Tuscaloosa Marine Shale Laboratory (TMSL)

Project Number (DE-FE0031575)

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U.S. Department of Energy

National Energy Technology Laboratory

2021 Carbon Management and Oil and Gas Research Project Review Meeting

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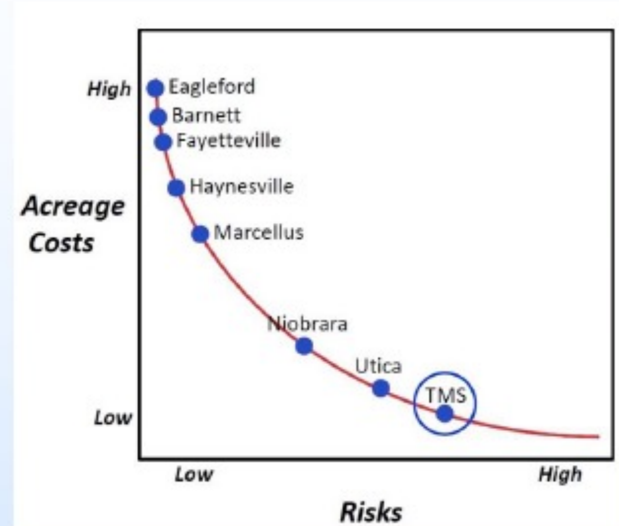
Presentation Outline

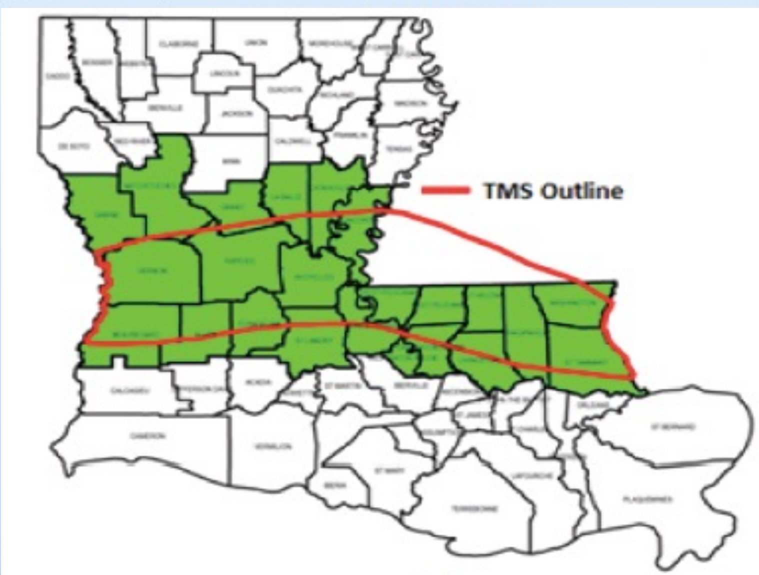
- Tuscaloosa Marine Shale Laboratory (TMSL) Team
- Objectives
- Accomplishments in BP3
    - Task 3: Improving TMS Drilling Efficiency and Wellbore Stability
    - Task 4: Improving TMS Formation Evaluation
    - Task 5: Digital Image Correlation
    - Task 6: Foam Generation with Nanoparticles
    - Task 7: Shale Hydrocarbon Phase Solubility
    - Task 8: Socioeconomics of TMS Development
- Organization Chatter
- Bibliography

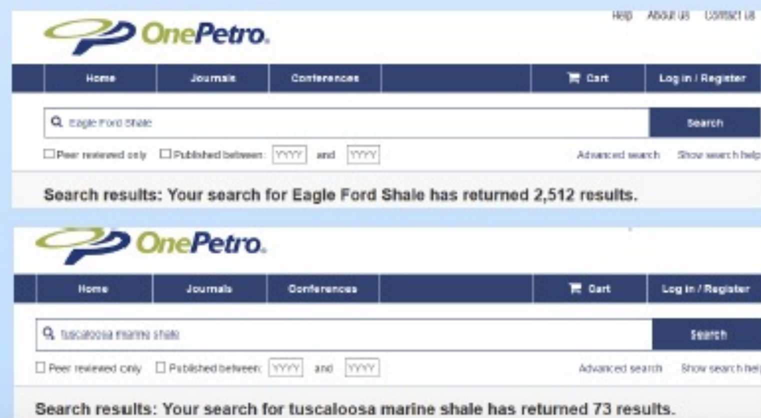
TMSL Consortium

TMS Background

- **High potential** unconventional play: "An Unproven Unconventional Seven Billion Barrel Oil? Resource - the Tuscaloosa Marine Shale (1997)"?
- **Limited public shared knowledge.**
- **Industry struggle** to develop this formation due to **technical and economic** issues.
- **Good timing:** availability of data and resources.







Major Goals of TMSL Project

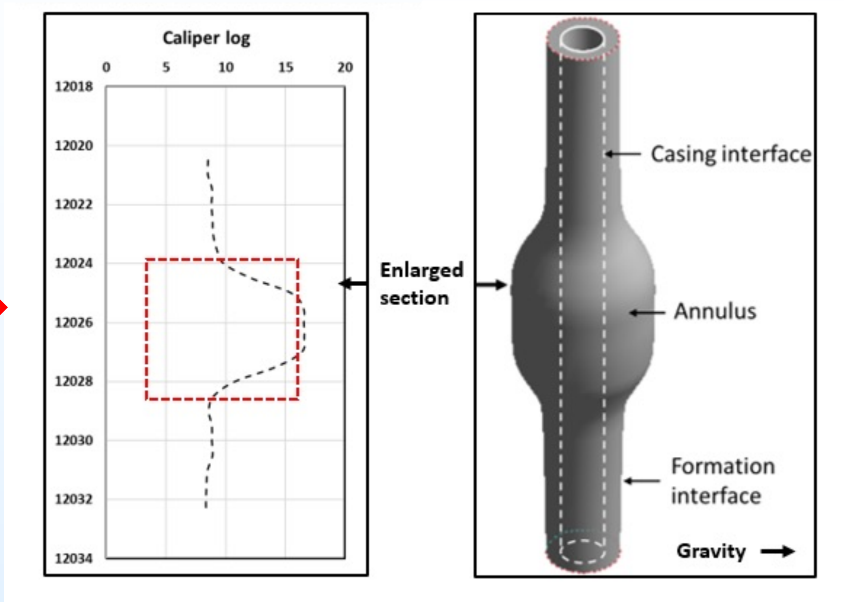
The overall goal of TMSL project is to form a consortium of science and industry partners to address critical gaps in the understanding of TMS with the following objectives:

- To improve drilling and completion efficiency for TMS wells by better understanding the source of wellbore instability issues and proposing innovative cementing solutions.
- To improve formation evaluation using laboratory techniques for the evaluation of f mineralogical composition, organic content, and produced water chemistry as well as well log and geophysical analysis.
- To examine the role of geologic discontinuities on fracture growth and deformation behavior using digital image correlation technique.
- To test the application of stable CO_2 foam and super-hydrophobic proppants for improving reservoir stimulation.
- To test the nature of water/hydrocarbon/CO_2 flow in clay and organic-rich formation and the role of kerogen and water/fluid interaction on oil recovery.
- To develop better socio-economic environment for TMS by community engagement.

Task 3.2 Numerical Models of Mud Displacement by Cement in Irregular Enlarged Wellbores

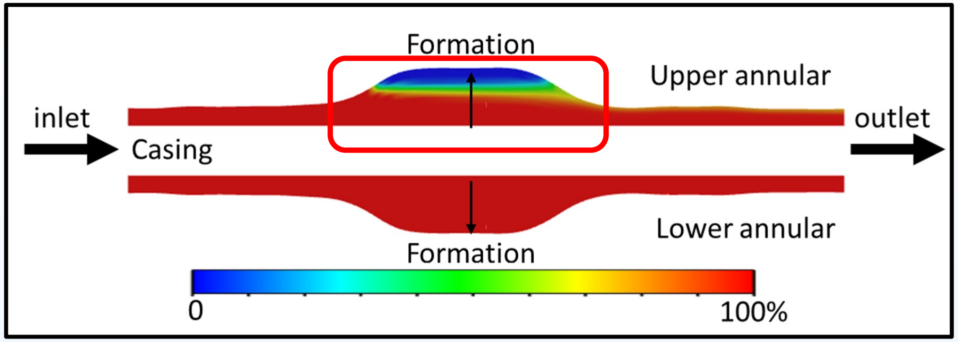
Properties	*WBM*	*G cement*	*Geopolymer*
Density (kg/m^3)	1234.25	2160.00	1970.00
Yield shear stress (Pa)	0.85	0.15	0.67
Consistency coefficient ($Pa \cdot s^n$)	1.50	3.21	0.36
Liquidity index	7.50	0.59	0.87

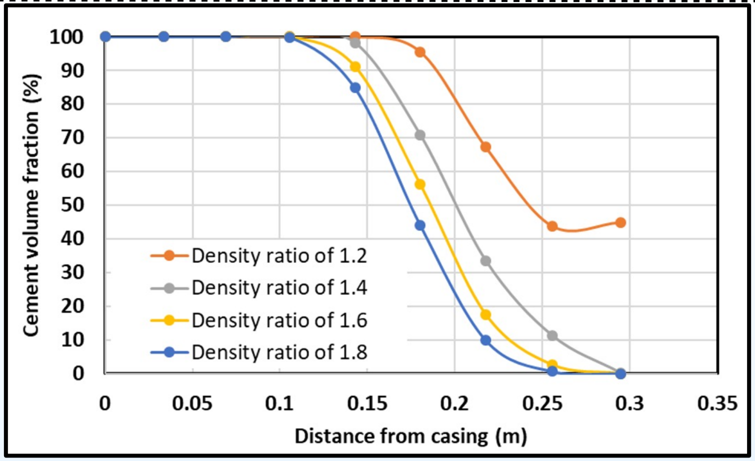
Eid et al., 2021



- Wellbore shape is conducted based on TMS well logging data.
- Rheology of mud and cement slurries are described using Herschel-Bulkley model (Foroushan et al., 2020).
- Simulation time is set as 12000 sec (or 13.586 bbl)

Task 3.2 Numerical Models of Mud Displacement by Cement in Irregular Enlarged Wellbores





- No voids observed as cement/mud density ratio equals to 1.2.
- Density ratio significantly affects displacement efficiency due to buoyancy effects.
- As density ratio increases from 1.2 to 1.8, incomplete mud removals happened at 0.11, 0.12, 0.14, and 0.17m to the casing surface.

Task 4.1 Well Log

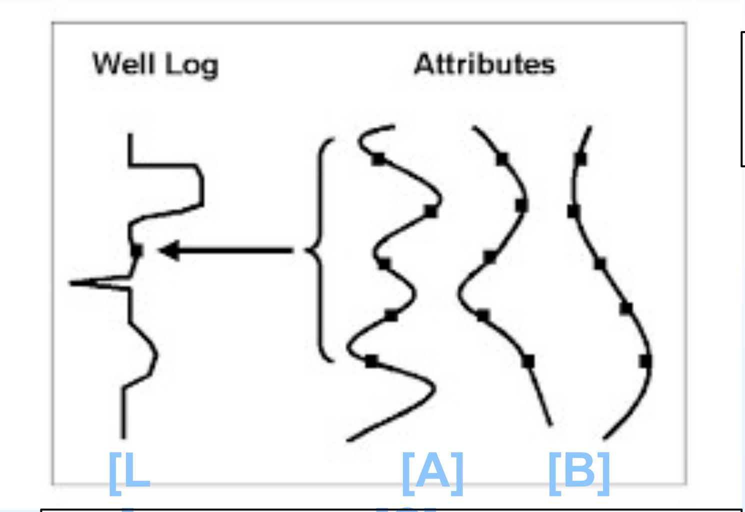
- Denkmann 33-28 H2, Thomas 38H-1, Soterra 6H-1, and Eads_Poitevent_et_al_1 wells were added to the analysis
- Borehole images allowed the identification of several zones affected by natural fractures with possible frac barriers located in between
- These are nearly-vertical or vertical natural fractures with dip magnitudes between 80 and 90 deg.
- There is a good agreement between the borehole image and shear-wave splitting analyses. Both show that fractures occur along the E-W direction in the TMS
- Fast shear azimuth plotting indicates that the S_{hmax} is oriented at 100^o E-W

Task 4.1 Well Log

- The S_{hmax} orientation is consistent throughout the TMS
- Most wells fall on the same paleostress line, but Lane 64-1 and Eads Poitevent_et_al_1 wells show a 10^{o} counterclockwise rotation from S to N of the stress field
- We recommend orienting lateral wells perpendicular to the direction shown on the map

Task 4.1 Well Log

Multi-attribute Analysis



$$L(t) = w_0 + w_1 * A(t) + w_2 * B(t) + w_3 * C(t) + \ldots$$

$$\begin{bmatrix} L_1 \\ L_2 \\ L_3 \\ L_4 \\ L_5 \\ L_6 \end{bmatrix} = w_0 \begin{bmatrix} 1 \\ 1 \\ 1 \\ 1 \\ 1 \\ 1 \end{bmatrix} + \begin{bmatrix} w_1(0) & 0 & 0 & 0 & 0 & 0 \\ w_1(1) & w_1(0) & 0 & 0 & 0 & 0 \\ w_1(2) & w_1(1) & w_1(0) & 0 & 0 & 0 \\ w_1(3) & w_1(2) & w_1(1) & w_1(0) & 0 & 0 \\ w_1(4) & w_1(3) & w_1(2) & w_1(1) & w_1(0) & 0 \\ 0 & w_1(4) & w_1(3) & w_1(2) & w_1(1) & w_1(0) \end{bmatrix} \begin{bmatrix} A_{11} \\ A_{21} \\ A_{31} \\ A_{41} \\ A_{51} \\ A_{61} \end{bmatrix}$$

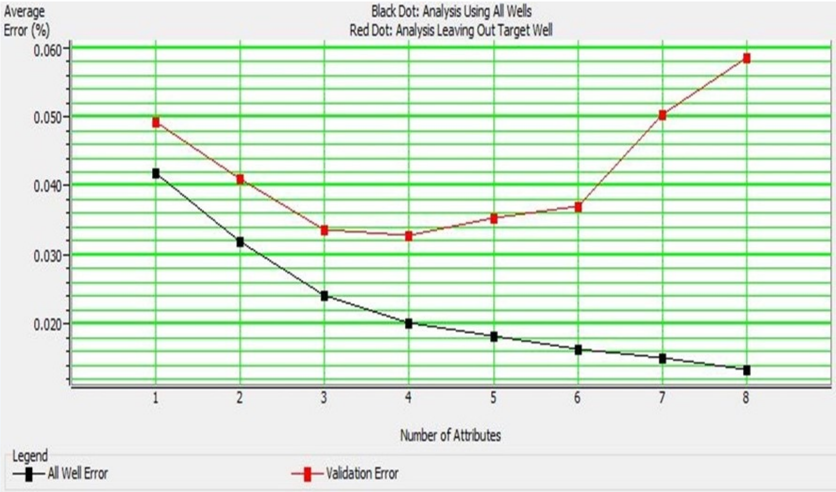
$$+ \begin{bmatrix} w_2(0) & 0 & 0 & 0 & 0 & 0 \\ w_2(1) & w_2(0) & 0 & 0 & 0 & 0 \\ w_2(2) & w_2(1) & w_2(0) & 0 & 0 & 0 \\ w_2(3) & w_2(2) & w_2(1) & w_2(0) & 0 & 0 \\ w_2(4) & w_2(3) & w_2(2) & w_2(1) & w_2(0) & 0 \\ 0 & w_2(4) & w_2(3) & w_2(2) & w_2(1) & w_2(0) \end{bmatrix} \begin{bmatrix} B_{11} \\ B_{21} \\ B_{31} \\ B_{41} \\ B_{51} \\ B_{61} \end{bmatrix}$$

$$+ \begin{bmatrix} w_3(0) & 0 & 0 & 0 & 0 & 0 \\ w_3(1) & w_3(0) & 0 & 0 & 0 & 0 \\ w_3(2) & w_3(1) & w_3(0) & 0 & 0 & 0 \\ w_3(3) & w_3(2) & w_3(1) & w_3(0) & 0 & 0 \\ w_3(4) & w_3(3) & w_3(2) & w_3(1) & w_3(0) & 0 \\ 0 & w_3(4) & w_3(3) & w_3(2) & w_3(1) & w_3(0) \end{bmatrix} \begin{bmatrix} C_{11} \\ C_{21} \\ C_{31} \\ C_{41} \\ C_{51} \\ C_{61} \end{bmatrix}$$

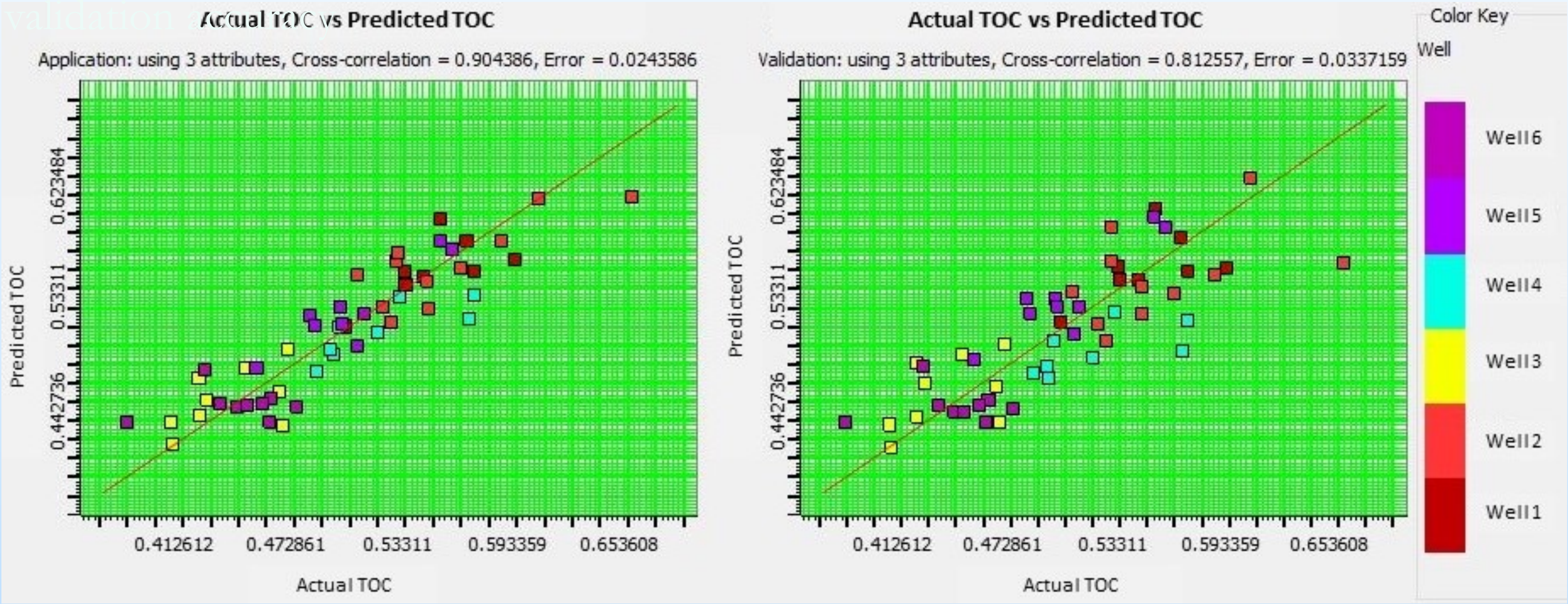
The target log L(t) is predicted from the combination of optimal seismic attributes A, B, C.

The weights w_1, w_2, w_3 are calculated by minimizing mean squared predicted error.

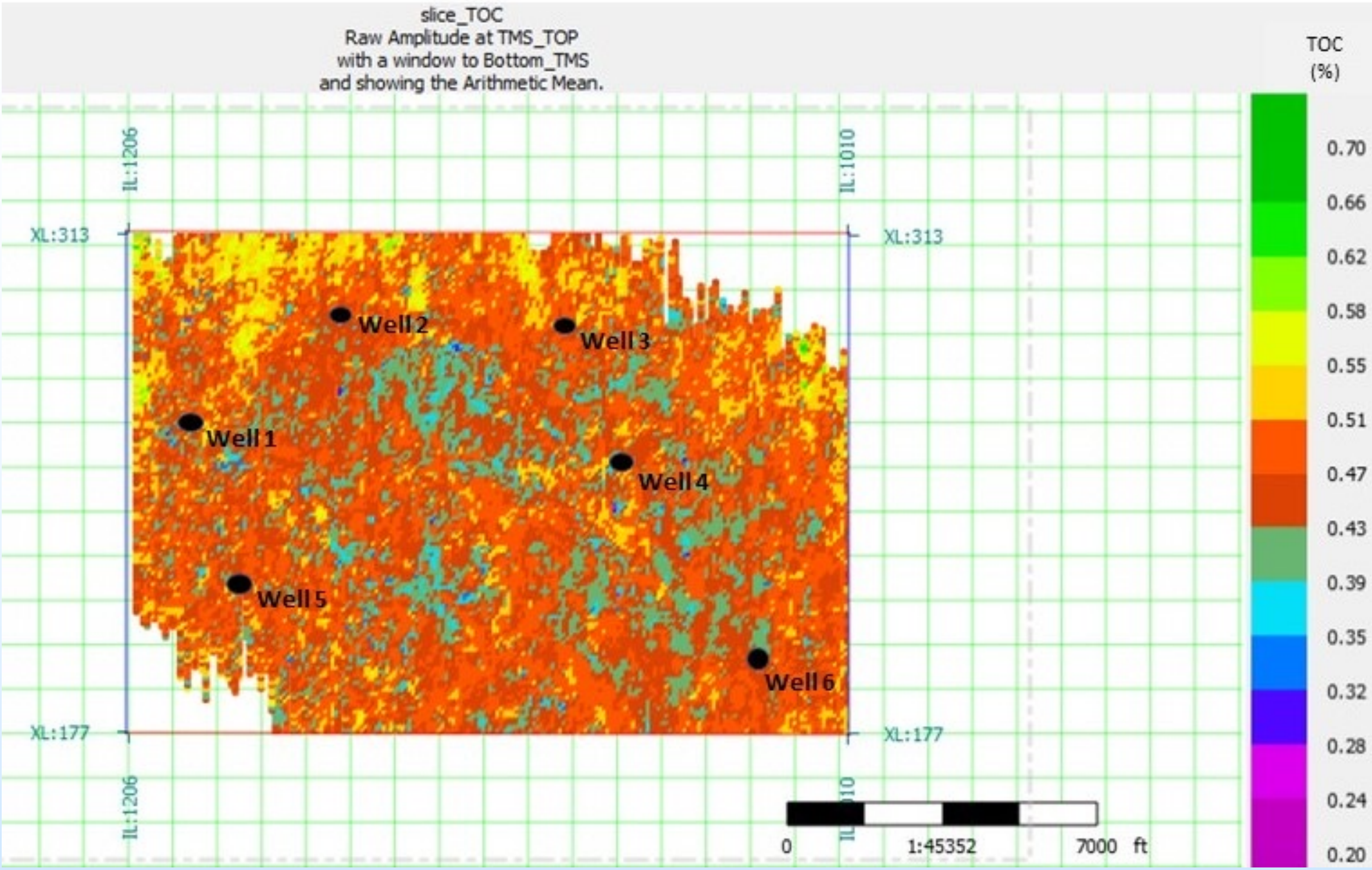
Task 4.1 Well Log



81% validation



Task 4.1 Well Log



TOC Map

Subtask 4.6 Produced Water Chemistry

Completion of Mineralogical and Geochemical Data Collection and Synthesis

- [1]Historical data from 11 wells that were previously published.
- Historical data from two additional wells.[2]
- Analysis of cuttings from horizontal portion of seven additional wells.[2]

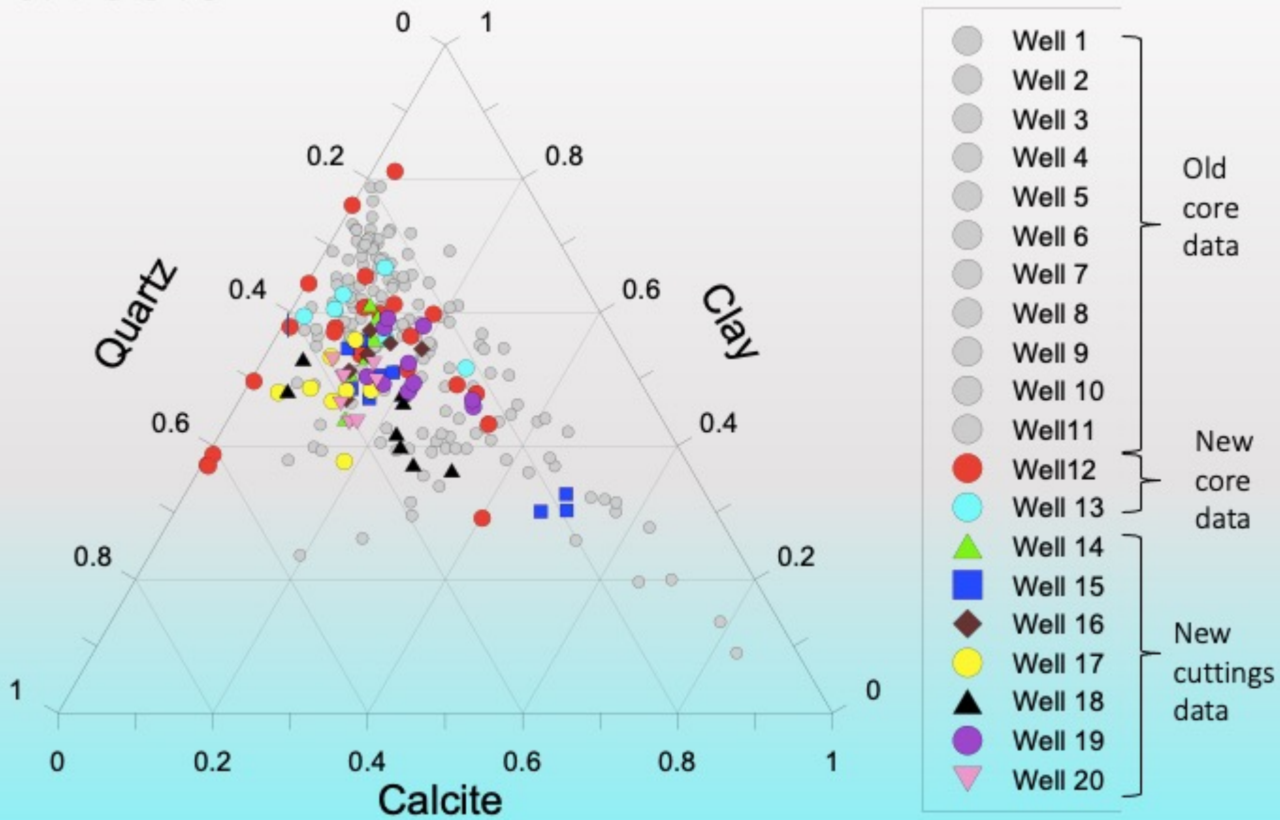
[1]Borrok et al. (2019) Heterogeneity of the mineralogy and organic content of the Tuscaloosa Marine Shale. Marine and Petroleum Geology 109, 717-731.

[2]Beitel, H.R. (2021) Relationships among mineralogy, geochemistry, and oil and gas production in the Tuscaloosa Marine Shale. Unpublished MS-degree thesis, 95 pages.

https://scholarsmine.mst.edu/masters_theses/7975/

Subtask 4.6 Produced Water Chemistry

Data Synthesis

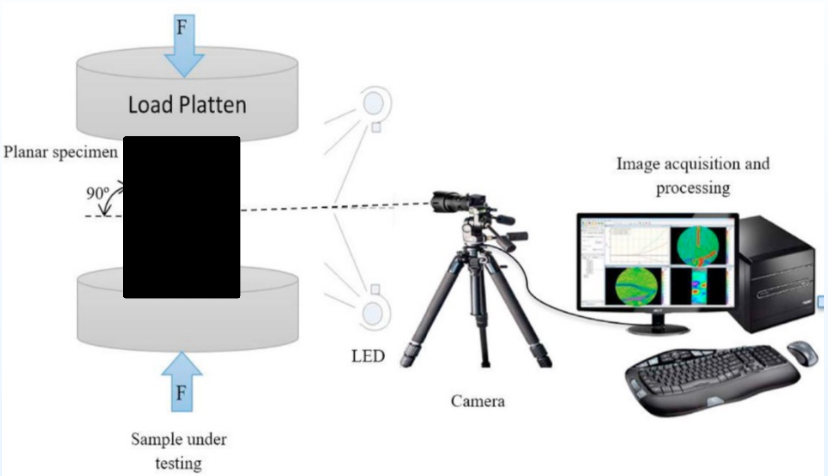


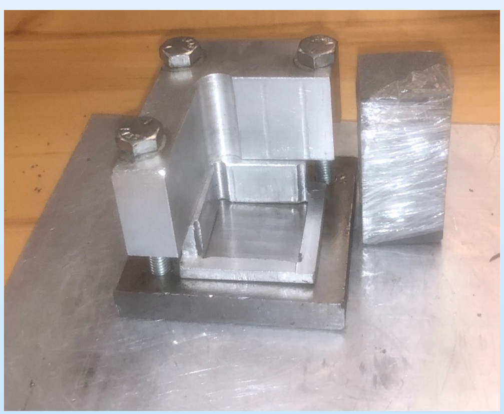
Subtask 4.6 Produced Water Chemistry

Comparison with previous work

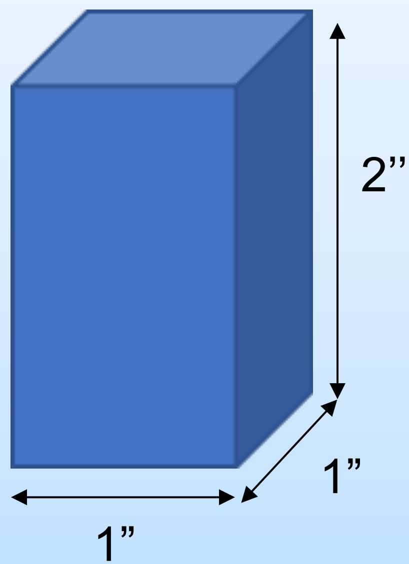
	Source of sampling	Depth range	n samples	Avg. Quartz (wt%)	Avg. Calcite (wt%)	Avg. Total clay (wt%)	Avg. TOC (wt%)
Lu et al. (2015)	Core from Spinks well in Pike County, MS	3337-3361 m (within HRZ)	7- XRD 6- TOC	9.98	13.02	52.96	1.85
		3283-3361 m (total TMS)	14- XRD 13- TOC	12.14	9.14	55.69	1.39
Besov et al. (2017)	Core from 1 well in TMS	N/A	12 FTIR & TOC	7	11	63	1.6
Lowery et al. (2017)	Core from Spinks well in Pike County, MS	3361.3-3319.3 m (within HRZ)	65- TOC	-	-	-	1.78
		3276.6-3361.3 m (total TMS)	135- TOC				1.43
Enomoto et al. (2017)	70 wells in TMS (cuttings and core)	Various	96 (within HRZ) - XRD & TOC	36	4	51	0.97
			116 (TMS outside of HRZ) - XRD & TOC	32	16	44	1.24
Borrok et al. (2019)	11 wells in TMS (core)	Various (all within HRZ)	161- XRD 136- TOC	22.8	17.2	47.6	1.65
Lohr 2020 (data from Enomoto et al. (2017) & Hackley et al. (2020)	37 wells in TMS (cuttings and core)	Various within 3002-4215 m	154 from 37 wells- TOC	-	-	-	1.03 (within HRZ)
							0.85 (total TMS)
This study	21 wells	Basal 20 m	241	25.2	16.8	47.0	1.58

Task 5.4 Creep Test with DIC



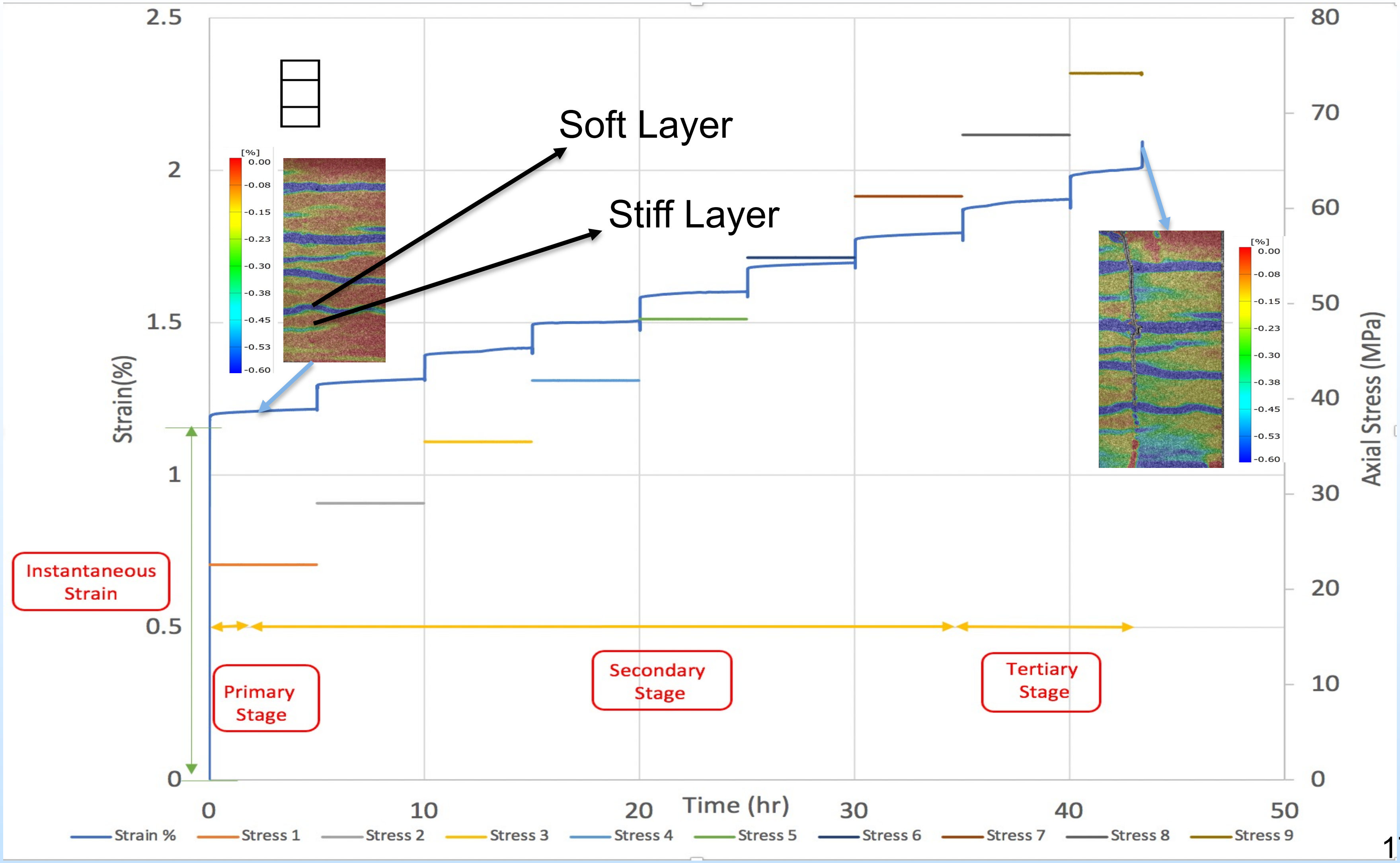


Capping Frame

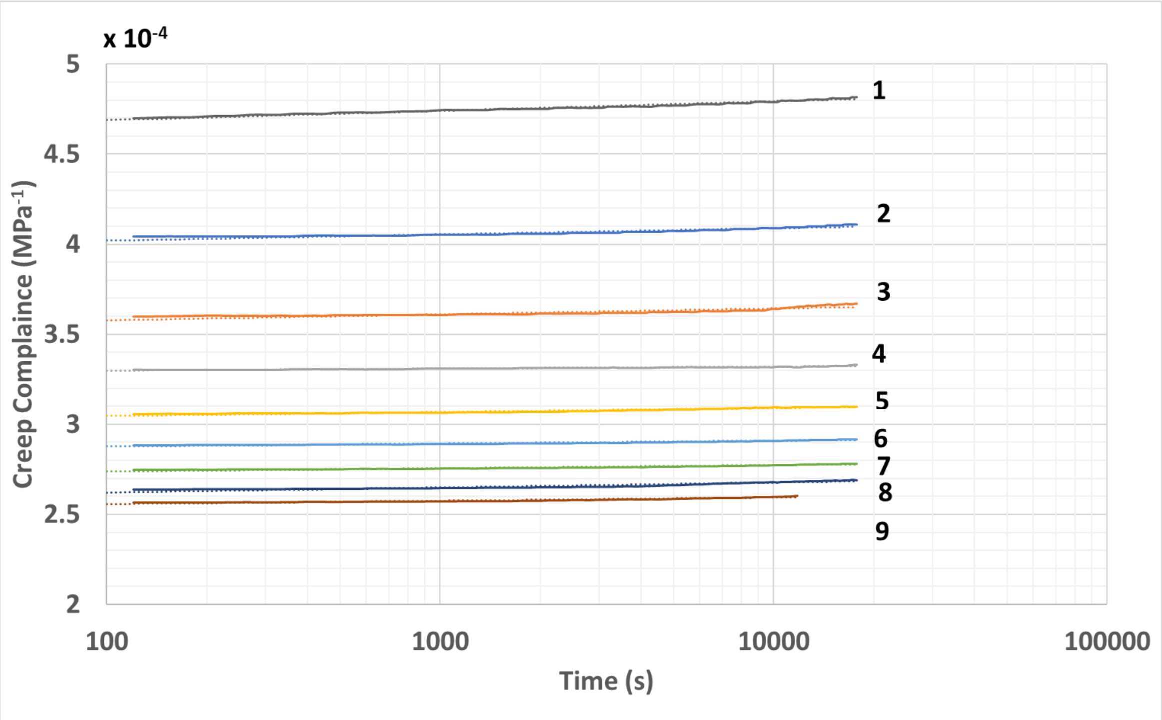


- **Trial Experiments:** single uniaxial compressional compliance creep test with one loading stress on Mancos shale in parallel and perpendicular sample and multistage uniaxial compressional compliance creep test with multiple step loading stress on plastic pipe.
- **Test Conducted:** multistage compressional compliance creep test for the TMS sample
- **Procedure:** Each loading stage was for 5 hours, First stage is with 70% of UCS load, Load increment was 20% of UCS for perpendicular sample and 10% of UCS for parallel sample until failure of the specimen
- **Sample Selection:** samples based on the different mineralogy (high clay content with low carbonate and rich carbonate with low clay content)

Task 5.4 Creep Test with DIC



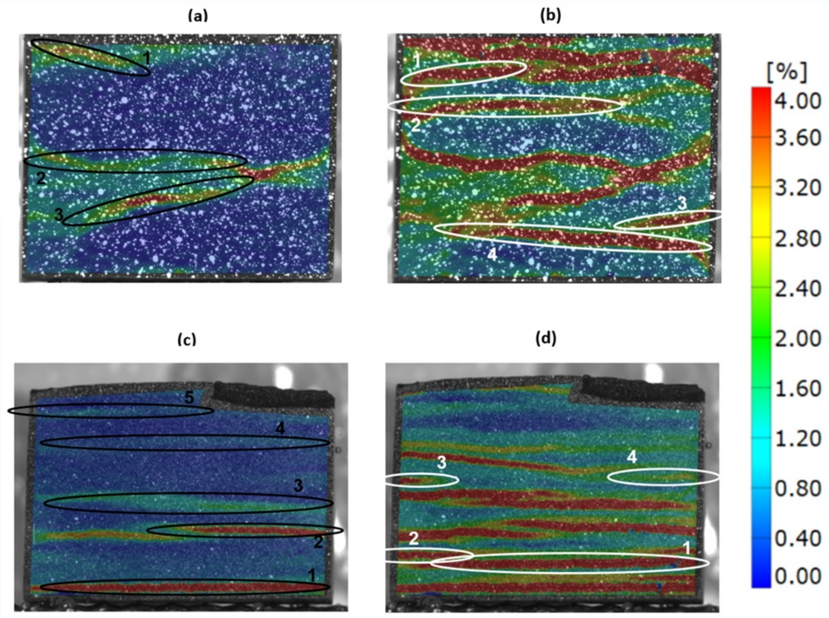
Task 5.4 Creep Test with DIC



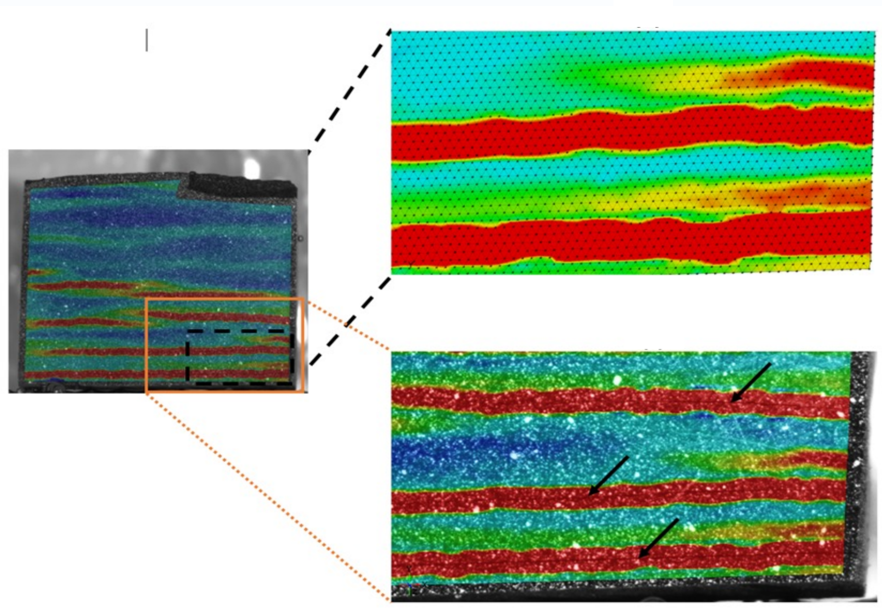
No	Stress (MPa)	B (x 10^{-4})	n
1	22	4.5857	0.0048
2	29	3.9521	0.0037
3	35	3.5134	0.0039
4	41	3.2769	0.0014
5	48	3.0024	0.0031
6	55	2.8448	0.0024
7	61	2.703	0.0028
8	67	2.5678	0.0045
9	74	2.5204	0.0031

- Using the Power Law equation and DIC measurement, we were able to generate linear regression of all the stress level of the previous specimen.
- B is decreasing at higher stress level while n is decreasing and increasing based on some stress level.
- B and n value can help predict the creep value over time.

Task 4.7 Shale Swelling with DIC



Vertical strain in two TMS specimens when immersed in water

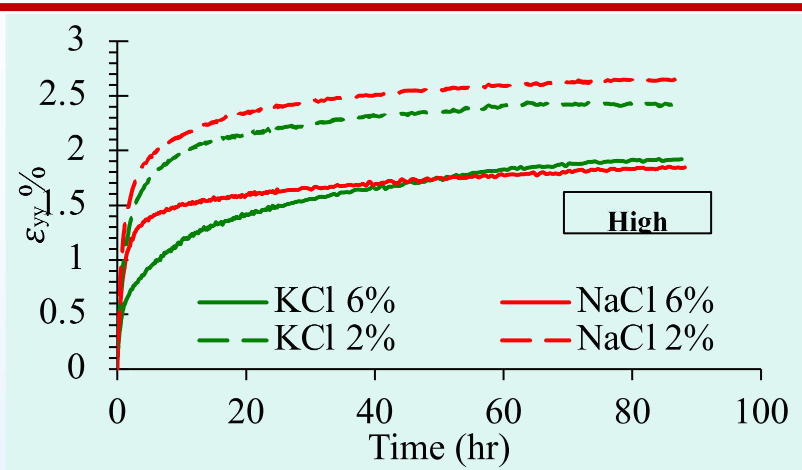


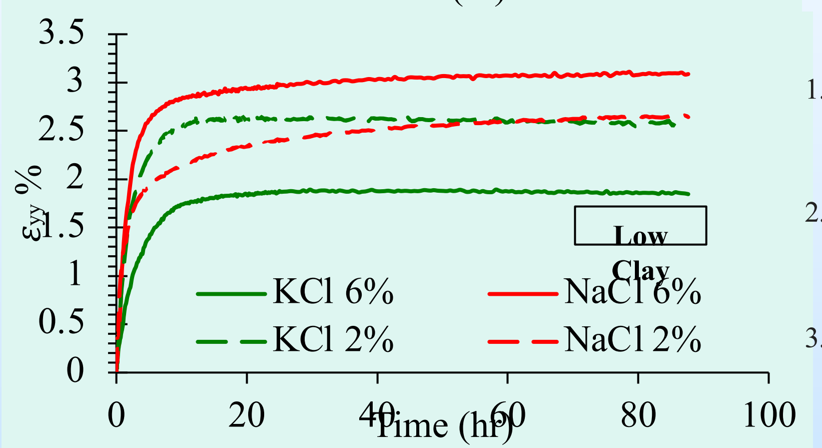
High spatial density of DIC measurement points and crack tracking

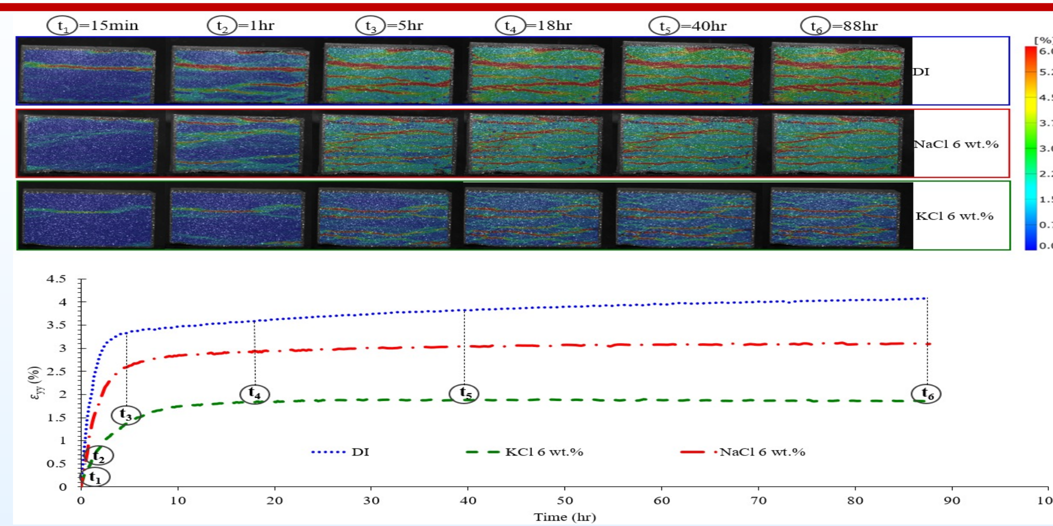
- New DIC setup enabled study shale and helped observe non-uniform deformation with clay-rich laminae showing localization of high strains
- Different clay-rich laminations swell at different times and swelling laminas stimulated growth of other swelling laminations
- Results were published in J. Energy Resour. Technol. “Measurement of Deformation Heterogeneity During Shale Swelling Using Digital Image Correlation”

Task 4.7 Shale Swelling with DIC

Effect of Brine and Concentration and Swelling Behavior of TMS







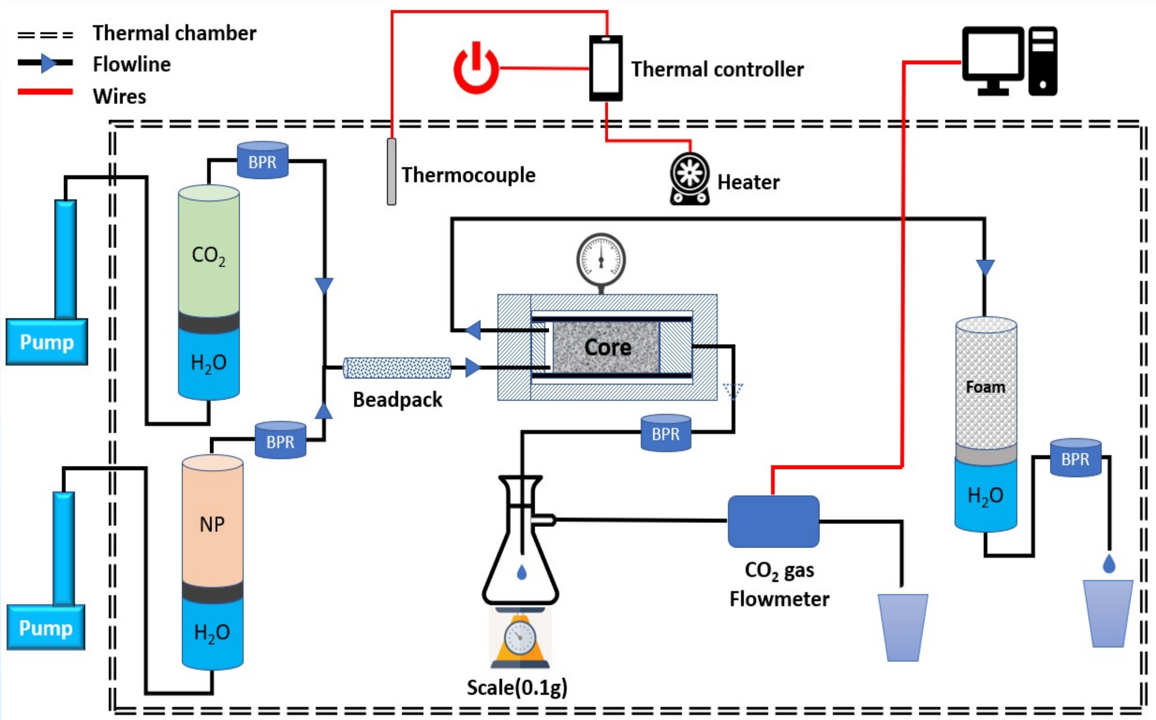
1. It was found that the rate of expansion in the period from the initial immersion to 5hr is the highest compared to the later strain development for all specimens exposed to the DI water and brines.
2. The ionic strength of the fluid significantly affects the rate of swelling and its progression. It was determined that the increase of KCl and NaCl concentration from 2 to 6% might reduce the shale swelling by 39 and 43%.
3. It was assessed that once a high strain region is formed in the samples immersed in DI water and NaCl brine, the hydration of a shale matrix in its immediate vicinity is initiated, which leads to a moderate strain development and formation of the new fractures. Whereas in the samples immersed in KCl brine, the high strain sites either propagate independently or coalescence with fractures extended from other regions
4. The induced fractures significantly affect the water intake by the shale. Thus, the rapid increase of shale swelling can be attributed to the formation of new fractures in the specimen.

Subtask 6.1c CO_2 foam Leak-off tests

$$V = V_{sl} + m * \sqrt{t}$$

$$C_w = 0.0328 * \frac{m}{A_c}$$

V is the total leakoff volume, cm^3, V_{sl} is the spurt leakoff volume before the steady leak off, cm^3, t is the time elapsed, min, A_c is the cross-sectional area of the core, cm^3, C_w is the leak-off coefficient, $\frac{ft}{\sqrt{min}}$.



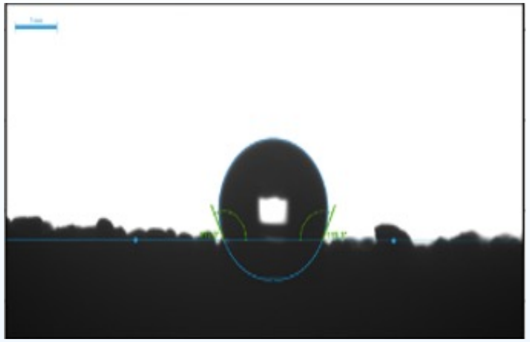
Schematic experimental setup for foam leak off test

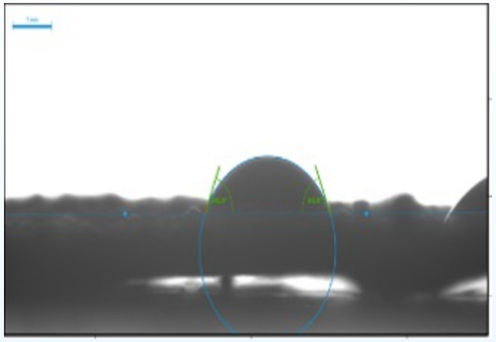
Subtask 6.1c CO2 foam Leak-off tests

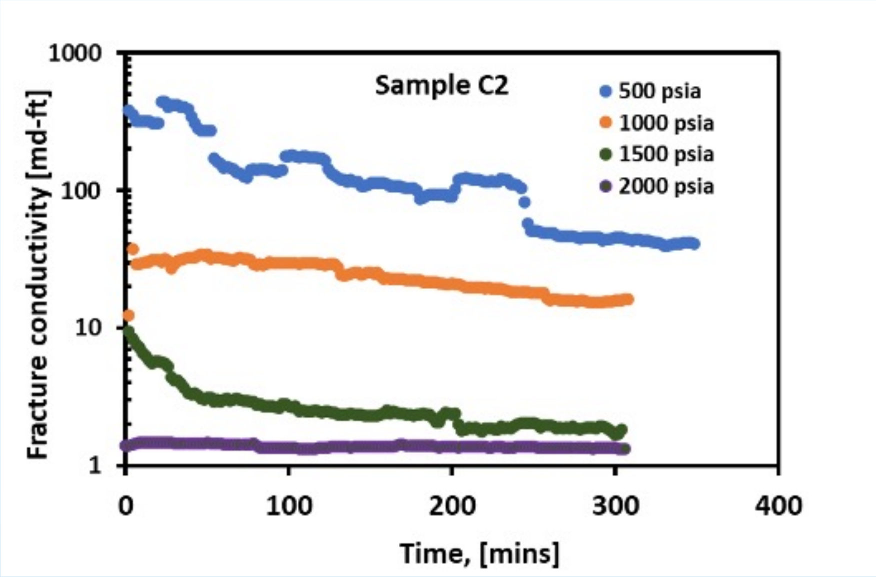
Comparison of leakoff coefficients

Fluid configuration	Leakoff coefficients ($ft/\sqrt{min}$)			
	Dynamic C_w		Static C_w	
Pure water, 1300psi, 18mL/min	0.264		0.020	
10% quality, 5% NaCl, 5000ppm NP, 1300psi, 18mL/min	C_{wgas}	$C_{wliquid}$	C_{wgas}	$C_{wliquid}$
	0.17156	0.06738	0.207	0.00134

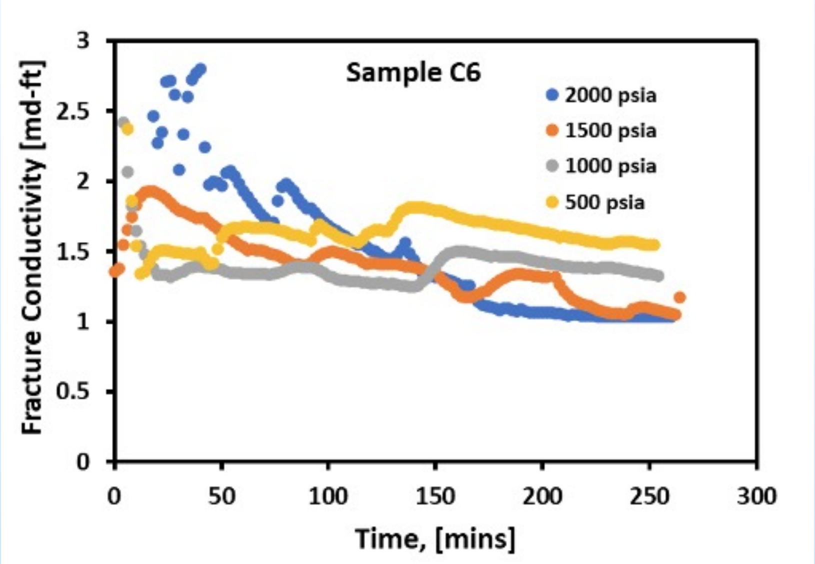
Subtask 6.3c: fracture conductivity using super-hydrophobic proppants and regular proppants.





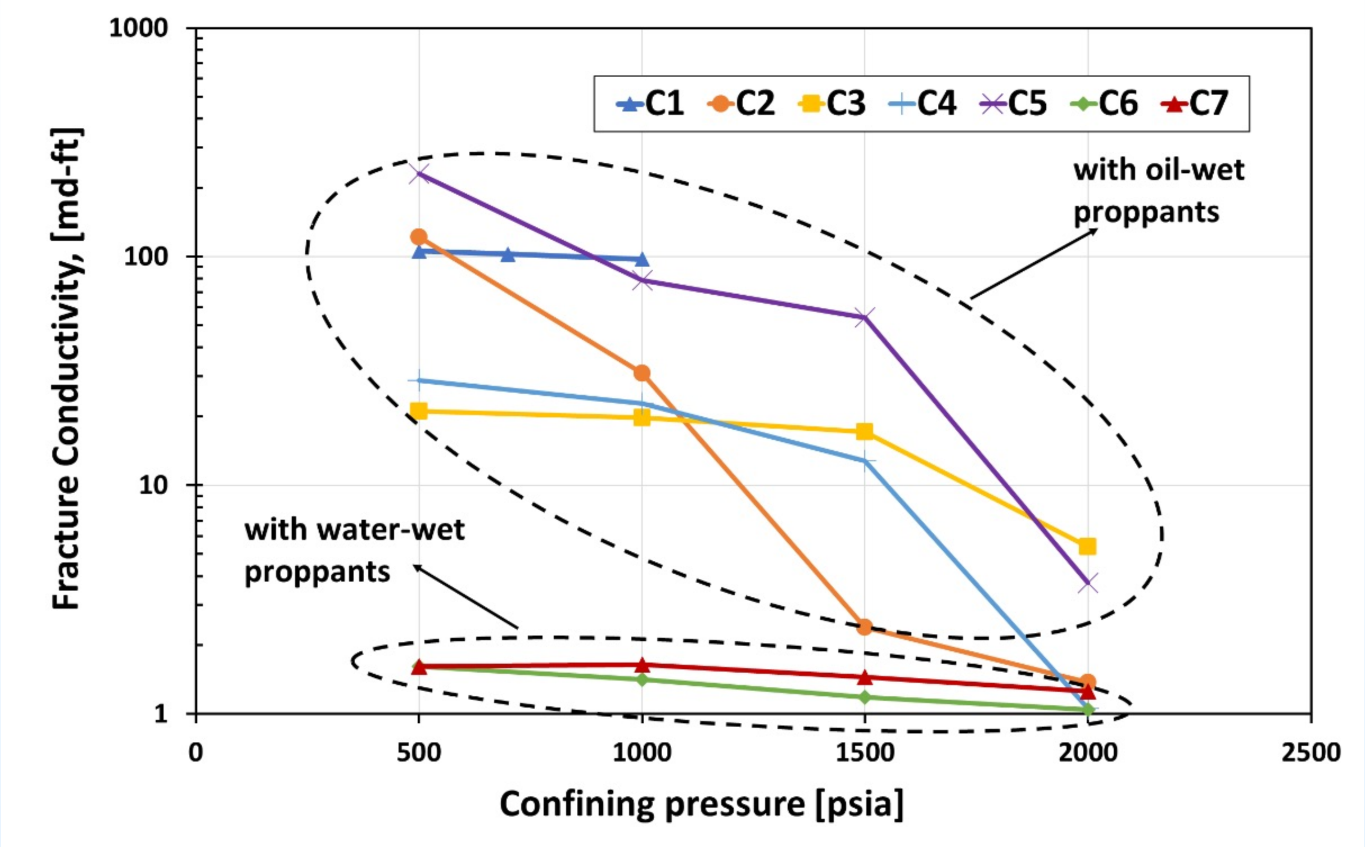


Time and stress dependent fracture conductivity for oil-wet proppants.



Time and stress dependent fracture conductivity for water-wet proppants.

Subtask 6.3c: fracture conductivity using super-hydrophobic proppants and regular proppants.

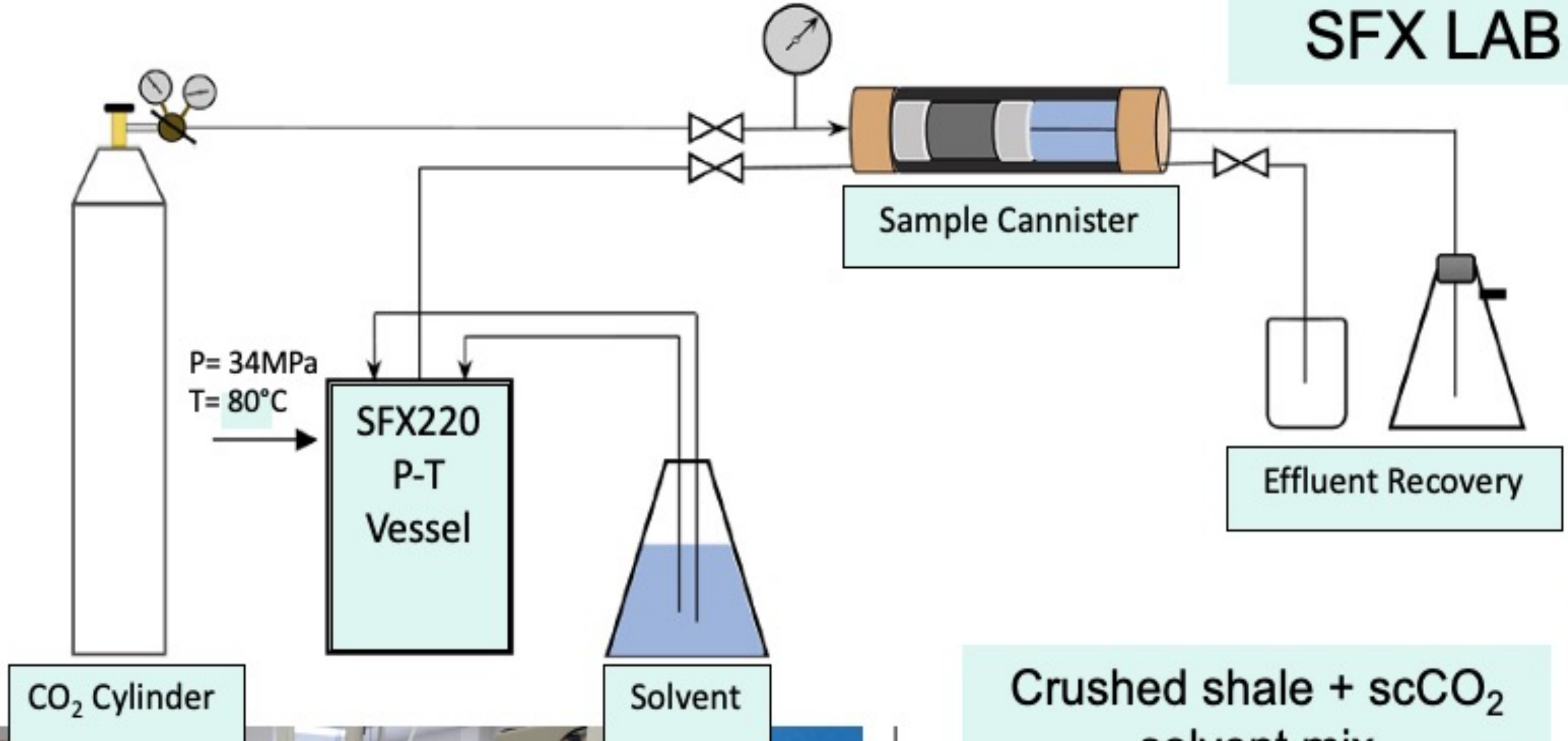


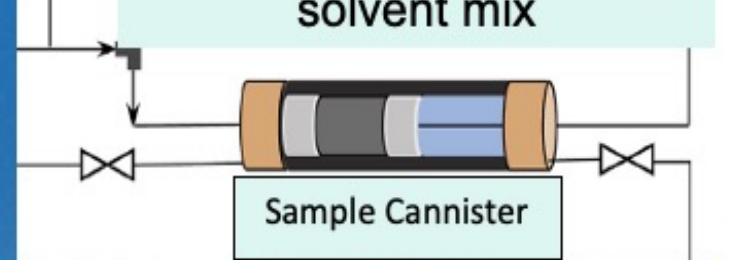
Comparison of fracture conductivity decline with confining pressure for samples with oil-wet proppants (C1 to C5) and samples with water-wet proppants (C6 and C7).

Enhanced *In-situ* Hydrocarbon Extraction: Background

- Fracking with $scCO_2$ coupled with horizontal drilling has resulted in tremendous production increases in unconventional shale reservoirs over the short term (months).
- Averaged over time however EOR is limited to the recovery of less than approximately 10% of the *in-situ* energy reserve.
- New *Huff-N-Puff* "green" gas extraction techniques are currently proposed for unconventional reservoir EOR. However they require significant operational downtimes.
- In this exploratory research, the feasibility and efficiency of enhanced *in-situ* hydrocarbon extraction using $scCO_2$ solvent + modifiers is discussed.
- Our experimental extraction results on oil shale samples at reservoir P-T conditions indicate that new CO_2 solvent mixtures can potentially increase fluid-rock interactions along fracture surfaces.
- If correct this may bring more efficiency to the production of O&G from "water sensitive" unconventional shale plays (TMS and EF) and significantly contribute to "greener" FE production over the next 30 year transition to alternate energy solutions.

SFX LAB at LANL

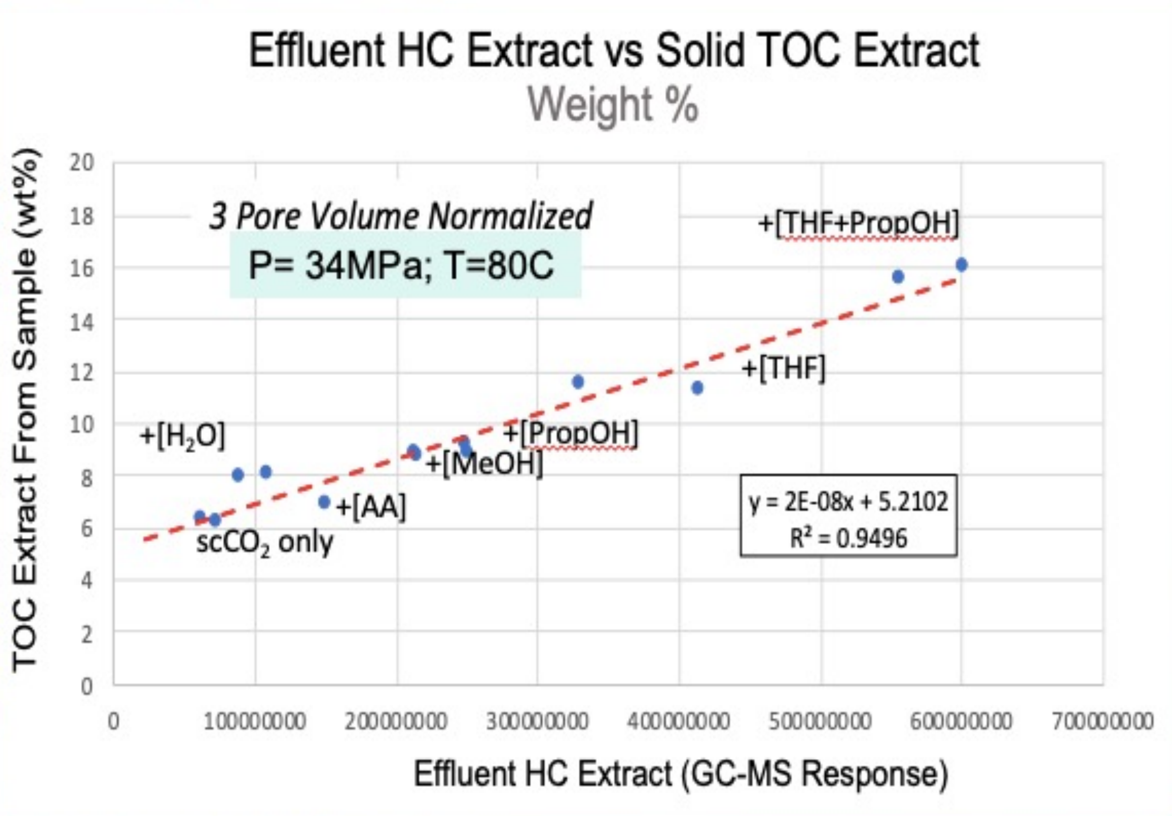




Enhanced In-situ Hydrocarbon Extraction Experiments

NB: Eagle Ford core (7wt% TOC) was used in this study for analytical reasons. Both EF and TMS plays are of Upper Cretaceous shallow marine origin that were deposited during transgressions of

Enhanced *In-situ* Hydrocarbon Extraction: Results

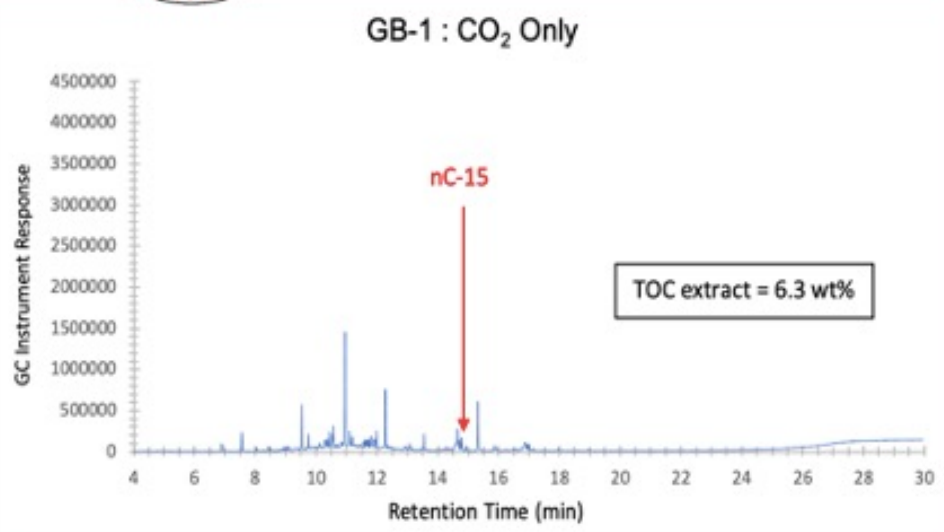


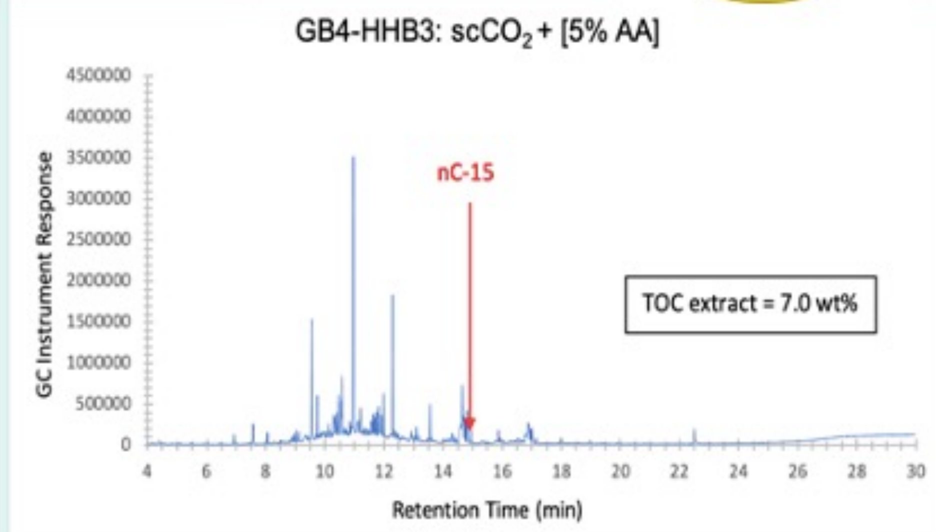
- 2019: Completed 17 tests using different co-solvent mixtures at P=34MPa, T= 80C.
- 2020: Effluent and solvent were reanalyzed for each test using GCMS and XRF, qXRD and ELMS to determine TOC, bulk composition and mineralogy.

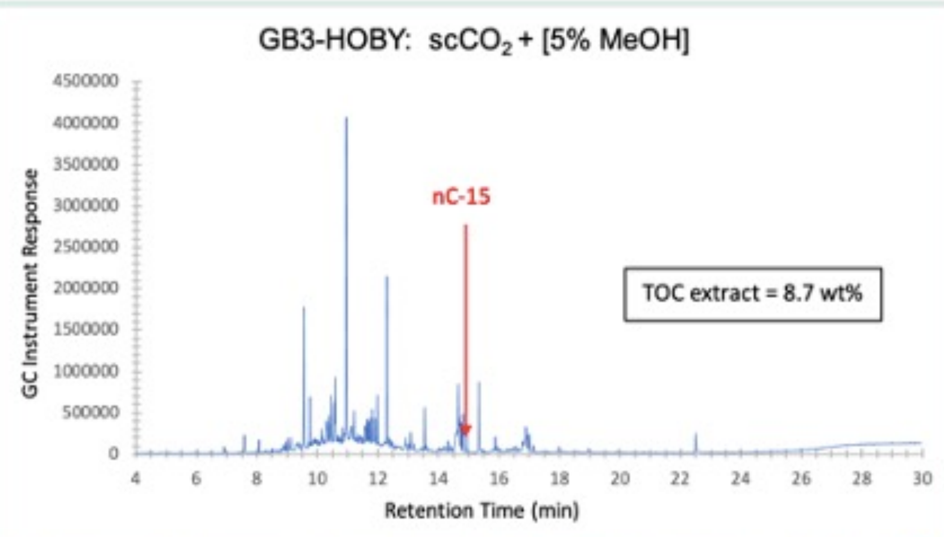
∴ RESULTS:

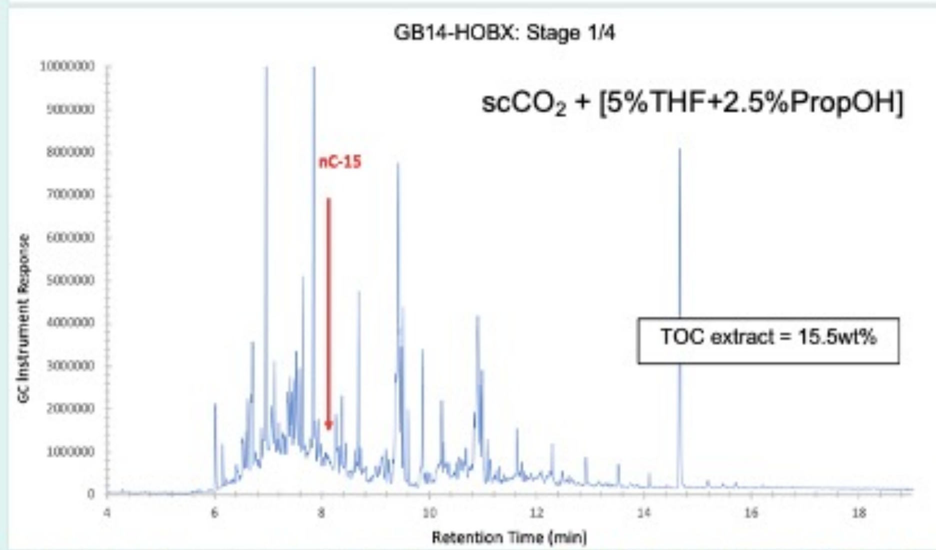
1. HC liquid effluent extracted at P-T is proportional to the TOC extracted from the shale.
2. The addition of cosolvents THF + PropOH to $scCO_2$ enhances HC extraction*.

Enhanced *In-situ* Hydrocarbon Extraction: GC Effluent Analyses



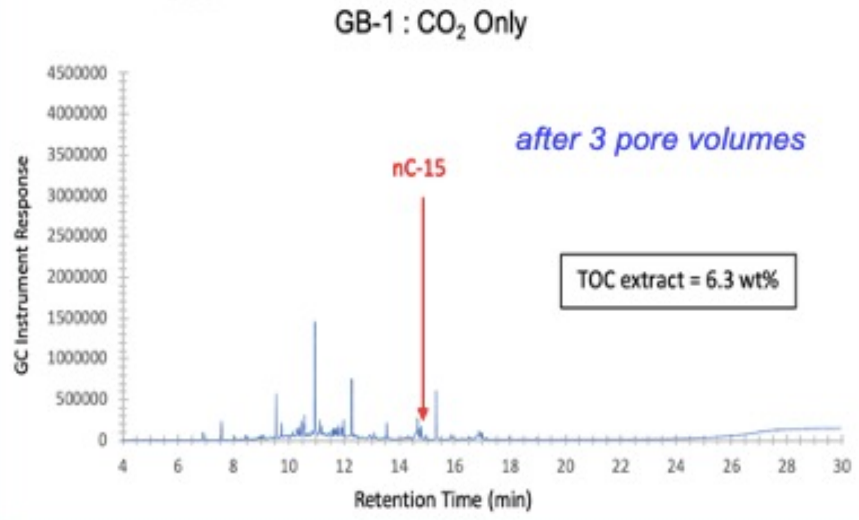


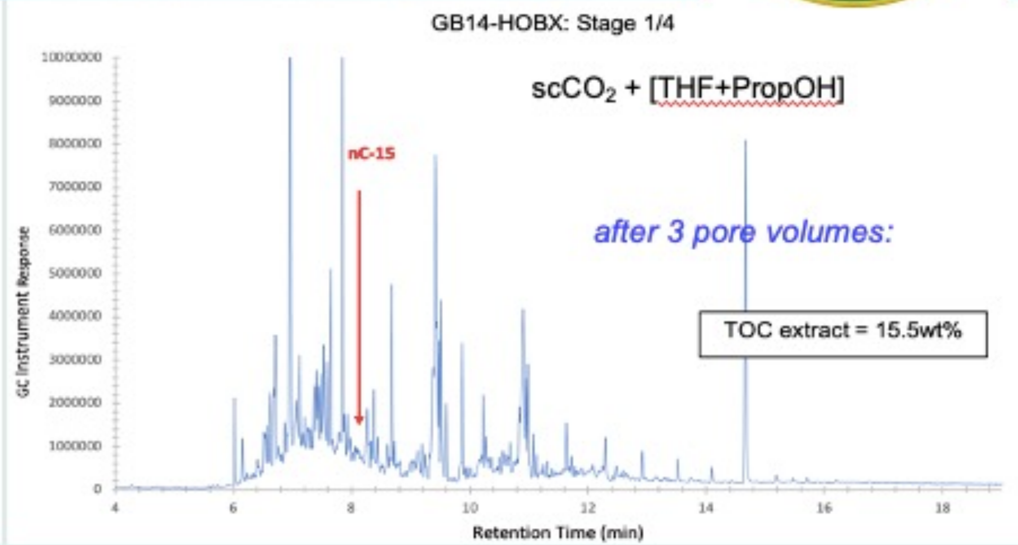




Enhanced *In-situ* Hydrocarbon Extraction: 4-Stage Effluent Extraction

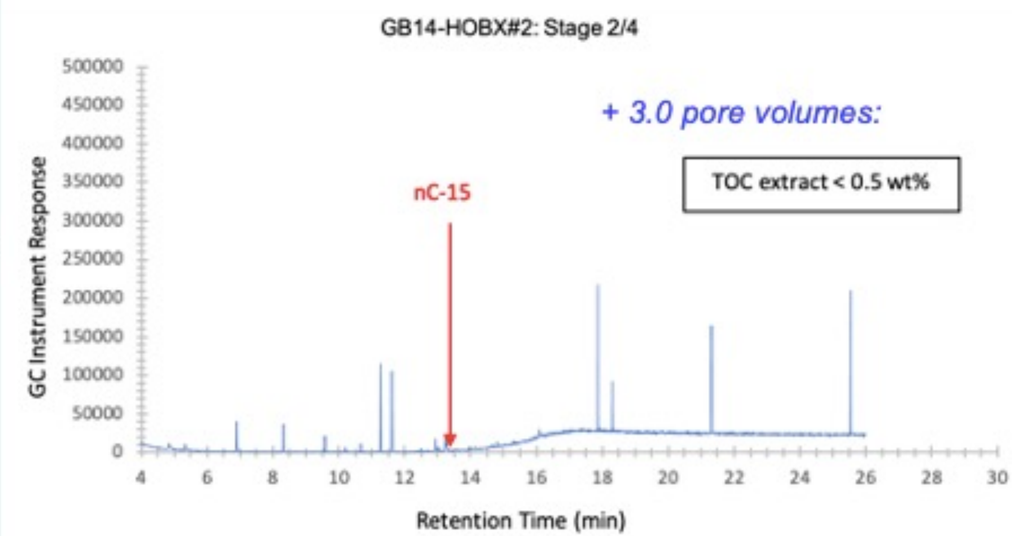
Tuscaloosa Marine Shale Laboratory



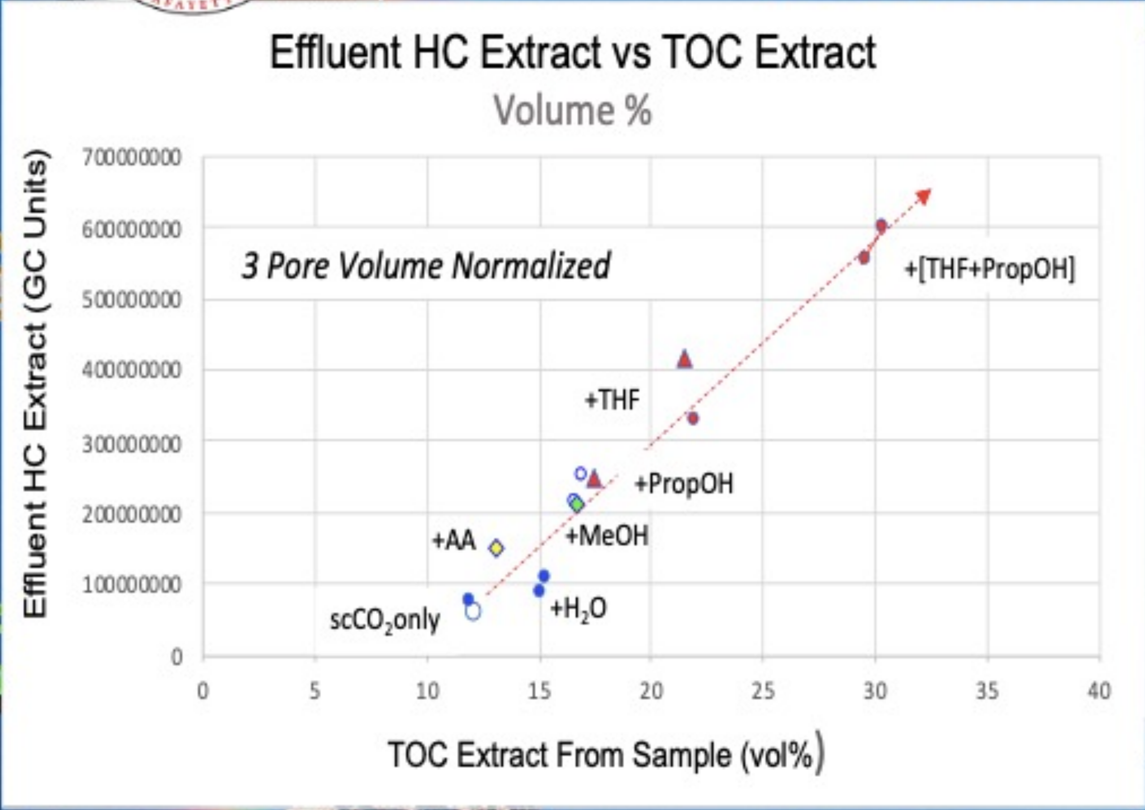


Results to date indicate that:

- $scCO_2$ + cosolvent modifiers [THF+PropOH] effectively enhance *in-situ* HC extraction by a factor of 2.5 over $scCO_2$ only extraction.
- Over 95% of the HC extraction occurs within the first 3 pore volumes (PV) equivalent to ≈16wt% of the shale TOC.
- This is likely due to the fact that co-solvent extraction may be limited to the fraction of kerogen (± bitumen) present in the shale.



Enhanced *In-situ* Hydrocarbon Extraction: Conclusions



1. We have verified that the addition of THF + PropOH to $scCO_2$ results in substantial HC extraction enhancement.
2. The GC analyses confirm that this is due to the extraction of heavier hydrocarbons ($15 \leq nC \leq 28$).
3. The HC extraction seems limited to 30 vol% and ≤ 3 pore volumes.
4. We hypothesize that the TOC extracted is limited to the amount of kerogen (±bitumen) present.

- In the next month we hope to conduct 3-5 repeat experiments to verify our results.
- This will also require verifying our hypothesis that kerogen was the main phase extracted by analyzing post-test solid residues and liquid effluents to ID extracted hydrocarbon phase(s).

Enhanced *In-situ* Hydrocarbon Extraction: Summary

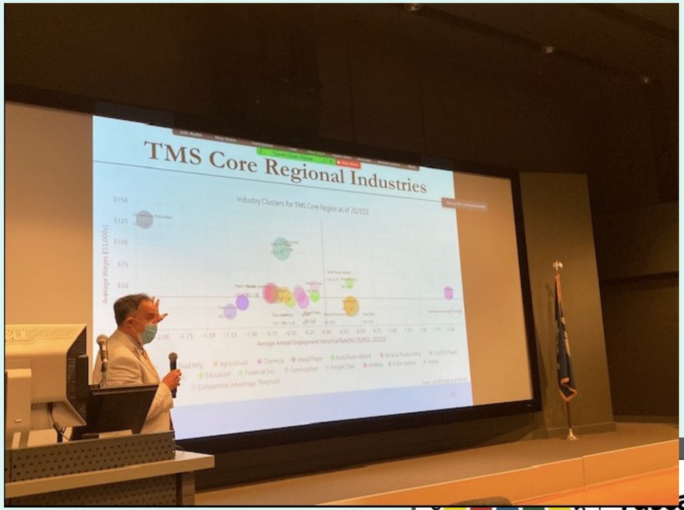
- The overarching goal of this study was to investigate the potential for enhancing the *in-situ* extraction of liquid hydrocarbon (HC) reserves from water-sensitive unconventional oil shale reservoirs (eg., TMS and EF).

- As a working hypothesis we postulated that this goal could be achieved by using scCO_2 co-solvent mixtures that act as chemical modifiers during fracking.

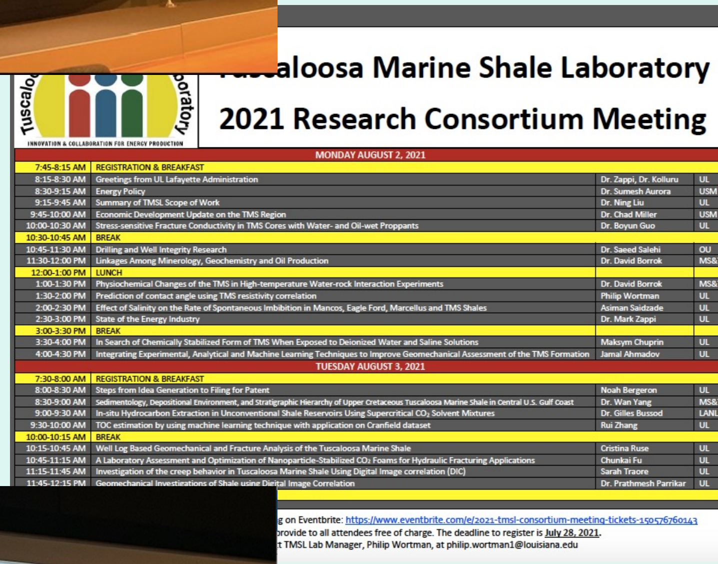
- During an18 month Laboratory closure due to the Covid-19 Pandemic we were unable to complete microfluidics testing – however we used that time to (i) rerun all post-extraction hydrocarbon analyses (C_{TOT}, TOC, ∂13C) in triplicate for the residue solid samples, and (ii) reprocess all gas chromatography analyses of the effluent extracts for each test.

- Our results confirm our hypothesis that at unconventional oil shale reservoir conditions (P= 5000psi; T= 80^{o}C), the addition of tetrahydrofuran (THF) and isopropanol (PropOH) to supercritical CO_2 fluids can potentially result in a substantial enhancement of current EOR extraction techniques.

Task 8.5 TMSL Consortium Meeting



- TMSL consortium Meeting was held in Lafayette, LA on August 2-3, 2021.
- The meeting will be an in-person event in Lafayette with remote access.


...aloosa Marine Shale Laboratory

2021 Research Consortium Meeting

INNOVATION & COLLABORATION FOR ENERGY PRODUCTION

MONDAY AUGUST 2, 2021			
7:45-8:15 AM	REGISTRATION & BREAKFAST		
8:15-8:30 AM	Greetings from UL Lafayette Administration	Dr. Zappi, Dr. Kolluru	UL
8:30-9:15 AM	Energy Policy	Dr. Sumesh Aurora	USM
9:15-9:45 AM	Summary of TMSL Scope of Work	Dr. Ning Liu	UL
9:45-10:00 AM	Economic Development Update on the TMS Region	Dr. Chad Miller	USM
10:00-10:30 AM	Stress-sensitive Fracture Conductivity in TMS Cores with Water- and Oil-wet Proppants	Dr. Boyun Guo	UL
10:30-10:45 AM	BREAK		
10:45-11:30 AM	Drilling and Well Integrity Research	Dr. Saeed Salehi	OU
11:30-12:00 PM	Linkages Among Minerology, Geochemistry and Oil Production	Dr. David Borrok	MS&
12:00-1:00 PM	LUNCH		
1:00-1:30 PM	Physiochemical Changes of the TMS in High-temperature Water-rock Interaction Experiments	Dr. David Borrok	MS&
1:30-2:00 PM	Prediction of contact angle using TMS resistivity correlation	Philip Wortman	UL
2:00-2:30 PM	Effect of Salinity on the Rate of Spontaneous Imbibition in Mancos, Eagle Ford, Marcellus and TMS Shales	Asiman Saidzade	UL
2:30-3:00 PM	State of the Energy Industry	Dr. Mark Zappi	UL
3:00-3:30 PM	BREAK		
3:30-4:00 PM	In Search of Chemically Stabilized Form of TMS When Exposed to Deionized Water and Saline Solutions	Maksym Chuprin	UL
4:00-4:30 PM	Integrating Experimental, Analytical and Machine Learning Techniques to Improve Geomechanical Assessment of the TMS Formation	Jamal Ahmadov	UL
TUESDAY AUGUST 3, 2021			
7:30-8:00 AM	REGISTRATION & BREAKFAST		
8:00-8:30 AM	Steps from Idea Generation to Filing for Patent	Noah Bergeron	UL
8:30-9:00 AM	Sedimentology, Depositional Environment, and Stratigraphic Hierarchy of Upper Cretaceous Tuscaloosa Marine Shale in Central U.S. Gulf Coast	Dr. Wan Yang	MS&
9:00-9:30 AM	In-situ Hydrocarbon Extraction in Unconventional Shale Reservoirs Using Supercritical CO_2 Solvent Mixtures	Dr. Gilles Bussod	LANL
9:30-10:00 AM	TOC estimation by using machine learning technique with application on Cranfield dataset	Rui Zhang	UL
10:00-10:15 AM	BREAK		
10:15-10:45 AM	Well Log Based Geomechanical and Fracture Analysis of the Tuscaloosa Marine Shale	Cristina Ruse	UL
10:45-11:15 AM	A Laboratory Assessment and Optimization of Nanoparticle-Stabilized CO_2 Foams for Hydraulic Fracturing Applications	Chunkai Fu	UL
11:15-11:45 AM	Investigation of the creep behavior in Tuscaloosa Marine Shale Using Digital Image correlation (DIC)	Sarah Traore	UL
11:45-12:15 PM	Geomechanical Investigations of Shale using Digital Image Correlation	Dr. Prathmesh Parrikar	UL

...g on Eventbrite: https://www.eventbrite.com/e/2021-tmsl-consortium-meeting-tickets-150576760143
...provide to all attendees free of charge. The deadline to register is July 28, 2021.
...t TMSL Lab Manager, Philip Wortman, at philip.wortman1@louisiana.edu

Appendix

TMSL Collaboratory Team: Multi-Disciplinary, Multi-Institutional, EPSCoR Region

DOE Project Manager (Bruce Brown)

PI: Mehdi Mokhtari: University of Louisiana at Lafayette

University of Louisiana at Lafayette (UL Lafayette)

Ning Liu

Rafael Hernandez

Boyun Guo

Rui Zhang

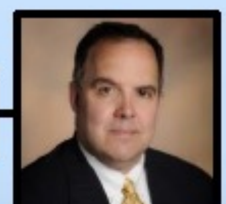
Missouri S&T: David Borrok

Missouri S&T: Wan Yang

The University of Oklahoma (OU): Saeed Salehi

Los Alamos National Laboratory (LANL): Gilles Bussod

University of Southern Mississippi (USM): Chad Miller



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3. Konate, N., 2021. Experimental Investigation of Shale-drilling Fluid Interaction and Its Implications on Drilling Efficiency. Master Thesis. The University of Oklahoma, Norman, OK.
4. Chunkai Fu, 2021. A Laboratory Assessment and Optimization of Nanoparticle-Stabilized CO2 Foams for Hydraulic Fracturing Applications. PhD Thesis, University of Louisiana at Lafayette, LA

Conference Publications

1. Hoffman, A., and Borrok, D.M. (2021) Experimental physiochemical investigation of high-temperature brine-shale interactions. Geological Society of America Joint 55th annual North-Central/South Central Meeting.
2. Ruse, C.M., Ahmadov, J., Liu, N., Mokhtari M. (2021) An integrated analytics and machine learning solution for predicting the anisotropic static geomechanical properties of the Tuscaloosa Marine Shale. Unconventional Resources Technology Conference (URTec: 5625)
3. C. Fu, N. Liu, Study the synergistic effect of nanoparticle-surfactant-polymer on CO_2 foam rheology and stability under high pressure and temperature, *Energy & Fuels*, 34 (2020) 13707-13716.
4. Yang, W., Borrok, D.M., Mokhtari, M., 2020, Depositional environments and stratigraphic hierarchy of upper cretaceous Tuscaloosa Marine Shale in central U.S. Gulf Coast - A core observation: Geological Society of America Abstracts with Programs. Vol 52, No. 6, 2020.
5. Wu, Y. and Salehi, S. A Numerical and Experimental Study On Cement Integrity Based On a Novel Method. ARMA 54th us rock mechanics/geomechanics symposium, June 28-July 1, 2020 at the virtual meeting.
6. Wu, Y. and Salehi, S. Numerical Study of Well Integrity in High-Temperature Wells. ARMA 54th us rock mechanics/geomechanics symposium at the virtual meeting, June 28-July 1, 2020.
7. Wu, Y. and Salehi, S. The Effect of Pressure Cycling on the Development of Micro-Annulus in Cement Sheath. Unconventional Resources Technology Conference, July 20-22, 2020 at the virtual meeting.
8. Ruse, C.M., and Mokhtari M., Characterization of elastic mechanical properties of Tuscaloosa Marine Shale from well logs using the vertical transversely isotropic model, Interpretation, 8 (2020) T1023–T1036.
9. D. M. Borrok, W. Yang, M. Mokhtari, H. Beitel, 2020, New Insights into the Mineralogy and Organic Content of the Tuscaloosa Marine Shale. AAPG Annual Meeting, Houston, TX.