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

Project Number **DE-FE-0031776**

Presenter

Institution

U.S. Department of Energy

National Energy Technology Laboratory

Oil & Natural Gas

2020 Integrated Review Webinar

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

DE-FE-0031776

Total DOE Award ~ $8M

Total Continental Resources Award ~ $12M

Research Team: Awarding Institution Oklahoma State University

Lawrence Berkeley Lab, Oklahoma Geological Survey, Pittsburgh University

Principal Investigator: Mileva Radonjic

DOE Program Manager: Joseph Renk

Caney Team

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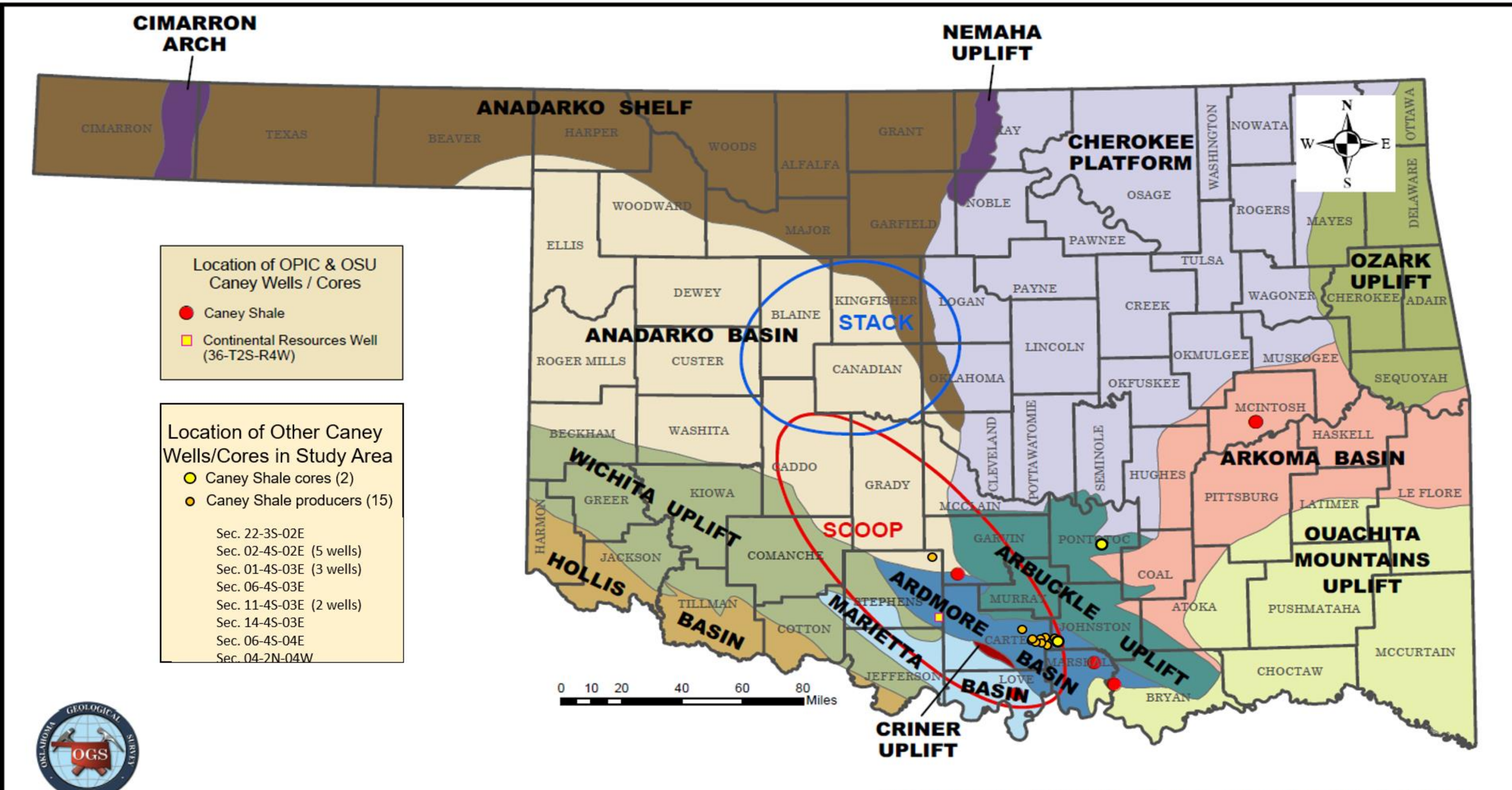
Project Objectives

- The main objective of this project is to establish the Caney Shale Field Laboratory in southern Oklahoma to conduct a comprehensive field characterization and to validate cost effective technologies that will lead to a comprehensive development plan for the Caney Shale, characterized by high clay content and ductile behavior.
- The first objective is development of an open, collaborative, and integrated program to comprehensively characterize the geophysical, geological, petrophysical, and geochemical properties of Caney Shale and its reservoir fluids. The geomechanical properties of clay-rich ductile shale are required and contribute to the know-how for fracturing such formations.
- The second objective is to improve our understanding of hydraulic fracture propagation, fracture and proppant embedment, and fluid-rock interaction in the Caney Shale using modeling and lab data.
- The third objective is validating the findings and recommendations from the first phase by drilling. stimulating, and testing a horizontal well. Based on the results from this study, a development plan and best practices manual will be developed for the Caney Shale in southern Oklahoma, and this will facilitate accelerated development of not only this particular play but help develop understanding of ductile shale fracturing and exploration of upcoming unconventional resources.

Caney Field Lab Location



After Seyedolali, 2019

Geologic Provinces Modified from Northcutt and Campbell, 1995; Cardott, 2013

Caney Core Workshop, February 2020

Caney shale core workshop participants in discussion (left)Allan Katende, Guofan Luo, Mileva Radonjic, Yulun Wang, Andy Rihn, Julie Cains, Rupom Bhattacherjee, Adam Haecker, Haden Kolmer, Maggie Benge, Ian Cox, Cory Hart, Kyle Bradford, Con Wethington, photo of Caney shale core on display (right). February 2020 OKC

Progress and Current Status of Project: Reservoir Characterization

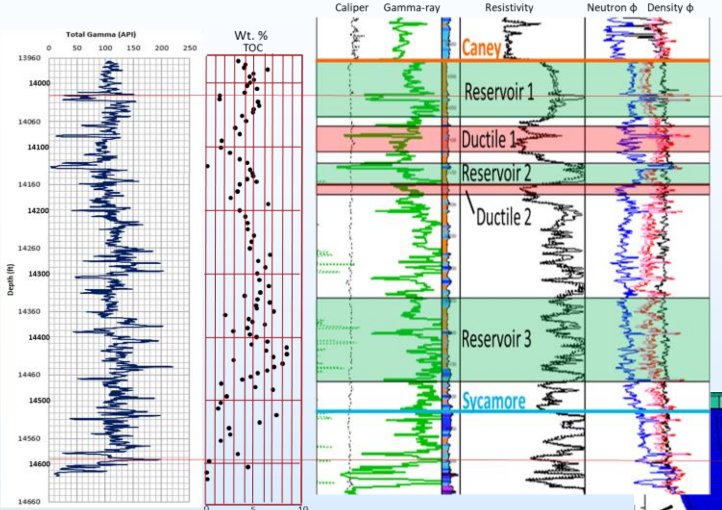
a. Description of the test equipment used/built in the project
b. Significant accomplishments and how they tie to the technology
    a. Established generalized log parameters for reservoir and seal intervals
    b. Structural and tectonic framework characterized in terms of bounding structures
    c. Preliminary burial and thermal history developed for Tomaney well and Ardmore Basin
    d. Detailed core description and high-resolution photography (Tomaney) and pore systems architecture (Davy Jones)
    e. Regional and local structure and thickness maps, % TOC and thermal maturity maps and BSE image analysis for total optical porosity and pore orientation
c. Performance levels achieved so far when compared to project goals and how the performance relates to the economic and technical advantages
    a. Core acquired, described and photographed; facies types defined from core
    b. Preliminary set of thin sections analyzed and Tight Rock Analysis (TRA) acquired
    c. On schedule with project goals and data delivery in 2021

Reservoir Characterization

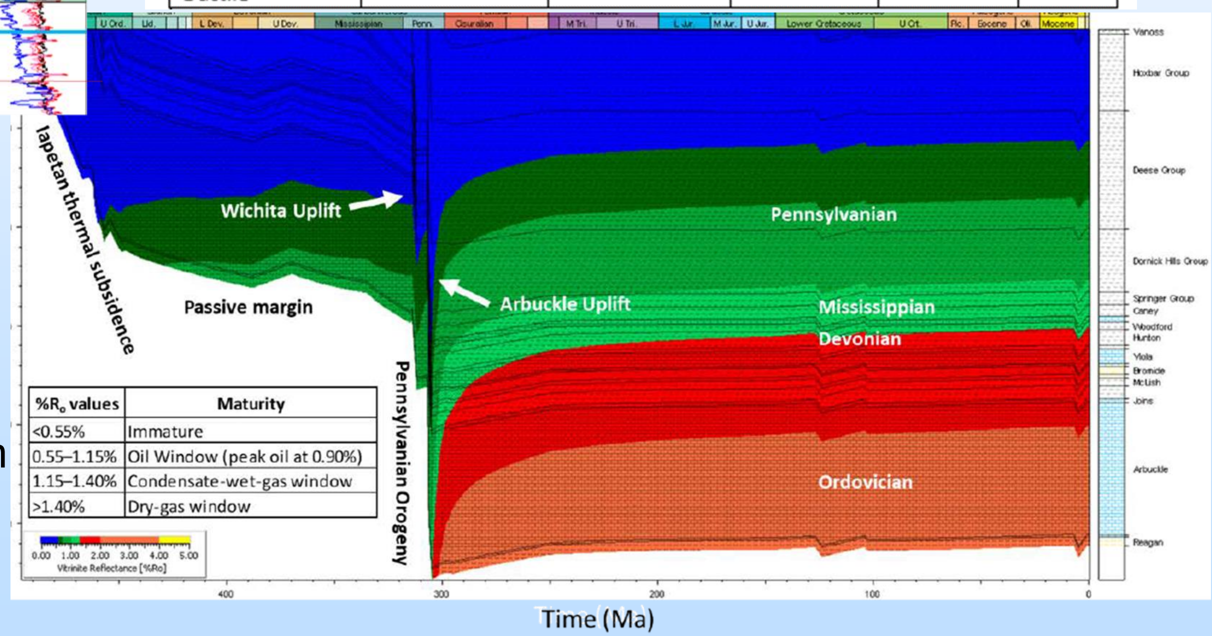
1. Technology we are supporting and novelty of it
    1. New structural and tectonic framework for the Ardmore Basin and depositional architecture for the Caney – reinterpretation using modern geologic concepts
    2. Geologic characterization of the Caney is the first using technology including Tight Rock Analysis, CT visualization of fractures and sedimentary features, rebound hardness, mineral and pore mapping using BSE and 3-D pore architecture using SEM
2. Major conclusions
    1. Mixed carbonate-siliciclastic facies are similar to those observed in STACK rocks, showing compartmentalized distribution at whole core scale
    2. Depositional processes include turbidity currents and debris flows
    3. Tomaney is in oil window and in area of thicker Caney section
3. Key focus during BP2
    1. Sample 2/3 portion of Tomaney core and conduct suite of analyses
    2. Develop integrated geologic reservoir model based on depositional facies, mineralogy, pore systems architecture (type, size, distribution) and relationship to sonic velocity and permeability, natural fracture type and distribution, OM content, thermal maturity and petrophysics to provide predictive framework to facilitate development

Reservoir Characterization

1. Established generalized log parameters for reservoir and seal intervals
2. Ductile Caney lacks neutron-density crossover evident in Woodford Shale



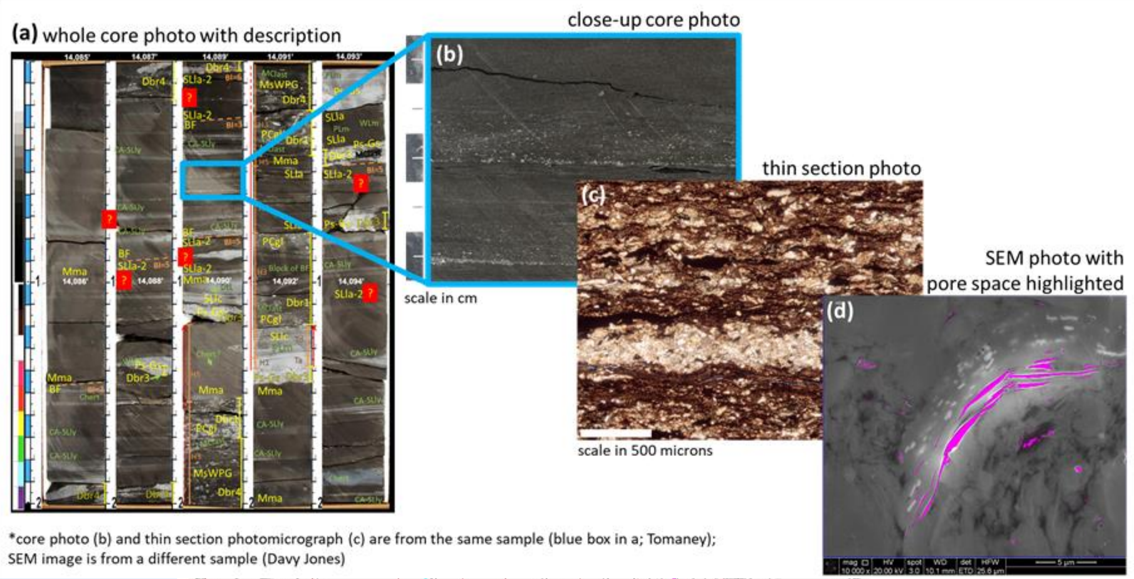
	Averages				
Zone	Gamma-ray (API)	Resistivity (ohm)	Neutron (pu)	Density (pu)	PE (b/e)
Caney Reservoir 1	116	188	0.28	0.11	3.0
Caney Ductile 1	102	33	0.23	0.05	3.6
Caney Reservoir 2	100	927	0.15	0.08	3.3
Caney Ductile 2	112	32	0.27	0.05	3.5
Caney Reservoir 3	134	637	0.25	0.10	3.7
Woodford Reservoir	290	500	0.18	0.21	3.4
Woodford Ductile	162	30	0.20	0.09	4.1



New structural and tectonic framework for the Ardmore Basin and depositional architecture for the Caney – reinterpretation using modern geologic concepts

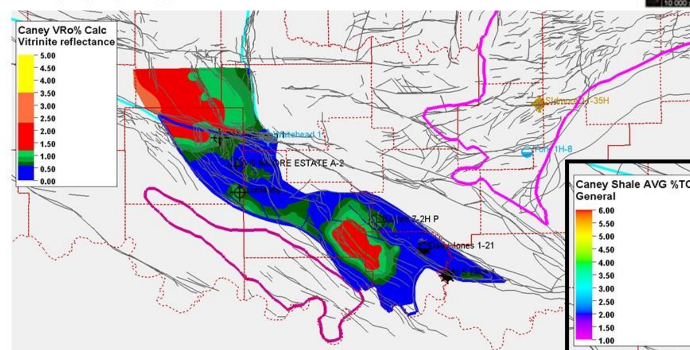
Tomaney is in oil window and in area of thicker Caney section

Reservoir Characterization



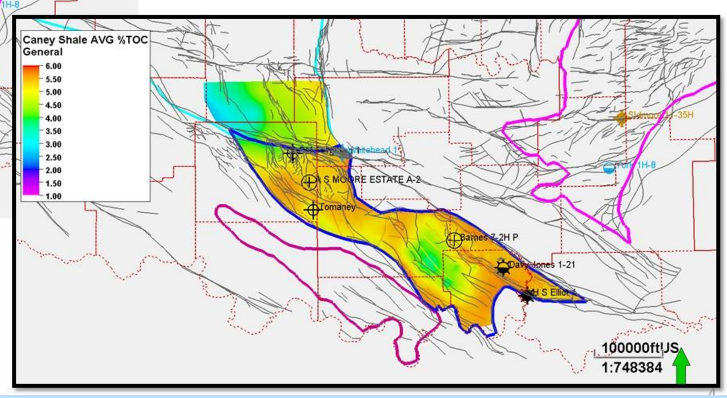
*core photo (b) and thin section photomicrograph (c) are from the same sample (blue box in a; Tomaney);
SEM image is from a different sample (Davy Jones)

1. Detailed core description and high-resolution photography (Tomaney) and pore systems architecture (Davy Jones)
2. Mixed carbonate-siliciclastic facies are similar to those observed in STACK rocks and depositional processes include turbidity currents and debris flows.



Thermal maturity of the Caney Shale in the Ardmore and parts of the Anadarko Basin color coded for oil/gas generation. Green is optimal for oil generation while VRo% above the green colors represent the gas window. The blues show the immature areas.

Estimated %TOC for the Ardmore and parts of the Anadarko Basin.



Novelty: Geomechanical Log and Drilling Optimization Using Drilling Data

by Geir Hareland

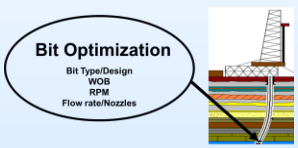
- **Application the D-Series Data Analytics Platform**
  - Applying surface drilling operational parameters, rig specification, lithology, pore pressure, mud properties and drill bit information with core data testing to generate a geomechanical log for stimulation design and for input to drilling simulation optimization.
  - The D-WOB software is used to calculate the wellbore friction coefficient and downhole weight on bit. From the D-ROCK software using core testing data and D-WOB output files, the rock UCS is and the Stimulation Index (STIX) which accounts for porosity, permeability, UCS, and the brittleness index is calculated versus depth in the reservoir.

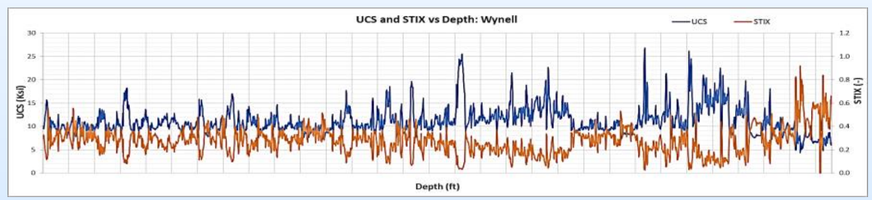
- **Drilling Optimizer Software**
  - From the D-WOB software output and drilling parameters generate the drilling strength log using inverted ROP models
  - The strength log from the Optimizer will be correlated to the Caney well survey to be drilled in Phase II and drilling process optimized
  - Current establishment of the drilling economics and drilling performance for the two existing Caney wells are underway.

Geomechanical Log and Drilling Optimization from Drilling Data

by Geir Hareland

- **Application the Novel D-Series Data Analytics Platform**
  - Data has been collected and quality controlled for the Wynell and Garrett wells in the Caney formation with preliminary determination of the UCS and STIX using core data correlations from the upper Eagle Ford formation.
- **Drilling Optimizer Software**
  - From the D-WOB down hole weight output and drilling parameters has been used to generate the drilling strength log using inverted ROP models





- **BP2 Plans - Completion – Geomechanical Log**
  - Incorporate the geomechanical logs with Caney shale core data to obtain complete geomechanical property correlations for enhanced stimulation selection in the completions of the new well in Phase II
- **BP2 Drilling Simulation**
  - Using the Pason Optimizer, generate the drilling strength logs for Wynell and Garrett wells will be correlated to the Caney well survey to be drilled in Phase II and drilling process optimized
  - Current establishment of the drilling economics and drilling performance for the two existing Caney wells are underway. Drilling economics optimization baseline will be established using Optimizer

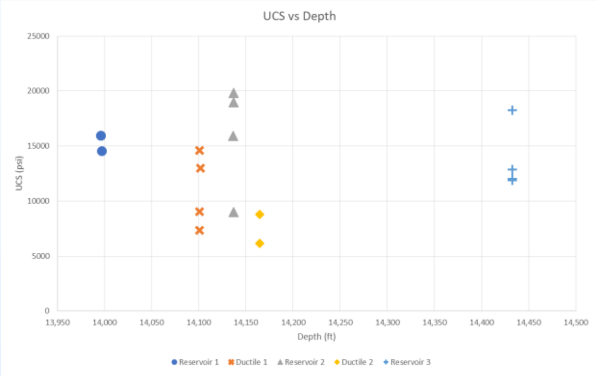
10/30/2020

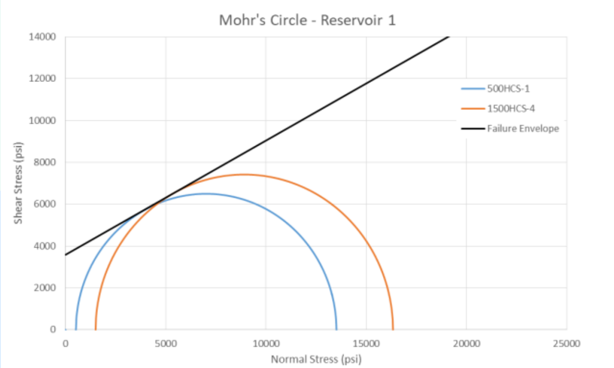
Mechanical Characterization Progress

- Drained triaxial compression tests at 90°C and 500, 1,500, 3,000 psi confinement
  Estimated in-situ formation stress: 3,000 psi
- Reservoir 1 failure envelope:
  Friction Angle = 29°, Cohesion = 3,600 psi (25 MPa)
- Unconfined compressive strength for all zones

Zone (depth in ft)	Average Compressive Strength (psi)
Reservoir 1 (13,996)	15,487
Ductile 1 (14,101)	10,991
Reservoir 2 (14,137)	15,932
Ductile 2 (14.165)	7,463
Reservoir 3 (14,433)	13,742

Sample (depth in ft)	Confining Pressure (psi)	Maximum Stress (psi/MPa)
R1-V-500HCS-1 (13,390.2)	500	13,490 / 93.01
R1-V-1500HCS-4 (13,395.2)	1,500	16,331 / 112.61
D1-V-1500HCS-3 (14,098.76)	1,500	15,718 / 108.40

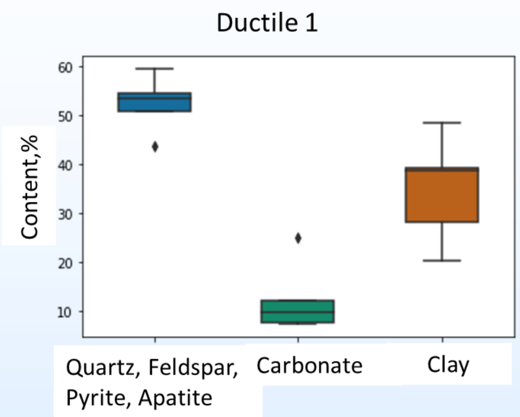


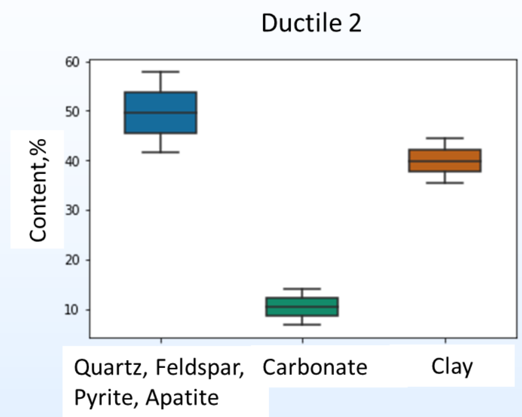


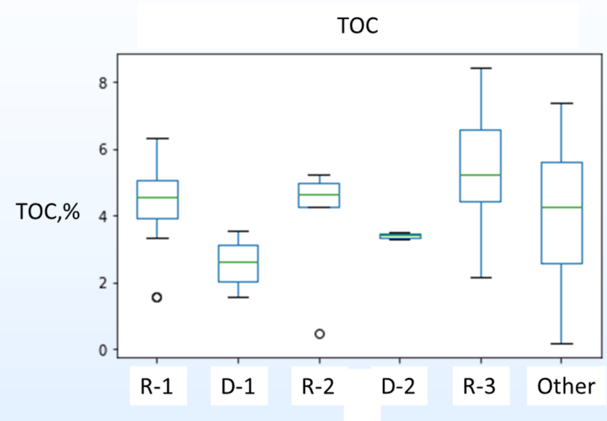
Mechanical Characterization Progress Summary

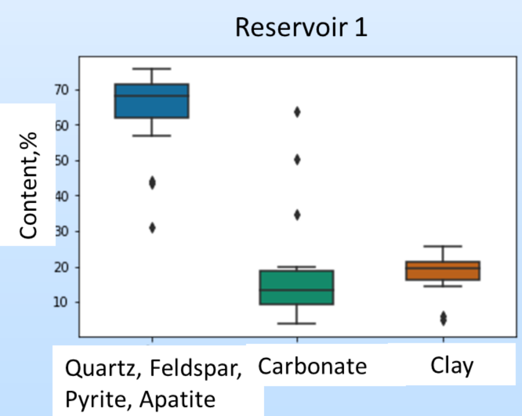
- *Technology Supported and Novelty*
  - Triaxial testing including both stress and temperature impacts
  - Obtaining elastic, strength, and creep properties
  - Simulating impact of materials properties on in-situ stress
- *Conclusion from BP1*
  - Identified and obtained samples from 3 reservoir and 2 ductile zones; Commenced triaxial strength tests
  - UCS is lower in ductile compared with reservoir zones
  - Geomechanical model indicates creep properties could have important impact on stress profile
- *Focus of BP2*
  - Triaxial strength and creep characterization
  - Other strength tests including Unconfined Compressive Strength and Tensile Strength
  - Incorporating elastic, strength, and creep properties into geomechanical stress model

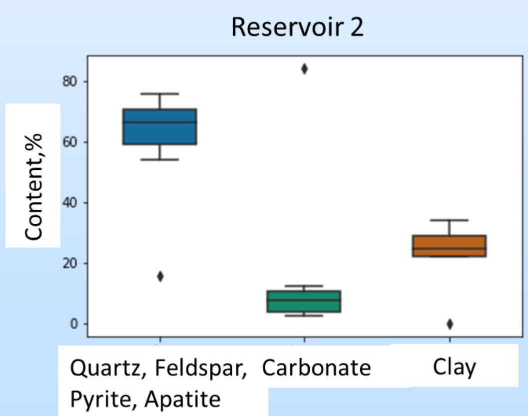
Rock-Fluid Characterization
Mineralogical composition

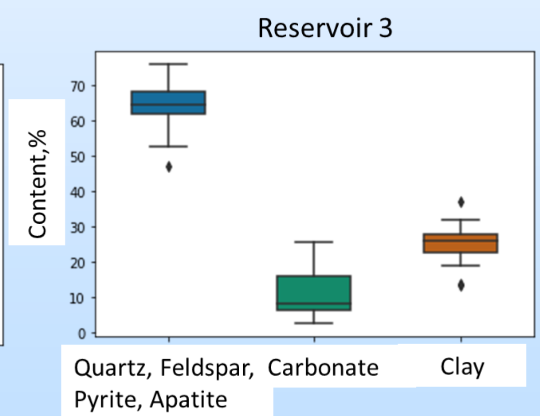












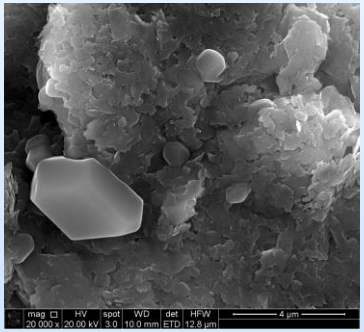
Project Goals & Accomplishments in BP1

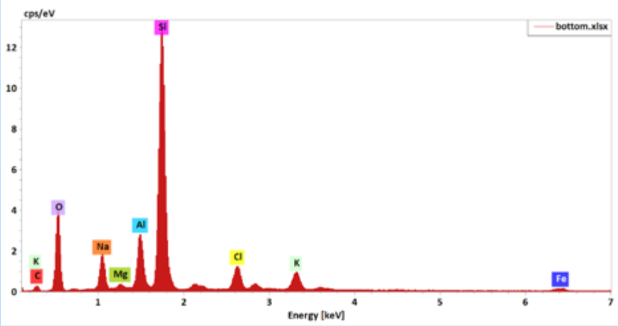
Goals

- Functionalizing geomaterial micromodels with clay minerals representative to Caney Shale
- Investigating following pore-scale behaviors of clay upon exposure to injection fluids*: Swelling; Fines migration; Wettability alteration; Porosity & permeability impairment; Formation damage*
- Measuring interfacial tension (IFT), and contact angle (CA) to provide data for two phase flow modelling

Accomplishments in BP1

- Procedure to functionalize micromodel with clay minerals has been developed to represent physicochemical aspects of Caney Shale
- Glass capillary tubes have been coated with illite clay to validate and make necessary adjustment to procedure
- SEM & EDS analysis on coated capillary tubes are currently being carried out to verify coating density, coverage, and elemental analysis
- A standard procedure to measure IFT, and advancing and receding contact angle is developed





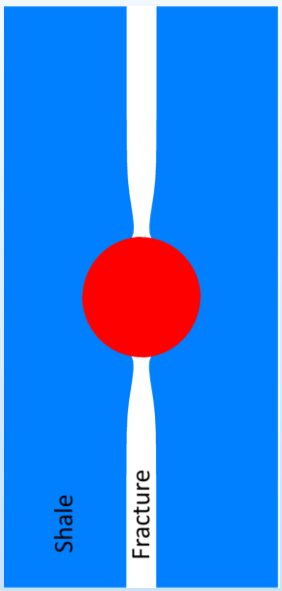
Tasks for BP2

- Clay coating procedure will be finalized with necessary adjustments
- Straight channel micromodels will be functionalized with illite-smectite (70/30) mixture, dominant clay minerals of Caney formation
- Pore-scale behavior of clay and their impact on formation damage and wettability alteration upon exposure to different drilling, completion, and production fluids will be investigated
- Results will be useful in designing injection fluids that will enhance hydrocarbon production with minimum damage to formation
- Contact angle and IFT data of Caney shale rock and fluid samples will be measured

Coupled Multiphase Flow and Geomechanics Modeling

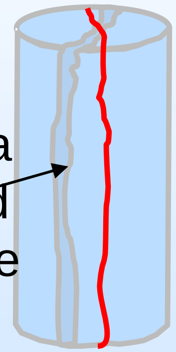
Jonny Rutqvist & Christine Doughty Lawrence Berkeley National Laboratory

Proppant Scale



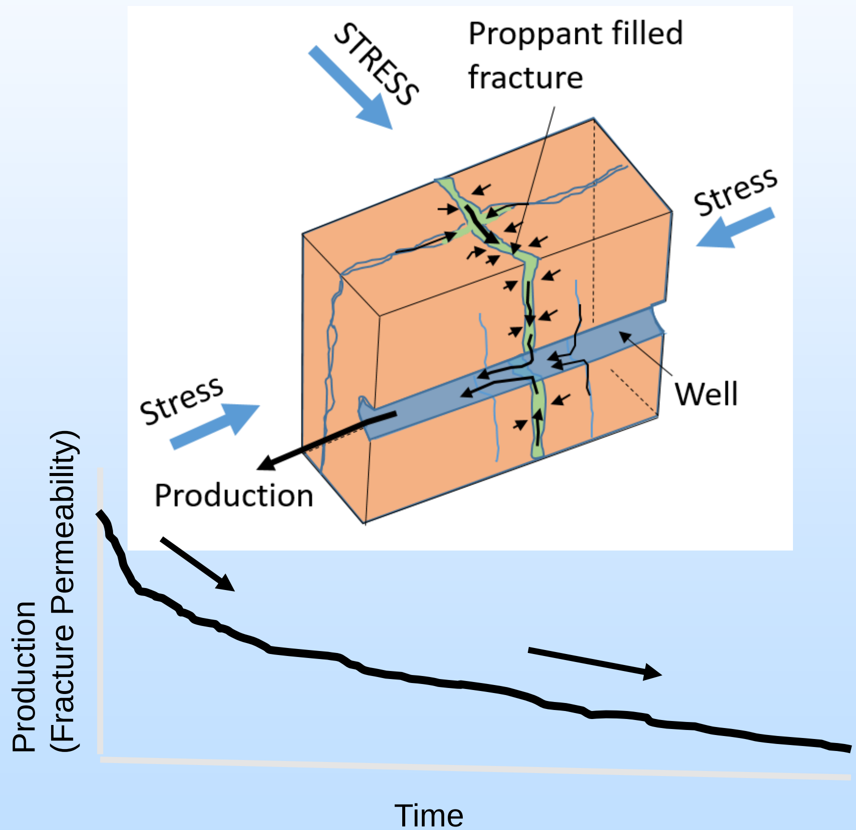
Core Scale

Proppant filled fracture



Time-dependent Fracture closure model

Well to Reservoir Scale

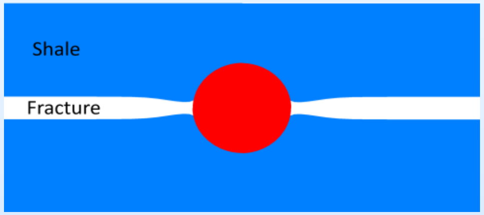


BP1 Accomplishments: Proppant Scale Modeling

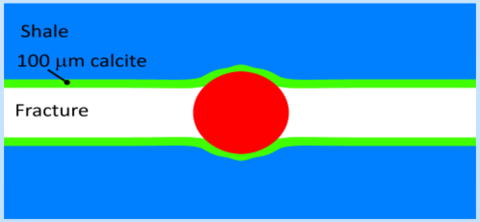
- Until site specific (Caney) laboratory data is available, modeling of shales from other DOE applied and fundamental shale projects at LBNL:

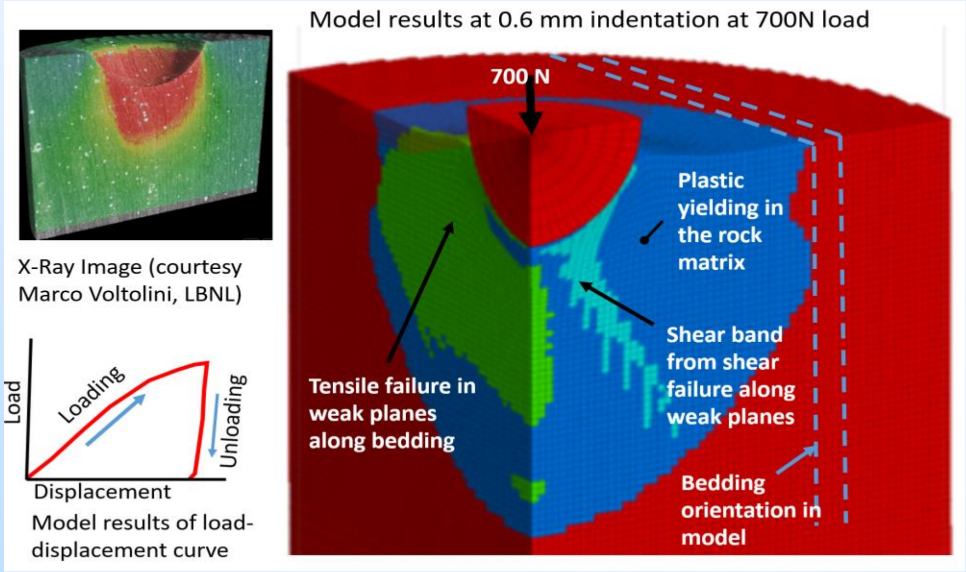
(1) Micromechanics from high-resolution synchrotron X-ray (Marco Voltolini, LBNL on Green River Shale)

(2) Controlling Sustainability of Hydraulic Fracture Permeability in Ductile Shales (PI Seiji Nakagawa, Modeling by Jonny Rutqvist)



Impact of calcite precipitate?





Proppant embedment modeling demonstrated for the Caney project….

Plans for BP2: Multiphase flow Modeling and Geomechanics

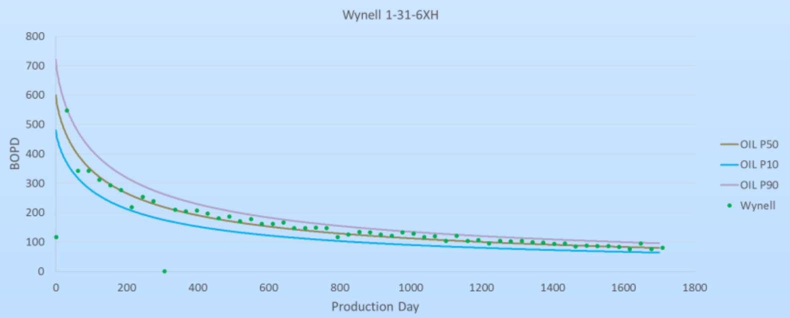
- Use collected information on the Fayetteville Shale, and the porosity/permeability data from the Tomaney to develop generic multiphase fluid flow models until more site-specific data are available
- Lab experiments conducted on the Fayetteville and other tight shales will be used to guide model design and validate model results
- Investigate different creep constitutive models for proppant embedment and closure of proppant filled fractures considering literature and new laboratory data on various US shales
- Examine different kinds of fracture networks observed in and hypothesized for Fayetteville and Caney Shales and their impact on gas production (builds on previous study, see next slide)
- Once more site-specific Caney data is available, model Caney laboratory experiments

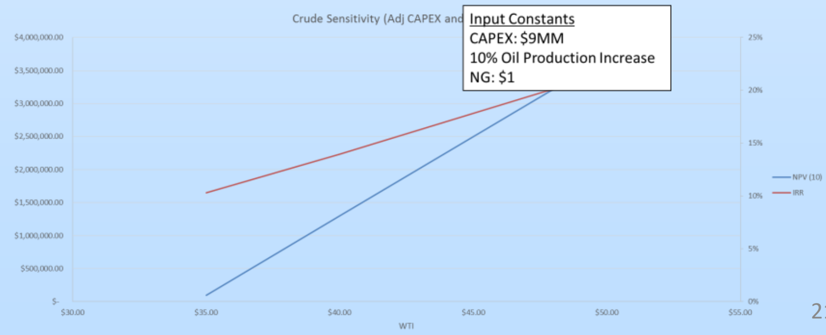
Task 8 Novelty: Apply novel drilling and stimulations simulation software to establish the Caney field optimal economic baseline development plan including drilling, completion and production

by Geir Hareland

Accomplishments

- **Completion Optimization**
  - The Wynell well was placed in the Caney "A" formation of the simulated reservoir in the stress grid profile of the GOHFER software and initial simulations have been performed
- **Flow Simulation and Production analysis of the Wynell and Garrett wells**
  - A preliminary type curve fitting using a P50 of 600 bbl/d, D exponent of 1.3, a B factor of 0.0052, and GOR of 3600 scf/bbl is shown below. Type curve matches well with production data for the Wynell well and Caney formation
- **Economics**
  - An economic sensitivity analysis tool has been developed for the Caney. Preliminary analysis shows that with a CAPEX of $9MM and 10% oil production increase from the Wynell the WTI breakeven is about $34.5.





Task 8: Caney Economical Field Baseline Plan for BP2

by Geir Hareland

- **Post Analysis of Flow Simulation and Production of Existing Well**
  - Finalize the reservoir set up in GOHFER using log suite from Tomaney well
  - Create a dip in the reservoir that follows the well path
  - Ensure the pressure match follows the field data. Fine tune reservoir inputs to match field production and run parametric studies.
  - Create economic calculator that adjust CAPEX based on completion size
- **Completion Optimization and Cost Analysis**
  - Using the horizontal foot-by-foot geomechanical log from Task 5, input the log into the GOHFER software to simulate the fracturing process
  - Optimize the hydraulic design of the planned well in Phase II
- **Drilling Optimization and Cost Analysis**
  - Establish drilling performance and economics of both wells from Task 5
  - Optimize the drilling performance of well to be drilled in Phase II, selecting optimal drill bits and operating parameters for lowest $/ft

*Optimization and Cost Analysis in both the drilling and completions, we should see the CAPEX decrease and production increase reducing the breakeven WTI price

Summary Slide

a. Tomaney well drilled
b. Core retrieved, CT obtained, and various rock core samples identified and prepared/ under testing
c. Several rock types identified, porosity, permeability, TOC and XRD completed.
d. BP2 will be used to compete rock characterization and test various modeling capabilities fit for this project.
e. Full recommendation for Phase 2 will be provided, and drilling of horizontal well in Caney formation.

Appendix

– These slides will not be discussed during the presentation, but are mandatory.

Caney Team

DOE NETL
PM: Joe Renk, Ph.D.

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Gantt Chart

Tasks Subtasks	Y1 Q1	Y1 Q2	Y1 Q3	Y1 Q4	Y2 Q1	Y2 Q2	Y2 Q3	Y2 Q4	Milestone Deliverables Completed
Task 1.0 Project Management Plan PMP	√							**Phase 1**	PMP 27-11-19
Kickoff Meeting/PPT	√							**Report**	PPT 28-10-19
Task 2.0 Work Force Readiness Plan WFP									Ongoing
Task 3.0 Data Management Plan DMP	√								DMP 30-12-19
Task 4.0 Geological Characterization									Ongoing
Core Description & Sampling									Not started
Core & Cuttings - Geophysical log calibration									Not started
Pore System Analysis									Not started
Core and Well log Analysis									Not started
Task 5.0 Geomechanics									Ongoing
Drilling Data Analysis									Ongoing
Core-based rock mechanics characterization									Not started
Geomechanical stress model									Not started
Task 6.0 Geochemistry & Microstructure of Rock-Fluid Interactions									Ongoing
Hydraulic fracturing rock/fluid design, charact.									Ongoing
Core flow-through experiments									Ongoing
Geomaterial Microfluidics									Ongoing
Solid-Oil Water/Gas Interfacial Properties									Not started
Task 7.0 Multiphase Fluid Flow Modeling									Not started
Modeling of tasks 5&6									Not started
Modeling of Fracturing & Production									Not started
Selection of Final Model									Not started
Task 8.0 Caney Economical Field Baseline									Ongoing
Simulation and production of existing wells									Ongoing
Completion optimization and cost analysis									Not started
Drilling optimization and cost analysis									Not started
Task 9.0 Well Candidate Selection									Not started
Decision will be based on Data Integration from Tasks 4-8									Not started