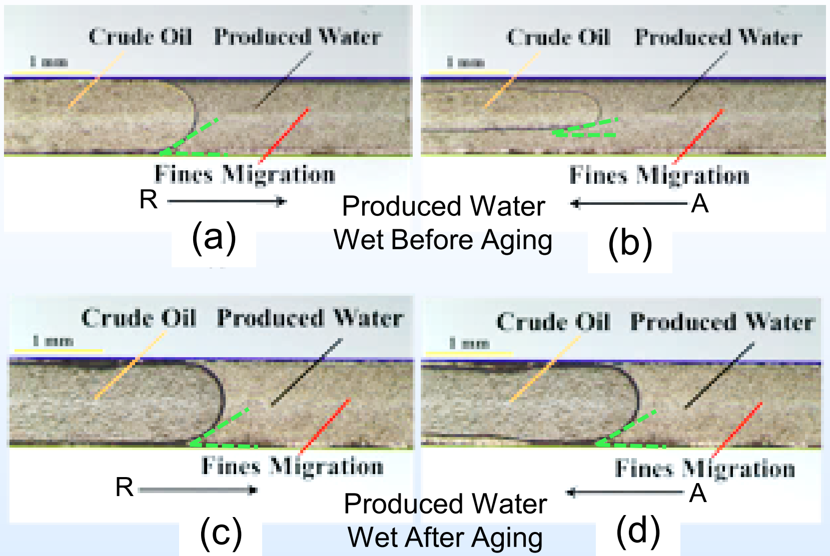
(a) Compliance over time and (b) Power-law description of creep for vertical samples (from Benge et al, 2023)



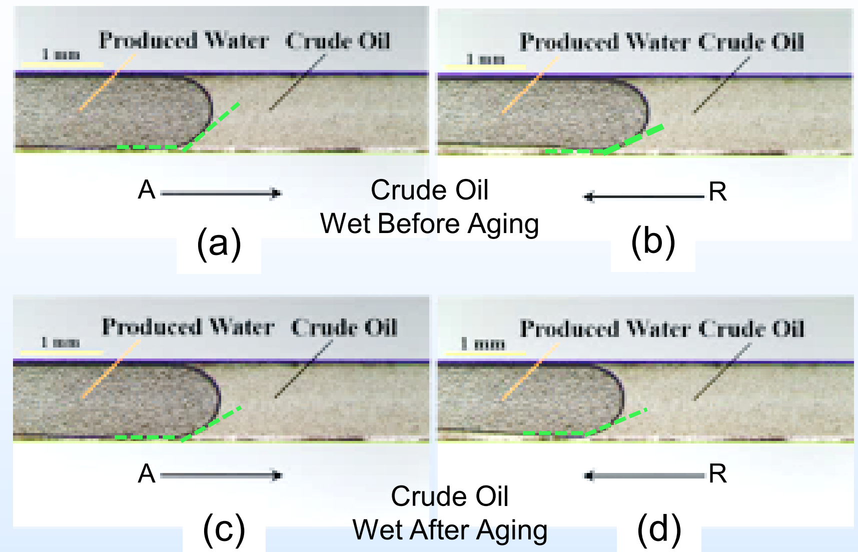
(a) Compliance over time and (b) Power-law description of creep for horizontal samples (from Benge, 2023)

Task 12c: Rock-Fluid Interactions in Produced Water-Crude Systems

Wettability of Illite-coated Microfluidic Surfaces



Illite-coated microfluidic channel **contacted by produced water first**: **(a)** produced water receding contact angle and **(b)** advancing contact angle in produced water-crude oil system before aging; **(c)** produced water receding contact angle and **(d)** advancing contact angle after aging.

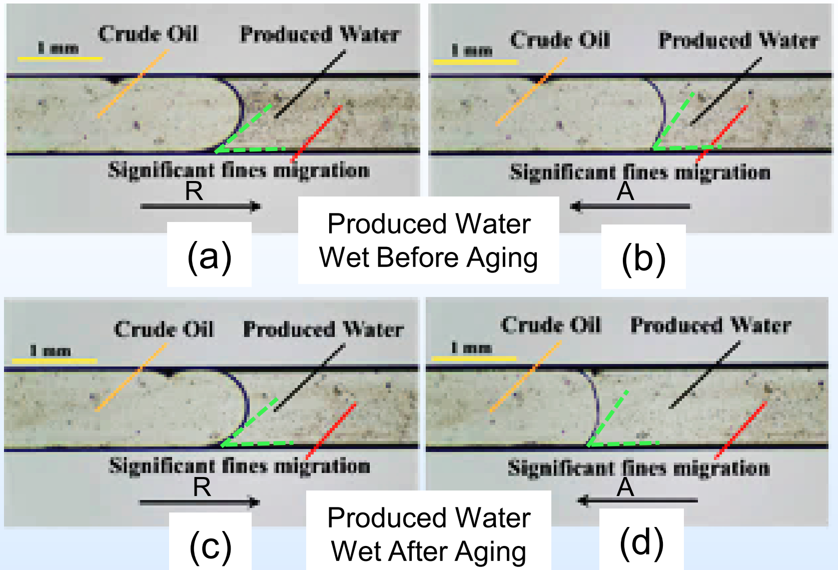


Illite-coated microfluidic channel **contacted by crude oil first: (a)** produced water advancing contact angle and **(b)** receding contact angle in produced water-crude oil system before aging; **(c)** produced water advancing contact angle and **(d)** receding contact angle after aging.

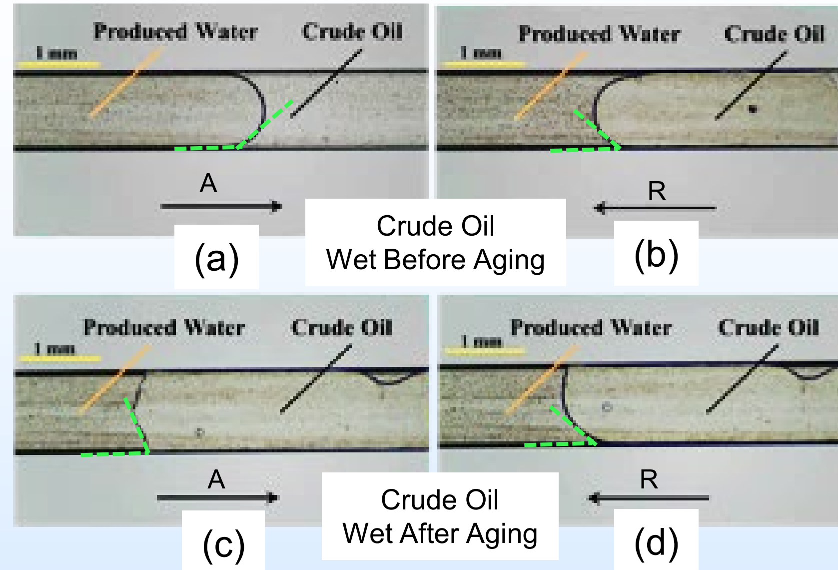
Experiment	Fluid contacting the microfluidic chip first	Wettability			
		Advancing Contact Angle (°)		Receding Contact Angle (°)	
		Before Aging	After Aging	Before Aging	After Aging
DI Water/ n-Decane	n-Decane	Oil Wet	Oil Wet	Oil Wet	Oil Wet
	DI Water	Water Wet	Oil Wet	Water Wet	Oil Wet
5k ppm brine/ n-Decane	n-Decane	Oil Wet	Water Wet	Oil Wet	Water Wet
	5k ppm brine	Water Wet	Water Wet	Water Wet	Water Wet
10k ppm brine/ n-Decane	n-Decane	Oil Wet	Oil Wet	Oil Wet	Oil Wet
	10k ppm brine	Water Wet	Water Wet	Water Wet	Water Wet
30k ppm brine/ n-Decane	n-Decane	Oil Wet	Oil Wet	Oil Wet	Oil Wet
	30k ppm brine	Oil Wet	Oil Wet	Oil Wet	Oil Wet
Produced water/ Crude oil	Crude oil	Oil Wet	Oil Wet	Oil Wet	Oil Wet
	Produced water	Water Wet	Water Wet	Water Wet	Water Wet

Task 12c: Rock-Fluid Interactions in Produced Water-Crude Systems

Wettability of Illite-Smectite-coated Microfluidic Surfaces



Illite-Smectite-coated microfluidic channel **contacted by produced water first**: **(a)** produced water receding contact angle and **(b)** advancing contact angle in produced water-crude oil system before aging; **(c)** produced water receding contact angle and **(d)** advancing contact angle after aging.



Illite-Smectite-coated microfluidic channel **contacted by crude oil first**: **(a)** produced water advancing contact angle and **(b)** receding contact angle in produced water-crude oil system before aging; **(c)** produced water advancing contact angle and **(d)** receding contact angle after aging.

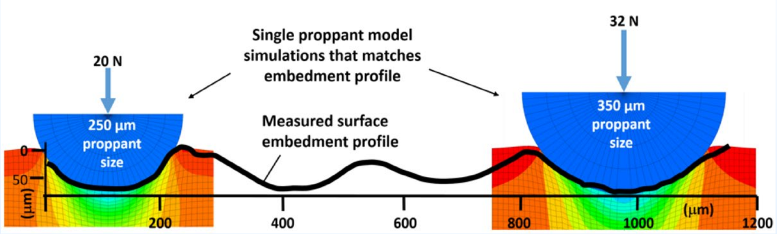
Experiment	Fluid contacting the microfluidic chip first	Wettability			
		Advancing Contact Angle (°)		Receding Contact Angle (°)	
		Before Aging	After Aging	Before Aging	After Aging
DI Water/ n-Decane	n-Decane	Oil Wet	Oil Wet	Oil Wet	Oil Wet
	DI Water	Water Wet	Oil Wet	Water Wet	Oil Wet
5k ppm brine/ n-Decane	n-Decane	Oil Wet	Water Wet	Oil Wet	Water Wet
	5k ppm brine	Water Wet	Water Wet	Water Wet	Water Wet
10k ppm brine/ n-Decane	n-Decane	Oil Wet	Oil Wet	Oil Wet	Oil Wet
	10k ppm brine	Water Wet	Water Wet	Water Wet	Water Wet
30k ppm brine/ n-Decane	n-Decane	Oil Wet	Oil Wet	Oil Wet	Oil Wet
	30k ppm brine	Water Wet	Water Wet	Water Wet	Water Wet
Produced water/ Crude oil	Crude oil	Oil Wet	Inter. Wet	Water Wet	Water Wet
	Produced water	Water Wet	Water Wet	Water Wet	Water Wet

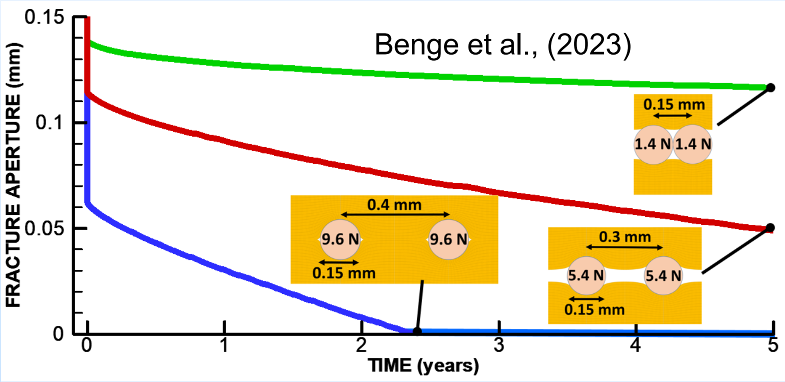
Progress - Task 13 Coupled Processes Modeling

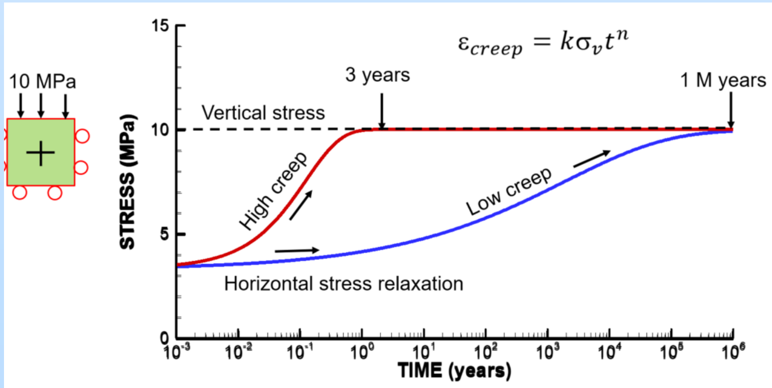
Proppant Embedment and Creep

- Completed modeling of propped fracture conductivity experiment (multilayer)
  - Sand compaction and grain crushing cause irreversible conductivity reduction
- Completed modeling of OSU flow through of monolayer propped fractures
  - Proppant embedment has significant impact on fracture conductivity
- Completed proppant creep embedment modeling using UPITT creep properties
  - Propped fractures in ductile units could close completely over time
- Ongoing modeling anisotropic creep caprock stress relaxation

Katende et al., (2023)







Progress - Task 13 Coupled Processes Modeling

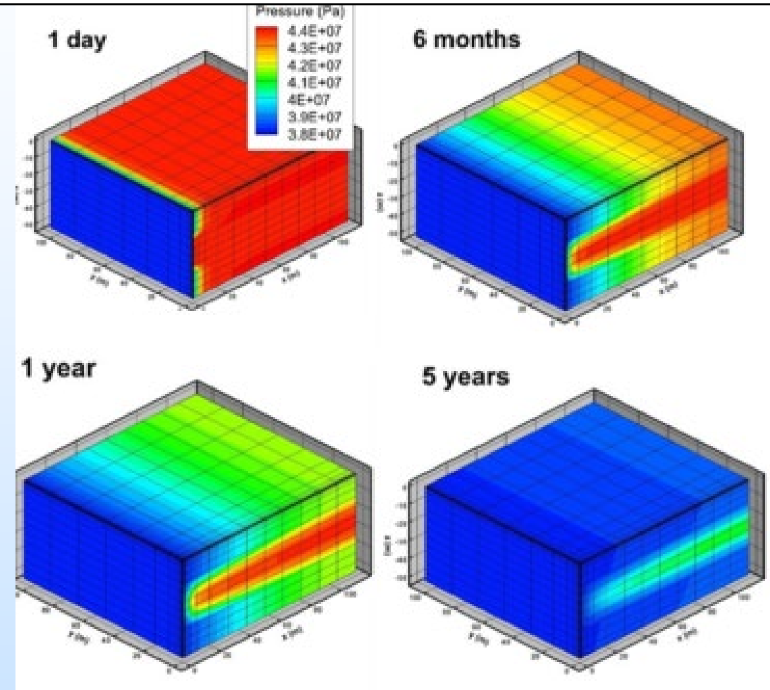
Multiphase Fluid Flow and Chemistry

- Completed production modeling for two-phase flow (gaseous CH_4 and aqueous-phase brine)
- Completed modeling at core scale, for flow-through experiments considering variability in wettability, including mixed-wet versus water-wet.
- Completed geochemistry modeling of batch reactor experiments considering deionized water, fracking fluid, and production fluid.

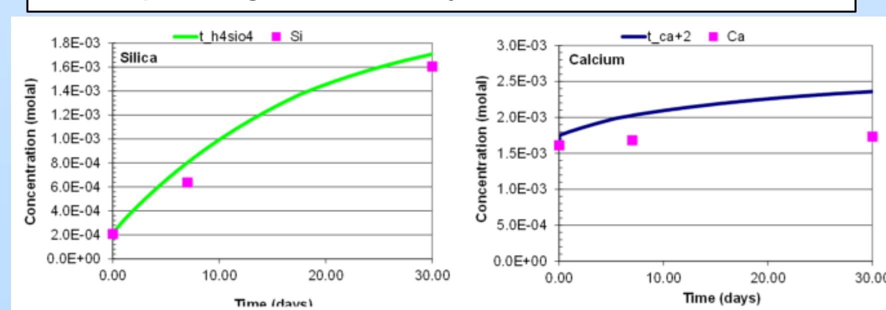
  Main minerals forming are chlorite $(Mg,Fe)_3(Si,Al)_4O_{10}(OH)_2 \cdot (Mg,Fe)_3(OH)_6$ and ferrihydrite (Fe_2-$0.5H_2O$)

- Ongoing field production modeling considering the mix-wet system and time dependent fracture closure

Example of production modeling results of pressure

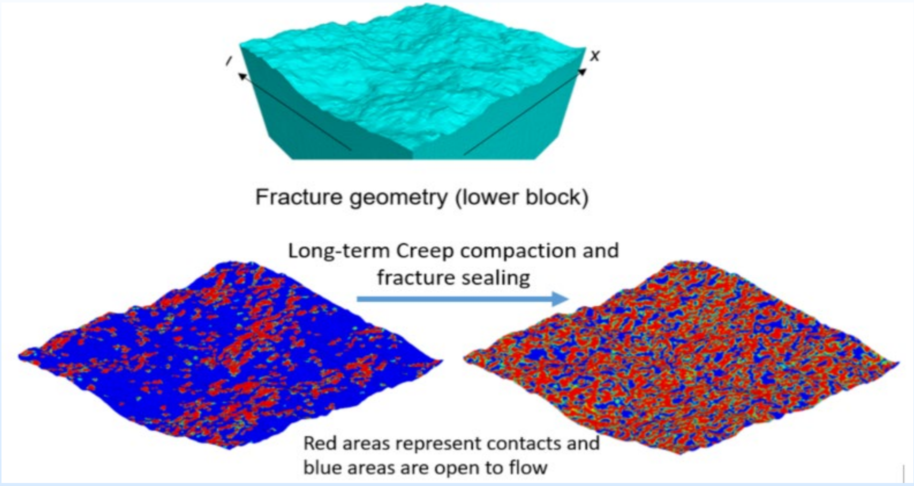


Example of geochemistry model and lab results

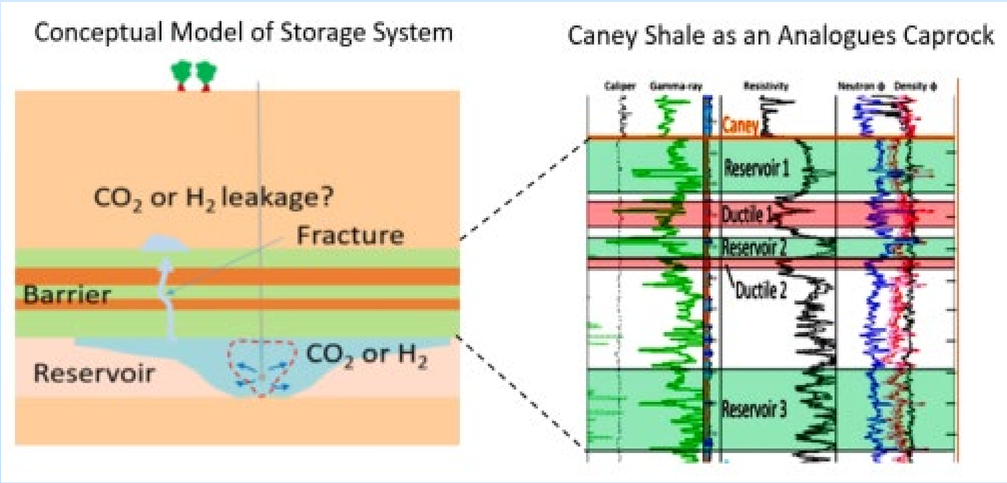


Progress – Task 13 Coupled Processes Modeling: New CO_2/H_2 Caprock Studies

- Investigating creep closure of induced fractures in Caney shale by roughness imaging and numerical modeling.
    - Use of tensile cracked Caney samples from UPITT
    - Surface roughness imaging (S. Nakagawa, LBNL)
    - Un-propped fracture closure modeling (J. Rutqvist, LBNL)



- Caney shale as analogue caprock for subsurface CO_2 and H_2 storage
    - Modeling new OSU CO_2 flow through experiments (C. Doughty)
    - Modeling potential leakage of CO_2 or H_2 through stacked Caney shale (Y. Zhang, LBNL)



Progress - Task 14: Drilling, Stimulation and Production Economical and Technical analysis

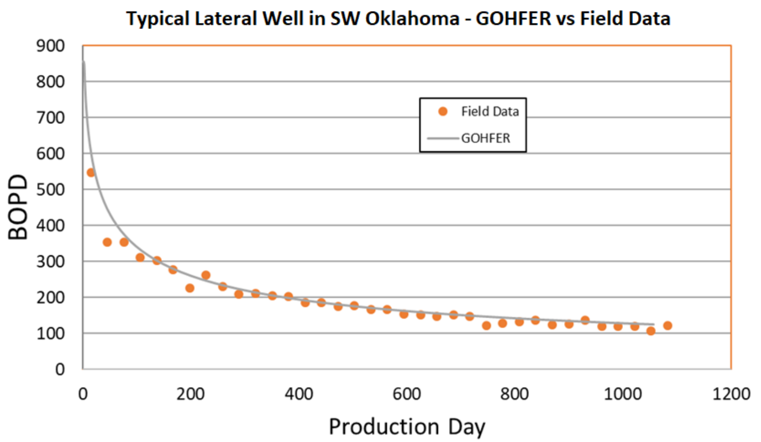
14.1 Post analysis of drilling and completion of the horizontal well

Drilling and Rock Mechanics

- Drilling offset data was used to pre-simulate the project drilled well with the Pason Optimizer yielding a great match within 2% total drilling time to total depth.

Production

- From the project cored and logged well, correlations were developed for geomechanical and petrophysical to rock strength obtained from drilling data for reservoir A and B.
- Production from the project competed well matched pre-predicted production using GOHFER with the geomechanical and petrophysical properties along the lateral.



Progress - Task 14: Drilling, Stimulation and Production Economical and Technical analysis

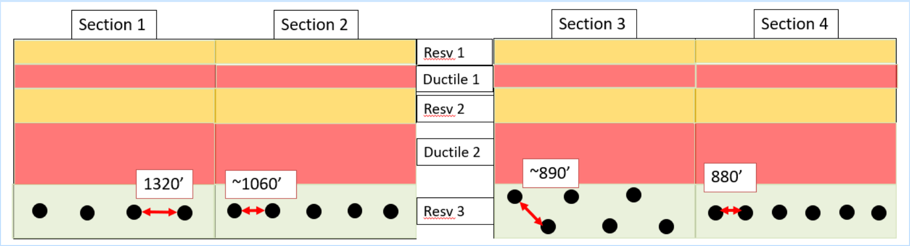
14.2 Design drilling and completion for individual areas

__Drilling__

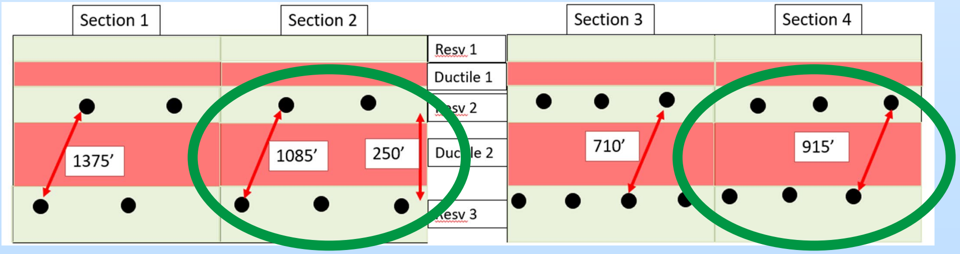
- Future Caney wells were further optimized resulting in a further CAPEX deduction of more than 10%

__Production__

- Both reservoir A and B in the Caney are deemed economical
- Studied parent child relations on reservoir and well spacing in GOHFER
- This pressure depletion impacted production, but the wells still generate high production values and maintain an 880’ spacing is adequate



Well Spacing Scenarios for a Single Pay Reservoir

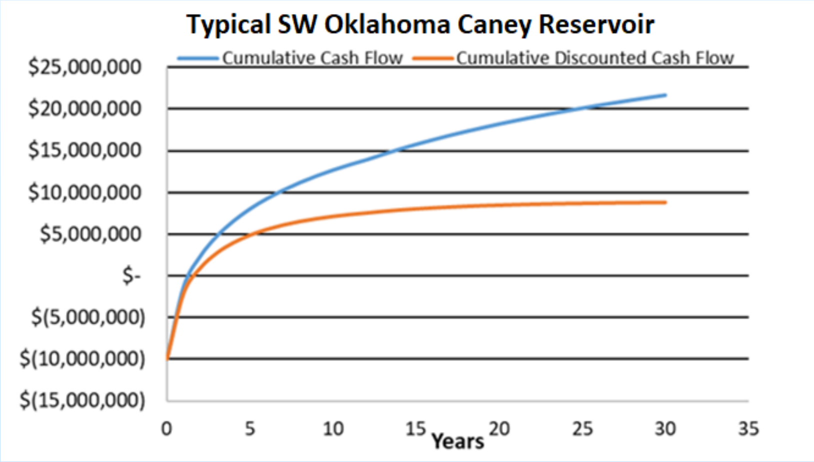


Well Spacing Scenarios for a Stacked Pay Reservoir

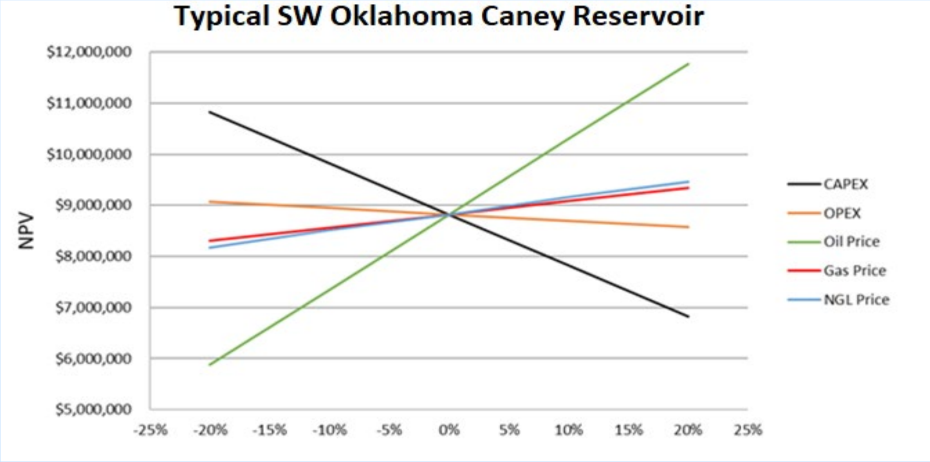
Progress - Task 14: Drilling, Stimulation and Production Economical and Technical analysis

14.3 Economical analysis

- The Caney Shale is an economic resource even with stressed commodity prices
- Single well analysis using older completion technology and non-optimized drilling indicate a WTI crude sensitivity break even of $42.5
- Applying optimized drilling effect on CAPEX and increased production due to newer technologies in stimulation decreases this substantially for a single well



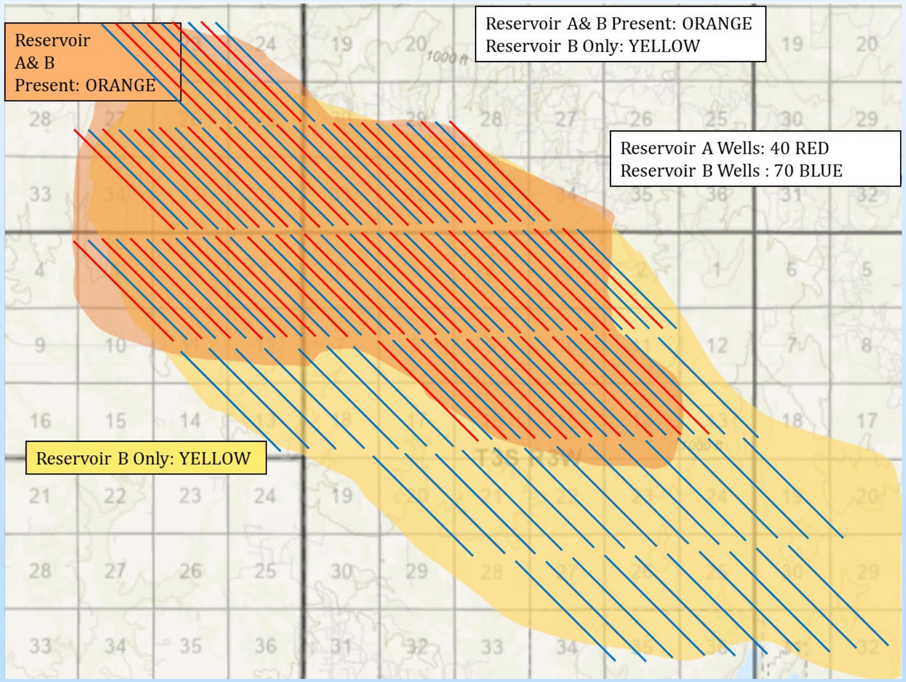
Cash Flow Analysis of Single Well



Single Well Net Present Value (NPV)
Sensitivity to Commodity Pricing

Progress - Task 14: Drilling, Stimulation and Production Economical and Technical analysis

- The effect of parent child effects give 3 tier type wells. The production decrease can be accounted for in field development via tiered production.
- All 3 tier well production classifies certain areas predicated on their realized or anticipated production to risk adjusted economic models
- The proposed field development plan suggested includes 110 lateral wells total in Reservoir A and B



Proposed development drilling locations for the 110 lateral wells overlayed on the geological structure

Project Summary

- **Objective**: Evaluate relatively unknown and unstudied reservoir in southern Oklahoma called the Caney Shale as a potential emerging unconventional oil and gas play.
- The foundation for the project was a 650+ feet long continuous core of the complete Caney section. First and only core of the complete Caney interval.
  - Geological Characterization essentially complete
  - Data were leveraged to investigate tectonic evolution of the area and understand how tectonism influenced Caney deposition and reservoir and seal evolution.
  - Core allowed a comprehensive geochemical and geomechanical characterization including LBNL models of long-term rheology as pressure and fluid composition change.
- Core-calibrated wireline log signatures were used to map distribution of reservoir and seal intervals.
- Detailed rock analysis including characterization on nanopores continues.
- Project well was successfully drilled and completed; results closely match modeled production
- Integrated core, logs and drilling data supported detailed modeling of completion strategies and overall field development.
  - Economic feasibility with sensitivity to commodity prices, CAPEX and OPEX completed.
  - Results corroborate industry partner predictions that Caney Shale is economic unconventional reservoir play.
- Further investigating seals and confining-bed integrity to evaluated potential post-production capacity for storage and sequestration of CO_2 and other fluids.

LBNL Budget-March 2024

Description	Activity	Commitments	Available
a. Personnel	1,926,090.87	35,942.52	114,310.84
b. Fringe Benefits	344,260.22	-	62,878.56
c. Travel	28,853.51	-	50,376.49
d. Equipment	467,126.66	392.04	93,410.30
e. Supplies	82,083.54	6,463.10	3,484.80
f. Contractual	2,092,971.62	793,030.75	24,334.63
g. Construction	-	-	-
h. Other	173,434.61	7,475.37	7,308.02
i. Total Direct Charges (sum of a to h)	5,114,821.03	843,303.78	356,103.64
j. Indirect Charges	1,308,091.73	-	168,658.82
k. Totals (sum of i and j)	6,422,912.76	843,303.78	524,762.46