Tuscaloosa Marine Shale Laboratory (TMSL)

Project Number: DE-FE0031575

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U.S. Department of Energy

National Energy Technology Laboratory

Mastering the Subsurface Through Technology Innovation, Partnerships and Collaboration: Carbon Storage and Oil and Natural Gas Technologies Review Meeting

August 13-16, 2018

Presentation Outline

- Tuscaloosa Marine Shale (TMS) Overview
- Accomplishments to Date
- TMS Laboratory (TMSL) Project Goals and Objectives
- Synergy Opportunities

Tuscaloosa Marine Shale Laboratory

Subtopic 1B: Emerging Unconventional Plays

- "A large portion of many plays, especially those that are lower pressure, contain **high clay content**, and/or contain more ductile rocks are uneconomical to produce with current technologies despite having **significant resource volumes**."

- "…proposed under Subtopic Area 1B must address **emerging unconventional oil** or natural gas plays where there is currently **less than 50,000 barrels** per day (equivalent) production."

FINANCIAL ASSISTANCE
FUNDING OPPORTUNITY ANNOUNCEMENT

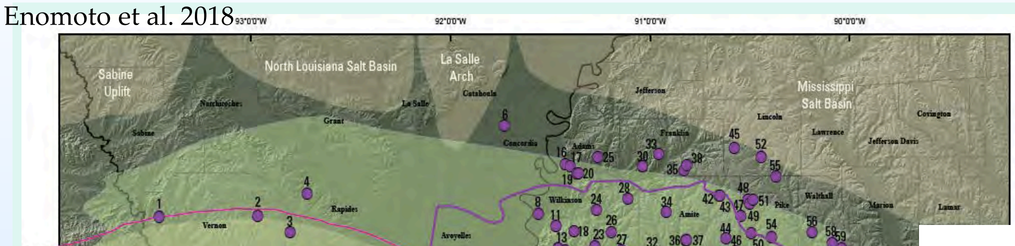
U. S. Department of Energy
Office of Fossil Energy
National Energy Technology Laboratory
"Advanced Technology Solutions for Unconventional Oil & Gas Development"
Funding Opportunity Number: DE-FOA-0001722

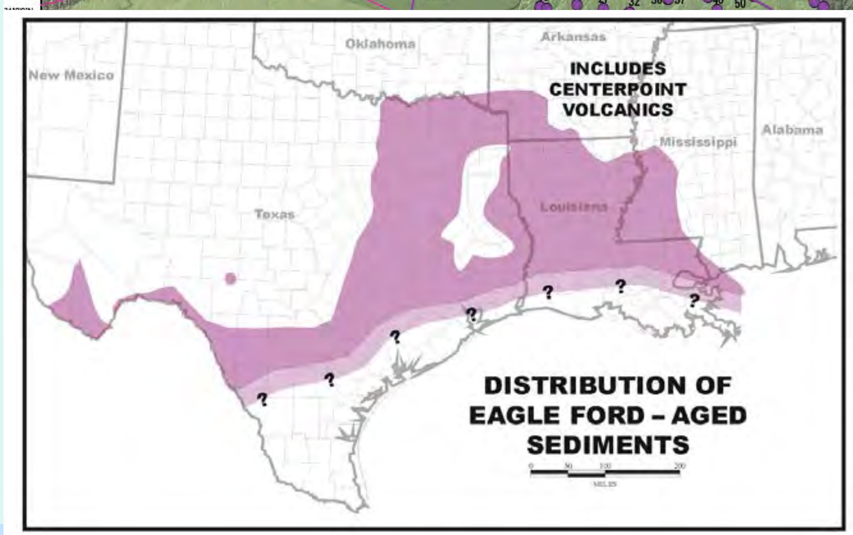
the goal of TMSL project is to form a consortium of science and industry partners to address critical gaps in the understanding of TMS to enable more cost-efficient and environmentally-sound recovery from this unconventional liquid-rich shale play

Geological Setting of TMS

TMS covers almost 7.4 million acres in central Louisiana and Southern Mississippi.

Enomoto et al. 2018

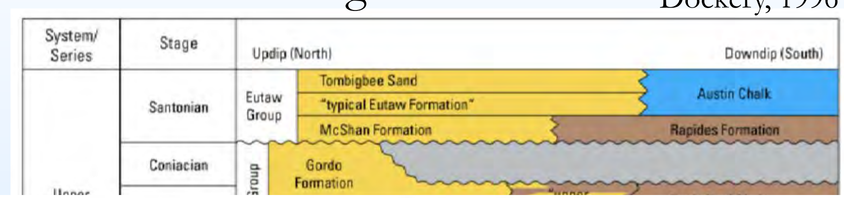


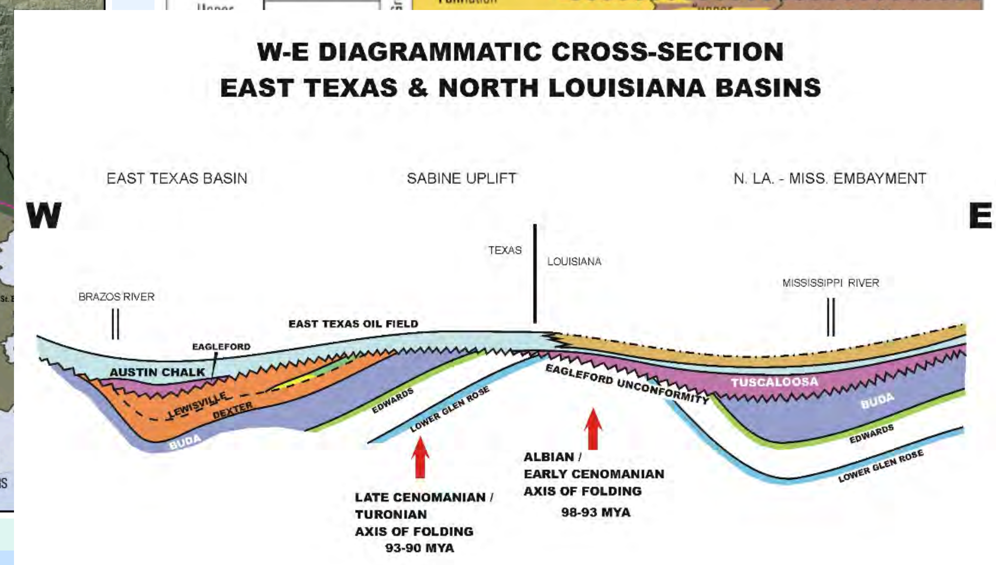


Adams R.L. and J.P. Carr, 2010.

TMS is sandwiched between Upper and Lower Tuscaloosa sands and it is same age as Eagle Ford shale.

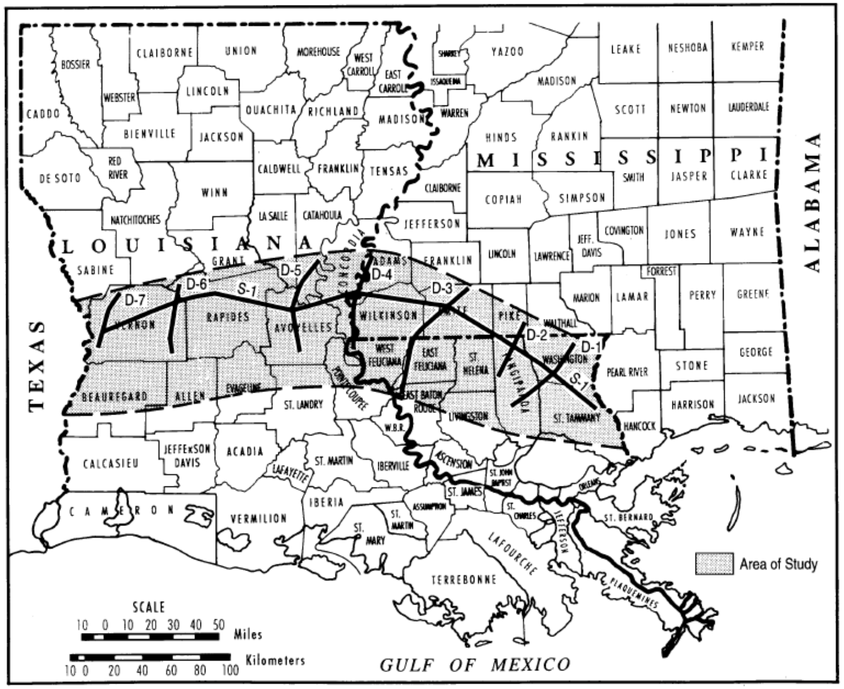
Dockery, 1996





Adams R.L. and J.P. Carr, 2010.

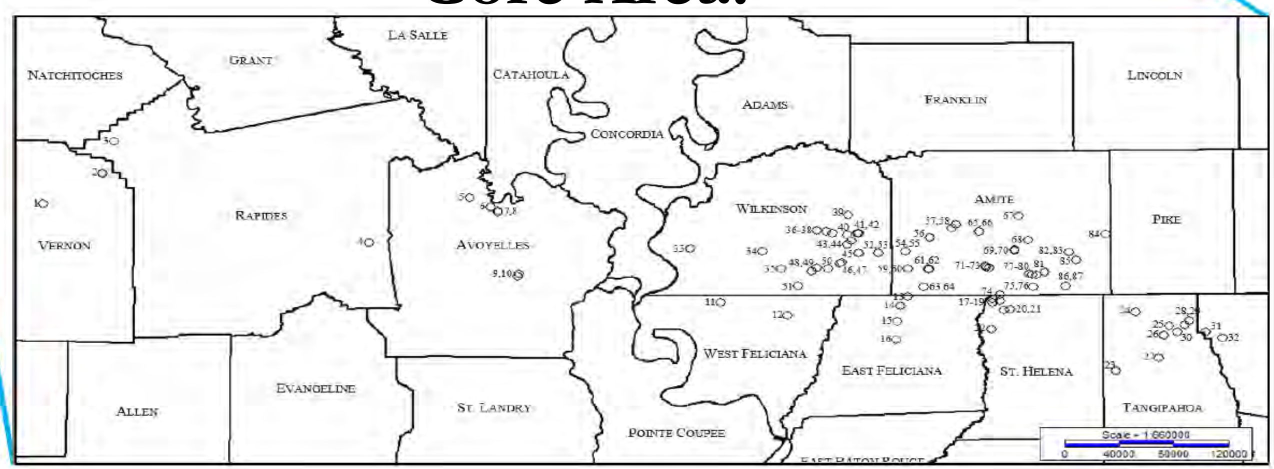
TMS Early Studies



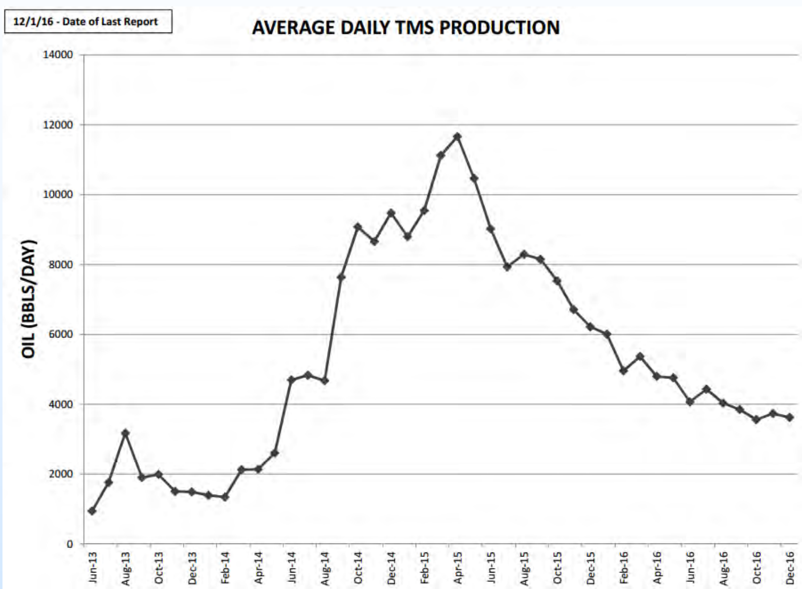
John, C.J., Jones B.L., Moncrief J. E, Bourgeois R.J., and Harder B.J., 1997. An unproven unconventional seven billion barrel oil resource – the Tuscaloosa Marine Shale, Basin Research Institute Bulletin

- "An Unproven Unconventional Seven Billion Barrel Oil? Resource - the Tuscaloosa Marine Shale (1997)"?
- Acreage: 7.4 million acres
- TMS has base depth from -10,500 to -14,000 ft
- Thickness from 230 – 500 ft.

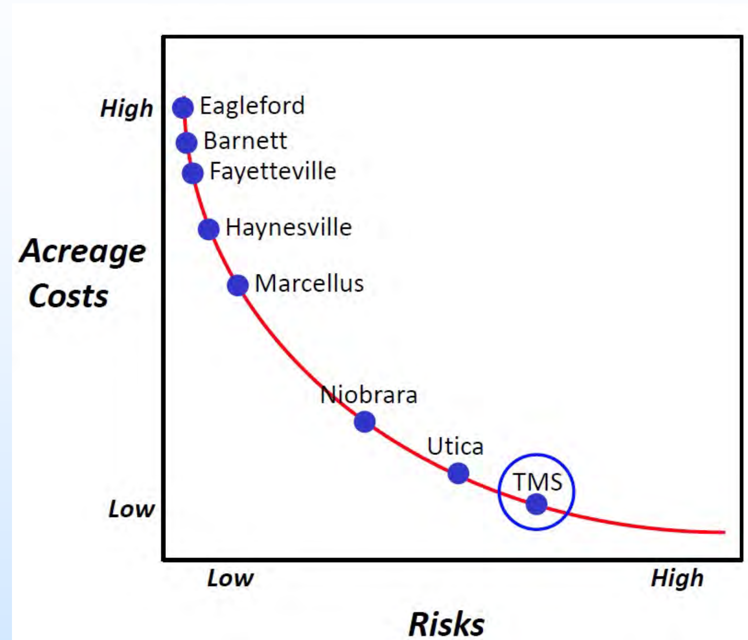
Core Area:



Negligible Current Production Rate



Low Acreage Cost/High Drilling & Completion Costs



Limited Shared Knowledge

- Positive tax environment in Louisiana and Mississippi
- Easy access to pipelines, refineries and availability of water supply

Availability of Recent Data

In 2012-2014, more than 80 wells were drilled in TMS but the activity declined significantly due to technical issues, industry downturn and high cost of TMS wells. It's now the "right time" to re-evaluate TMS.

The past experiences of major industrial players in the TMS show the necessity of open and collaborative efforts to better understand the critical gaps in the development of such challenging shale play.

	Name of well	API	County (State)	Company	Year	log	Initial BOPD
1	Crosby 12-1H 1	2315722037	Wilkinson, MS	Goodrich	2013	Y	1300
2	Smith 5-29H #1	2300520756	Amite, MS	Goodrich	2013	Y	1045
3	Foster Creek 20-7H	2315722047	Wilkinson, MS	Goodrich	2013	Y	
4	Huff 18-7H #1	2300520773	Amite, MS	Goodrich	2012	Y	
5	CMR 8-5H #1	2300520774	Amite, MS	Goodrich	2013	Y	950
6	Lewis 30-19 1H	2300520789	Amite, MS	Goodrich	2014	Y	1450
7	Nunnery 12-1H 1	2300520790	Amite, MS	Goodrich	2014	Y	815
8	Denkmann 33-28H2	2300520799	Amite, MS	Goodrich	2012	Y	1250
9	Bates 25-24H#1	2300520791	Amite, MS	Goodrich	2014	Y	
10	Foster Creek 31 22H 1	2315722095	Wilkinson, MS	Goodrich	2014	N	1140
11	Foster Creek 24-13H 1	2315722089	Wilkinson, MS	Goodrich	2014	Y	1215
12	Spears 31-6H #1	2300520809	Amite, MS	Goodrich	2014	Y	1360
13	Foster Creek 8H1	2315722097	Wilkinson, MS	Goodrich	2014	Y	
14	Foster Creek 8H2	2315722098	Wilkinson, MS	Goodrich	2014	Y	
15	T. Lewis 7-38H #1	2300520866	Amite, MS	Goodrich	2014	Y	
16	Beech Grove 94H 1	1703720157	E- Feliciana, LA	Goodrich	2014	Y	740
17	SLC Inc. 81H 1	1712520132	W-Feliciana, LA	Goodrich	2014	Y	900
18	Verberne 5H-1	1710520049	Kentwood, LA	Goodrich	2014	Y	1375
19	Blades 33H-1	1710520046	Tangipahoa, LA	Goodrich	2014	Y	1270
20	Williams 46H-1	1710520050	Kentwood, LA	Goodrich	2014	Y	1240
21	Weyerhaeuser 51 H 1	1709120152	St. Helena, LA	Goodrich	2013	Y	
22	Indigo 25 H 1	1711520230	Vernon, LA	Goodrich	2014	N	
23	Kent 41 H 1	1710520048	Tangipahoa, LA	Goodrich	2014	Y	
24	B-Nez 43 H 1	1710520055	Tangipahoa, LA	Goodrich	2014	Y	
25	Painter Etal 5 H 1	1711720247	St. Landry, LA	Goodrich	2014	Y	
26	W Alford 10 H 1	1711720248	St. Landry, LA	Goodrich	2015	Y	
27	Joe Jackson 4-13H	2300520714	Amite, MS	Australis	2007	Y	
28	BOE 1H	2300520727	Amite, MS	Australis	2008	Y	340
29	Joe Jackson 4H-2	2300520748	Amite, MS	Australis	2012	Y	
30	Horseshoe Hill 10H	2315722027	Wilkinson, MS	Australis	2012	Y	656
31	Anderson 17H #1	2300520739	Amite, MS	Australis	2011	Y	1083
32	Anderson 18H #1	2300520741	Amite, MS	Australis	2012	Y	1072
33	Anderson 17H #2	2300520760	Amite, MS	Australis	2013	Y	1540
34	Anderson 17H #3	2300520761	Amite, MS	Australis	2013	Y	
35	Ash 31H #1	2300520745	Amite, MS	Australis	2012	N	
36	Ash 31H #2	2300520746	Amite, MS	Australis	2012	Y	730
37	Lawson 25H #1	2300520762	Amite, MS	Australis	2013	Y	709
38	Lyons 35H #1	2300520786	Amite, MS	Australis	2014	Y	618
39	Pintard 28H #1	2315722054	Wilkinson, MS	Australis	2014	N	1254
40	Mathis 29-32H #1	2300520798	Amite, MS	Australis	2014	Y	1300
41	Lewis 7-18H #1	2300520801	Amite, MS	Australis	2014	Y	1500
42	Lyons 35H #2	2300520787	Amite, MS	Australis	2014	Y	1535
43	Pintard 28H #2	2315722055	Wilkinson, MS	Australis	2014	N	
44	Sabine 12H #1	2300520796	Amite, MS	Australis	2014	N	
45	Sabine 12H #2	2300520797	Amite, MS	Australis	2014	N	
46	Ash 13H #1	2300520802	Amite, MS	Australis	2014	Y	
47	Ash 13H #2	2300520803	Amite, MS	Australis	2014	Y	
48	Mathis 29-17H #1	2300520857	Amite, MS	Australis	2014	N	1570
49	Longleaf 29H #1	2300520794	Amite, MS	Australis	2014	N	
50	Longleaf 29H #2	2300520795	Amite, MS	Australis	2014	N	

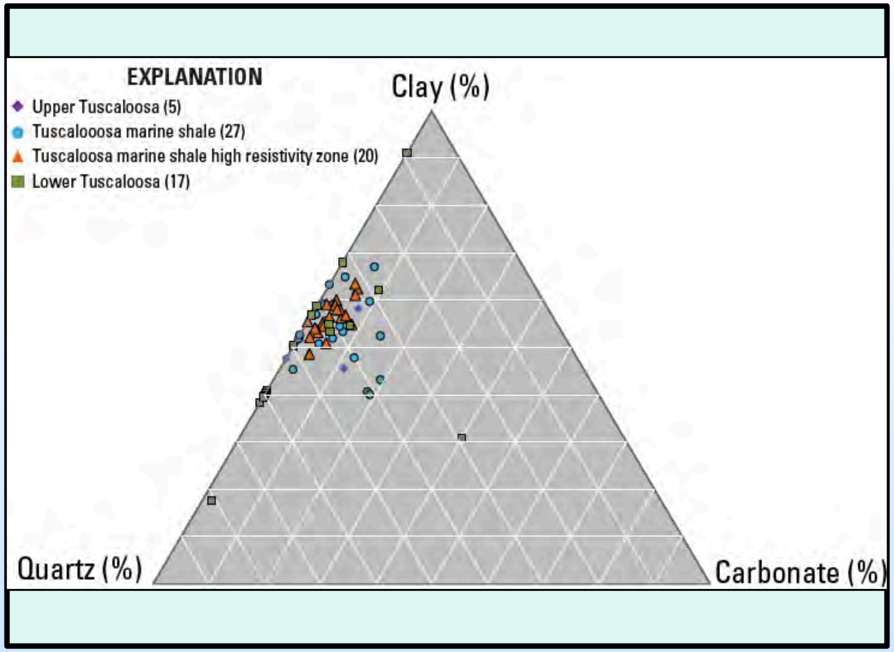
TMS Wells (2012-2014)

- 9.4 million barrels of oil and 5.5 billion cubic feet of gas were produced from about 80 horizontal TMS wells (IHS Energy Group, 2016).
- Oils range from 36–48 API gravity with gas/oil ratios of 300–900 and low sulfur.

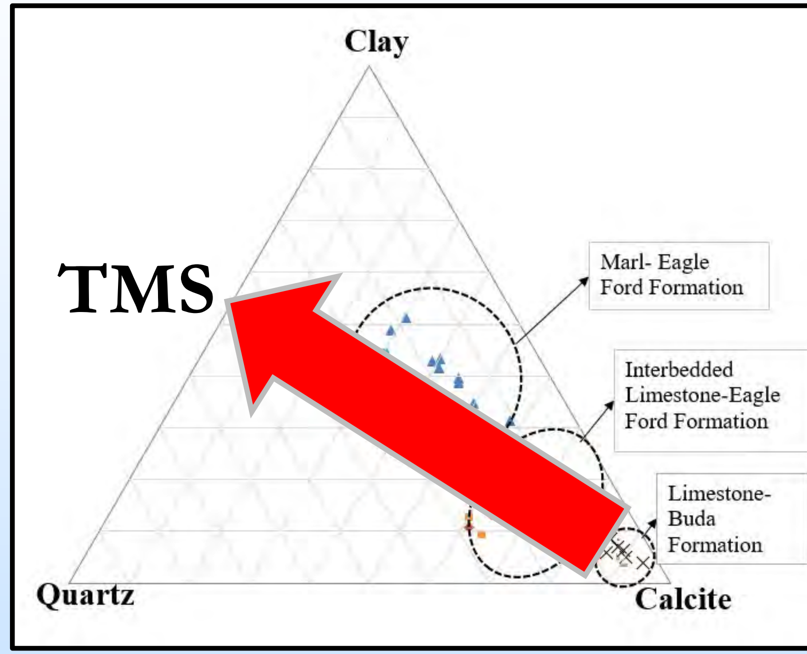
51	Lawson 25-13H #1	2300520804	Amite, MS	Australis	2014	Y	
52	Reese 16H #1	2300520845	Amite, MS	Australis	2014	N	
53	McIntosh 15H #1	2300520843	Amite, MS	Australis	2014	N	
54	Dry Fork East Unit 2H	2315722083	Wilkinson, MS	Sanchez	2014	Y	
55	St. Davis Unit #1H	2300520819	Amite, MS	Sanchez	2014	Y	1140
56	Morris 2H	2315722176	Wilkinson, MS	Sanchez	2015	Y	
57	Bloomer #2H	2315722240	Wilkinson, MS	Sanchez	2015	Y	
58	Board of Education B1	2300520441	Amite, MS	Sanchez	2011	Y	
59	BOE 16-7 4	2311320232	Pike, MS	Sanchez	2011	Y	
60	Lewis "B" # 1	2300520431	Amite, MS	Sanchez	2011	Y	
61	Pike County Farm # 1	2311320234	Pike, MS	Sanchez	2011	Y	
62	Charles Spears #1A	2300520688	Amite, MS	Sanchez	2004	N	
63	Horseshoe Hill 11-22	2315722045	Wilkinson, MS	Halcon	2014	Y	1548
64	Black stone 4H #2	2315722060	Wilkinson, MS	Halcon	2014	Y	715
65	Fassmann 9H #1	2315722067	Wilkinson, MS	Halcon	2014	Y	
66	S.D. Smith #1H	2315722102	Wilkinson, MS	Halcon	2014	Y	
67	Shuckrow 10H #1	2315722104	Wilkinson, MS	Halcon	2014	Y	
68	George Martens #2H	2315722140	Wilkinson, MS	Halcon	2014	Y	
69	Rogers 1H	2315722156	Wilkinson, MS	Halcon	2015	Y	
70	Creek Cottage W- 1H	2315722133	Wilkinson, MS	Halcon	2014	Y	
71	Broadway H 1	1707920539	Rapides, LA	Halcon	2012	Y	
72	Beech Grove 68H-1	1703720151	E-Feliciana, LA	Devon	2011	Y	85
73	Soterra 6H-1	1710520039	Tangipahoa, LA	Devon	2012	Y	176
74	Richland Farms 74H-1	1703720154	E-Feliciana, LA	Devon	2012	N	320
75	Weyerhaeuser 14H-1	1709120148	St. Helena, LA	Devon	2012	Y	692
76	Murphy 63H-1	1712520131	W-Feliciana, LA	Devon	2012	Y	287
77	Thomas 38H-1	1710520042	Tangipahoa, LA	Devon	2012	Y	505
78	Weyerhaeuser 72H	1709120151	St. Helena, LA	Devon	2014	N	354
79	Lane 64 H	1703720153	E-Feliciana, LA	Devon			
80	Weyerhaeuser 60H-1	1709120147	St. Helena, LA	Encana	2014	Y	1100
81	Weyerhaeuser 60H-2	1709120150	St. Helena, LA	Encana	2012	Y	
82	Weyerhaeuser 73H-1	1709120145	St. Helena, LA	Encana	2011	Y	700
83	Dupuy 20H1	1700920645	Avoyelles, LA	Encana	2012	Y	459
84	Dupuy Land Co 1	1700920642	Avoyelles, LA	EOG	2012	Y	
85	Gauthier 1	1700920643	Avoyelles, LA	EOG	2012	Y	
86	Gauthier 14 H 1	1700920644	Avoyelles, LA	EOG	2012	Y	
87	Paul 15 H 1	1700920648	Avoyelles, LA	EOG	2013	Y	
88	Dupuy Land Co 30H 1	1700920649	Avoyelles, LA	EOG	2013	Y	
89	Spears 1	2300520025	Amite, MS	Humble	1969	Y	
90	#1 Stockard	2300500103	Amite, MS	Humble	1950	N	
91	Bentley Lumber 34H 1	1707920538	Rapides, LA	Indigo	2012	Y	351
92	Lambert 1H	2300520664	Amite, MS	Exchange	2000	N	400
93	Blades No. 1	1710520007	Tangipahoa, LA	Tex-Pacific	1975	Y	
94	Richland Plantation A	1703720145	E-Feliciana, LA	UPRC	1998	Y	117
95	#1 Braswell 24-12	2311320221	Pike, MS	Worldwide	1999	Y	
96	Montrose Plantation 1	2315721328	Wilkinson, MS	Hess	1985	N	
97	Foster Creek 28-40 1H	2315722099	Wilkinson, MS	Comstock	2014	Y	
98	Weyerhaeuser No. 1	1709120137	St. Helena, LA	Encore	2008	Y	323
99	Bentley Lumber 32-1	1711520211	Vernon, LA	Indigo	2011	Y	
100	W P Spinks 1	2311320020	Pike, MS	Sun Oil	1972	Y	

Mineralogical Composition of TMS

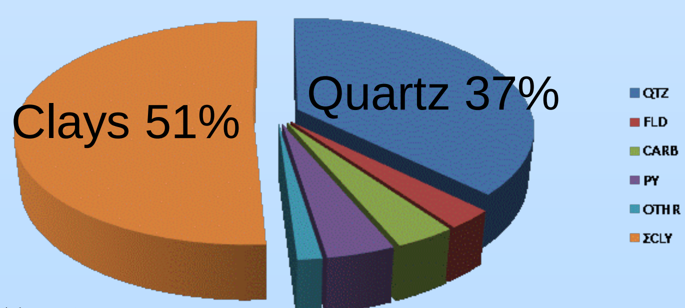
Tuscaloosa Marine Shale



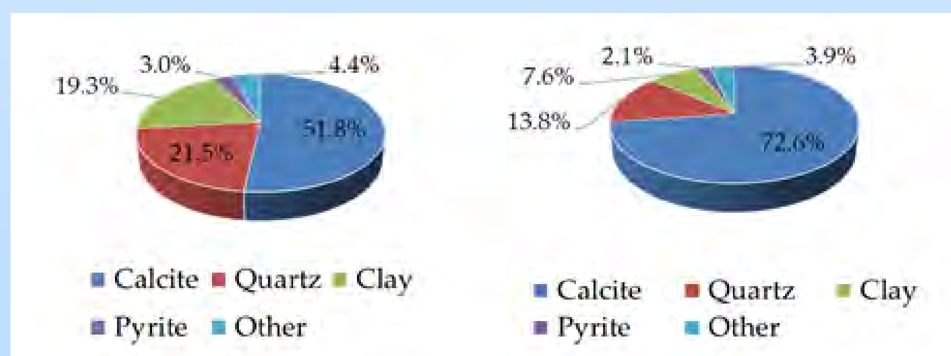
Eagle Ford Shale



Tuscaloosa Marine Shale



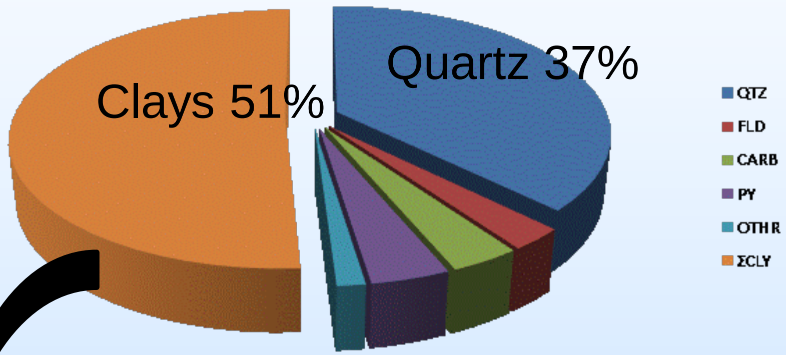
EF Marl EF Limestone

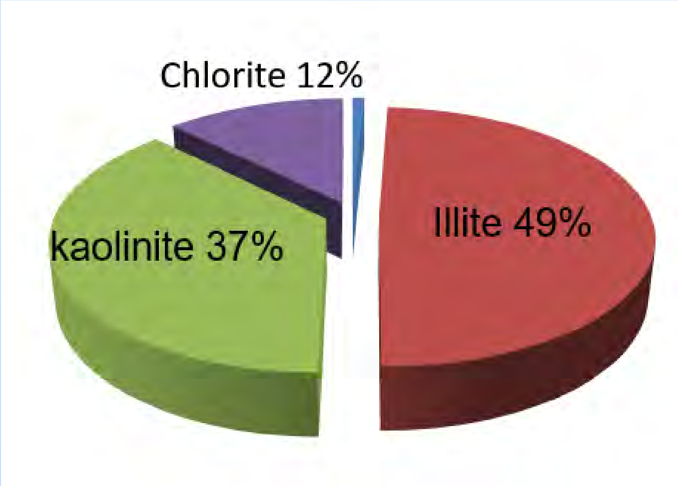


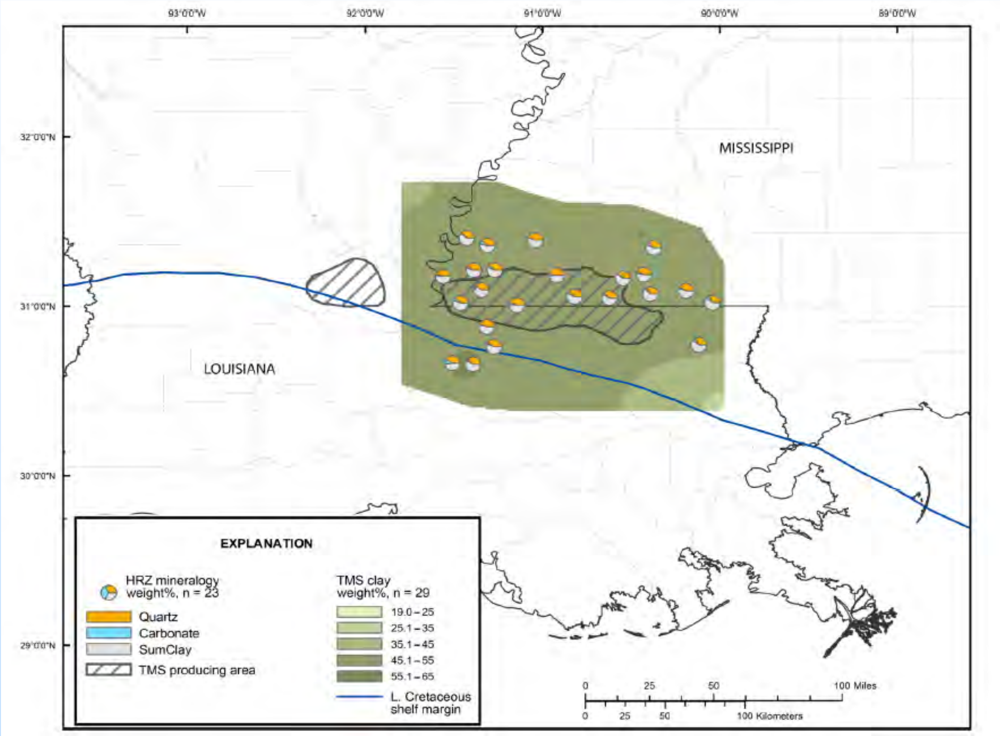
Paul Hackley 2018

Mokhtari and Jiang, 2017

Mineralogical Composition of TMS







Accomplishments to Date

- TMSL project officially started on May 2018.
- PMP was approved in July 2018.
- DMP is submitted.
- TMSL 1st consortium meeting will be held on September 6 & 7 in Lafayette, Louisiana.
- TMS Virtual Laboratory and data center will be established by October 2018.

Accomplishments to Date: TMSL 1st Consortium Meeting

- The objective of Task 1 is to **form a consortium of science and industry partners** to address critical questions about TMS to make the development of emerging shale more cost-efficient and environmentally-sound.

- An **advisory committee** comprised of industry representatives and technical area experts will assist and guide project progress as well as reviewing project results.

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

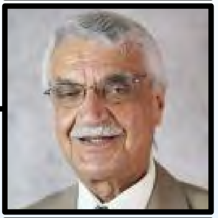
DOE Project Manager (Bruce Brown)

PI: Mehdi Mokhtari:
University of Louisiana at Lafayette

University of Louisiana at Lafayette (UL Lafayette)

Mehdi Mokhtari

A. Hayatdavoudi



Boyun Guo

Ning Liu

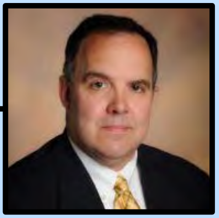
Rui Zhang

Missouri S&T: David Borrok

The University of Oklahoma (OU): Saeed Salehi

Los Alamos National Laboratory (LANL): Gilles Bussod

University of Southern Mississippi (USM): Chad Miller



Accomplishments to Date: TMS Virtual Laboratory

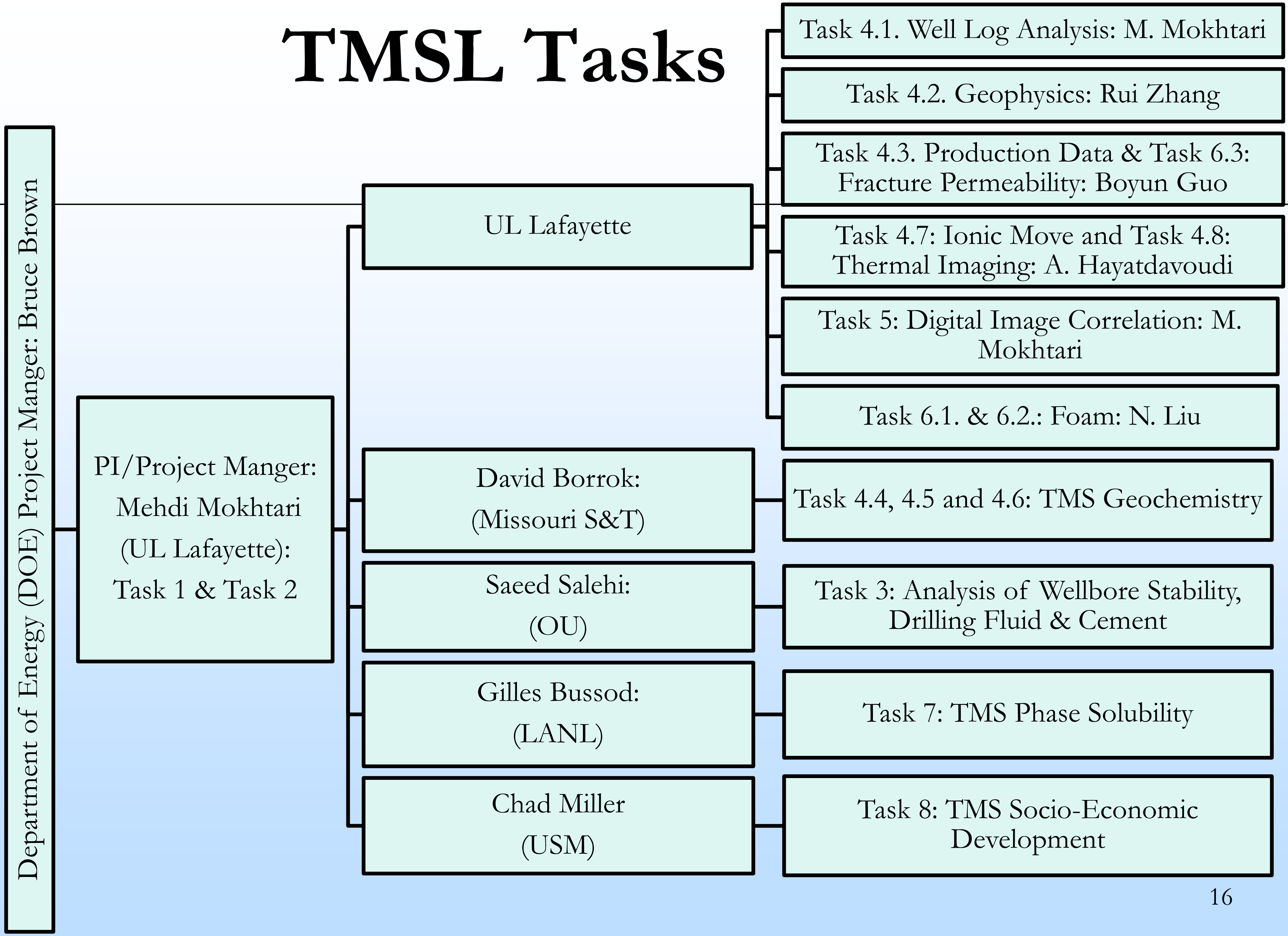
- The purpose of Task 2 is to collect and manage core and other well data from various industry partners and state agencies; catalog and store the physical samples and data; and make it available to interested parties for analysis. Task 2 develops a working virtual TMS laboratory at UL Lafayette. A TMSL website will be developed to facilitate data access to consortium members and approved researchers.

  - Whole cores of 6 wells are collected and stored.
  - Well logs, drilling reports, completion reports of 37 well are collected and stored.
  - Water and oil samples from 25 wells is scheduled for collection on September 4 & 5, 2018.
  - Production data of more than 70 wells are collected.
  - Cuttings from 37 TMS wells are collected and stored.

Sources of TMS Data and Core Samples

Other Possible Sources of TMS Data and Core Samples

TMSL Tasks


Department of Energy (DOE) Project Manger: Bruce Brown
PI/Project Manger: Mehdi Mokhtari (UL Lafayette): Task 1 & Task 2
UL Lafayette
Task 4.1. Well Log Analysis: M. Mokhtari
Task 4.2. Geophysics: Rui Zhang
Task 4.3. Production Data & Task 6.3: Fracture Permeability: Boyun Guo
Task 4.7: Ionic Move and Task 4.8: Thermal Imaging: A. Hayatdavoudi
Task 5: Digital Image Correlation: M. Mokhtari
Task 6.1. & 6.2.: Foam: N. Liu
David Borrok: (Missouri S&T)
Task 4.4, 4.5 and 4.6: TMS Geochemistry
Saeed Salehi: (OU)
Task 3: Analysis of Wellbore Stability, Drilling Fluid & Cement
Gilles Bussod: (LANL)
Task 7: TMS Phase Solubility
Chad Miller (USM)
Task 8: TMS Socio-Economic Development

TMS Drilling Issues:

- Drilling the lower section of the TMS has been troublesome due to an area called the "rubble zone": large pieces of rock that slough off.

- "Gumbo shales" in surface and intermediate sections.

- Difficulty in running centralizers: drag from the centralizers in such unstable wellbore.

- Post-fracture casing deformation: the casing deformation appears to get worse with attempts to perform the cleanout work.

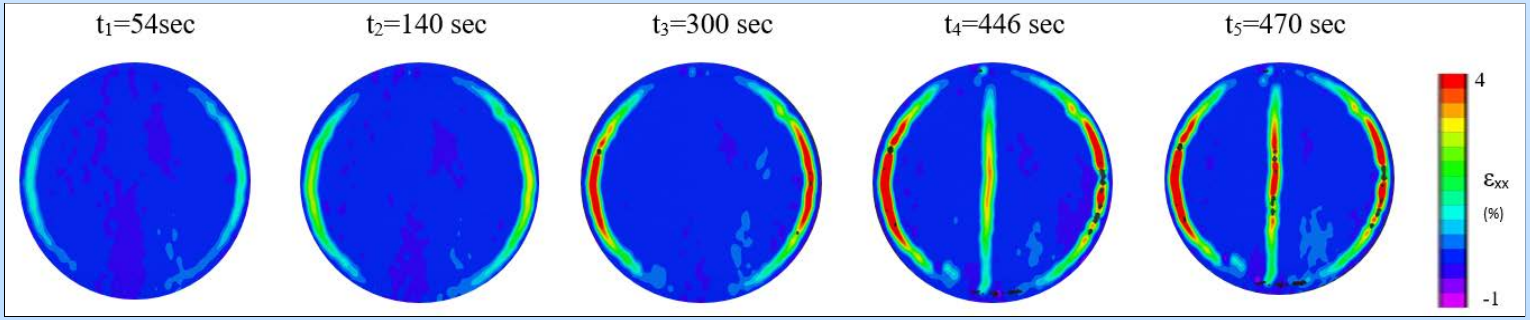
- Objective: To improve **wellbore integrity** by better understanding the sources of the wellbore instability issues, proposing innovative mud and cement design for the TMS.

TMS Well Integrity

1. Analyses of Current Drilling Practices in TMS.

2. Compatible Drilling Fluid & Cement Design Based on TMS Clay Content.

3. Digital Image Correlation and Numerical Simulation of Casing/Cement Bonding



Some TMS Formation Evaluation Issues

- The Passey method has traditionally been used to estimate the Total Organic Carbon (TOC) content of the TMS. The Passey method is based on overlaying the sonic transit time curve on the deep induction resistivity curve. Separation between sonic and resistivity logs illustrates the presence of organic-rich formations.

- **The presence of high clay content, which usually causes wellbore enlargement in TMS wells, can lead to poor sonic data. Therefore, the separation of sonic and resistivity logs can be artificially high due to wellbore conditions.**

- The presence of pyrite affects both the resistivity and density of shale samples since pyrite is a semi-conductor and is typically denser than most other minerals (e.g., clays, quartz, calcite, etc.) in these shales.

- **The presence of pyrite can lead to errors in TOC calculations since the conventional method for TOC calculation is based on infinite resistivity of minerals in the formation while pyrite can act as semi-conductive material.**

Improving TMS Formation Evaluation

- To improve TMS **formation evaluation** using laboratory techniques for the evaluation of mineralogical composition, organic content, and produced-water chemistry as well as well log and geophysical analysis:

- TOC and mineralogical composition will be analyzed using laboratory techniques of pyrolysis, resistivity, density, ultrasonic, XRD and XRF and the laboratory data will be integrated with well logging and seismic data.

- TMS water samples will be analyzed using Ion Chromatography-Inductively Coupled Plasma Mass Spectrometry (ICP), Metal-free ion chromatography (IC).

- Ionic Movement between TMS Cores and Water will studied using Ion Selective Electrodes such as: Ca, Mg, and Na.

Fracture Mechanics & Fracture Geometry

- One of the main questions with regard to Hydraulic Fracturing technology is still debated: How does the fracture geometry look like?

- Several TMS fractured wells have demonstrated excessive water production which might be attributed to the vertical growth of fractures to the water zones in the Lower Tuscaloosa sands.

- Excessive water production especially occurs when operators try to land the well in the lower section of TMS to avoid issues with the "rubble zone".

- Due to high clay content, ductile behavior of TMS and its interaction with water and proppant is critical to understand.

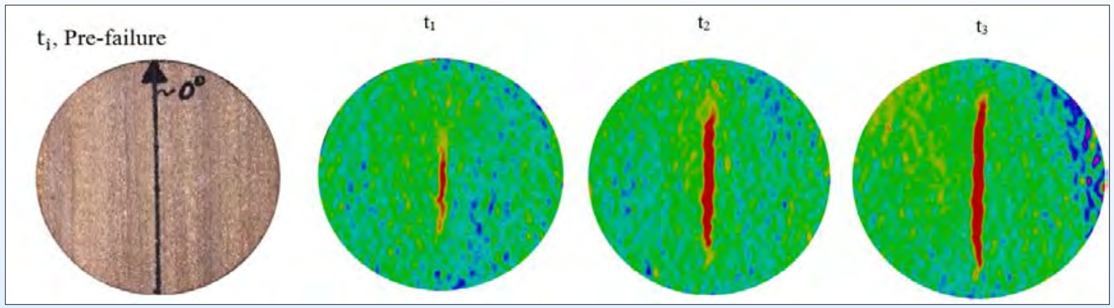
"Seeing is Believing" Using Digital Image Correlation (DIC) to Analyze TMS Fracture and Creep Behavior

- DIC is based on a high-speed camera recording of an object monitoring the random contrast speckle pattern painted at facing surface of the specimen.

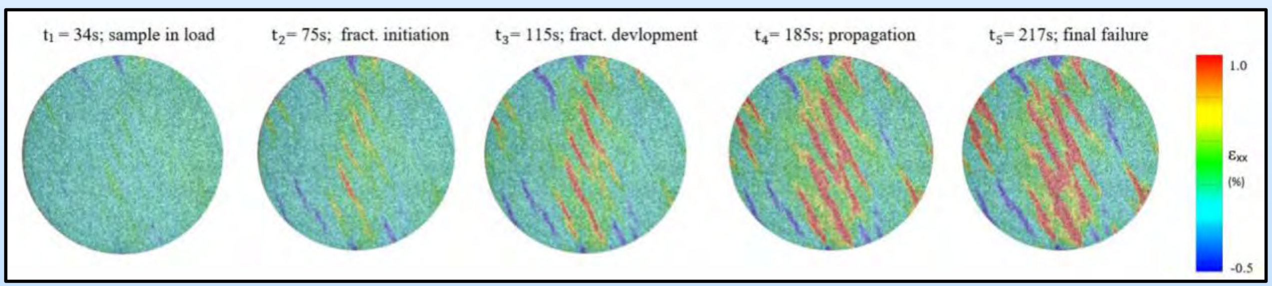
- To improve **hydraulic fracturing** performance in TMS by better understanding on the role of geologic discontinuities on fracture growth and shale creep behavior using digital image correlation technique.

“Seeing is Believing” Using Digital Image Correlation (DIC) to Analyze TMS Fracture and Creep Behavior

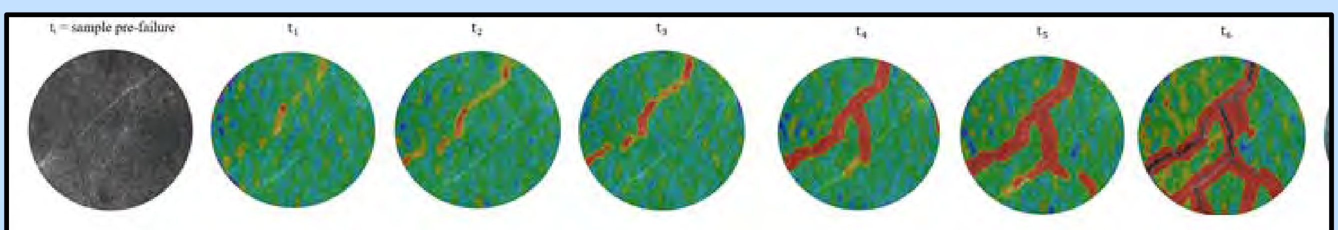
Isotropic: Central Vertical Fracture



Vertical Transverse Isotropic: Lamination (15-deg) Activation

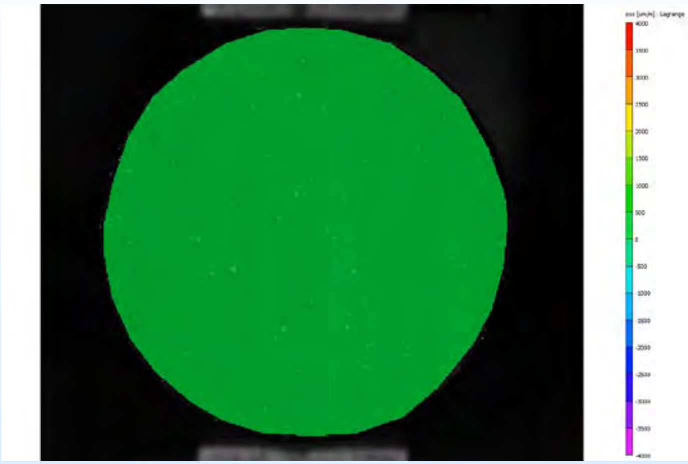


Anisotropic with Natural Fractures: Complex Fracture Mechanism

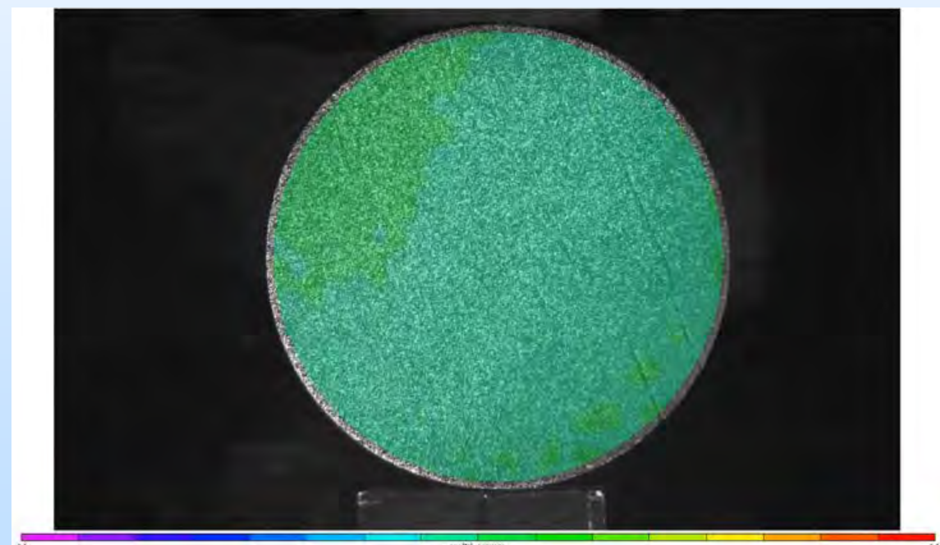


“Seeing is Believing” Using Digital Image Correlation (DIC) to Analyze TMS Fracture and Creep Behavior

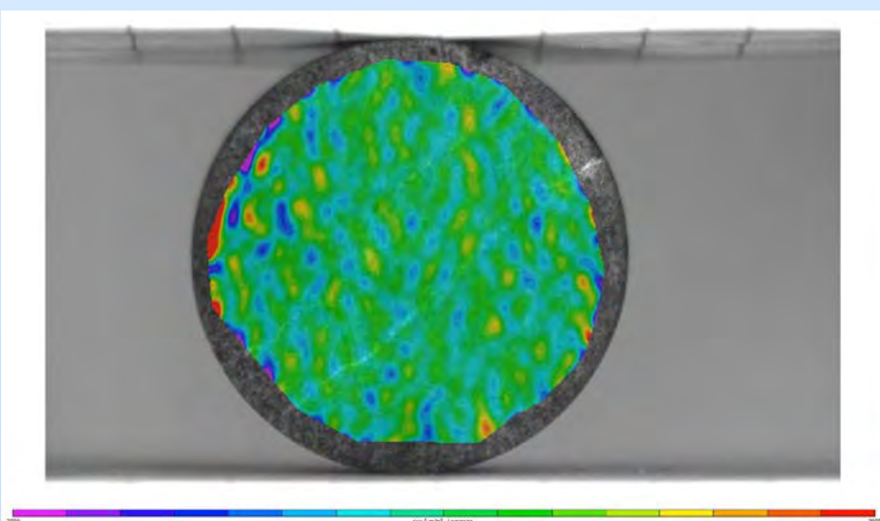
Isotropic: Central Vertical Fracture



Vertical Transverse Isotropic: Lamination (15-deg) Activation



Anisotropic : Complex Fracture Mechanism



Investigation of CO_2 Foam Generation with Nanoparticles for TMS

- Due to high clay content, water/rock interaction is a major issue for the TMS fracturing performance.

- As an alternative, nanoparticle-stabilized CO_2 foam as a fracturing fluid for TMS is investigated.

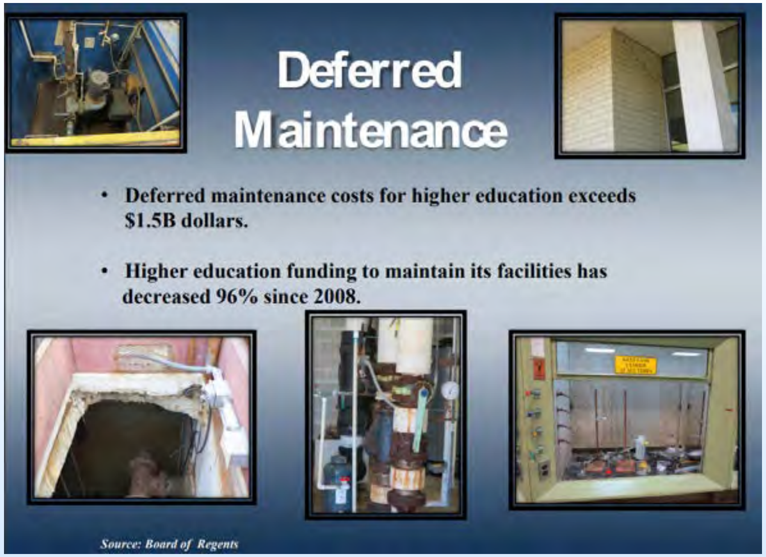
- Investigate the process of particle-stabilized CO_2 foam generation under reservoir conditions.

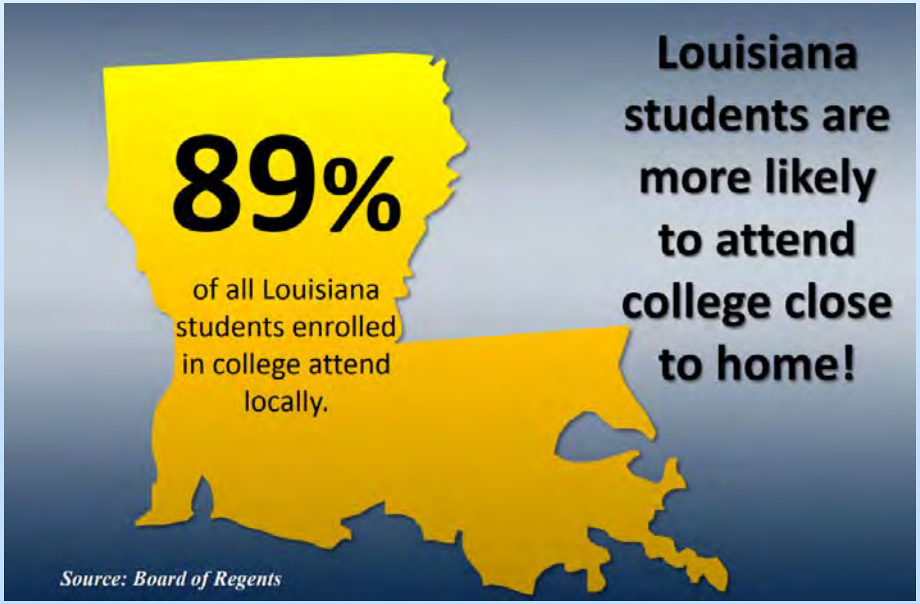
- Factors such as particle concentration, brine/CO_2 phase ratio, brine salinity, and temperature effect on CO_2 foam generation and the foam stability will be investigated.

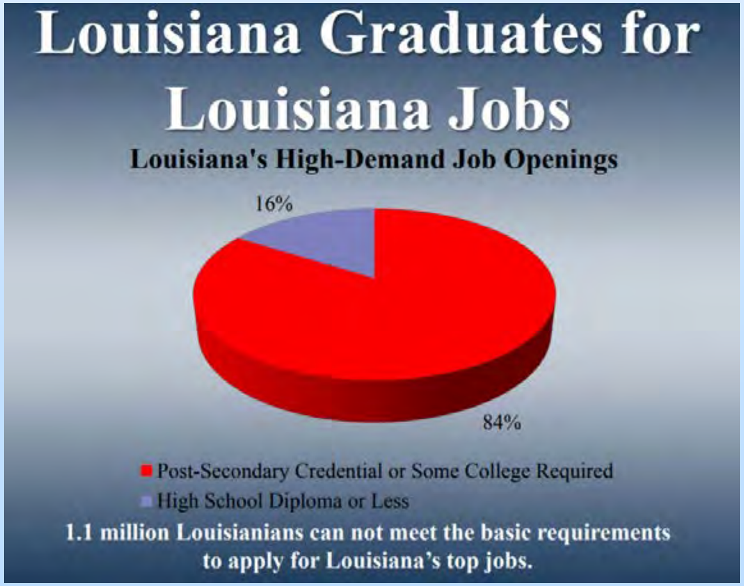
- To investigate the application of stable **CO_2 foam** and **super-hydrophobic proppants** for improved reservoir stimulation.

Evaluation of the Major Needs/Socioeconomics for the Development of TMS

- Sixty percent of the population in the rural southern regions of Mississippi have a high school diploma or less and over 17,000 are unemployed. Local, state, and federal government is by far the largest employer in the region followed by retail. (Miller & Bolton 2016)







Evaluation of the Major Needs/Socioeconomics for the Development of TMS

- Analyze supply chain in TMS operations by interviewing various industries involved in the development of TMS.

Community Engagement

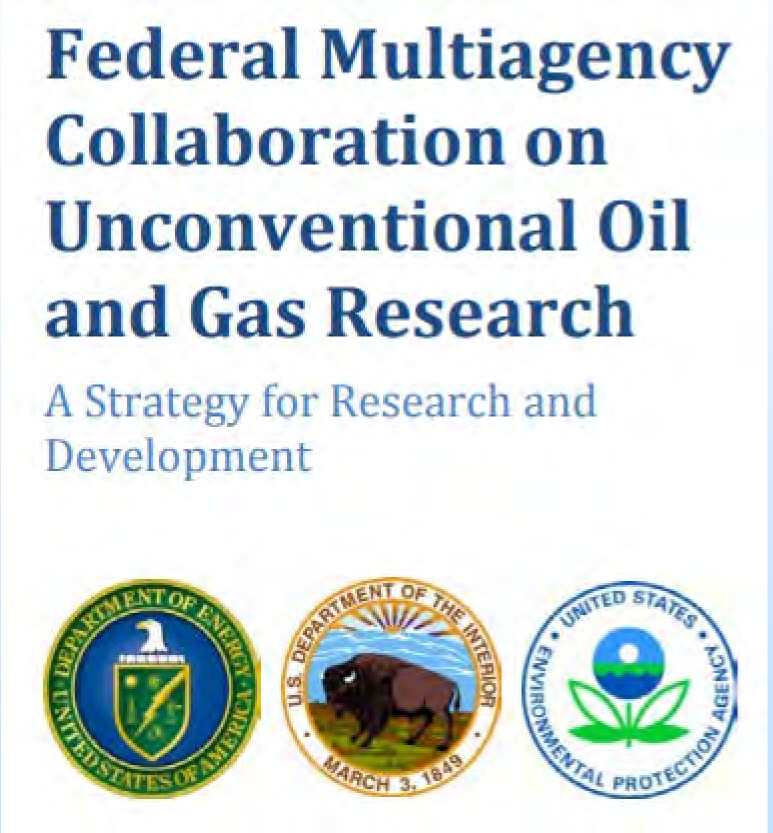
- Evaluation of workforce training programs through evaluation of possible, eventual hiring of local workers, when possible as well as the training needs to develop transferable skills for cyclical periods.
- Business assistance and diversification programs will be identified to retain the local suppliers of the oil and gas extraction industry during cyclical periods.
- Organize a multi-disciplinary training event to present and share the findings of this project with TMS stakeholders including public officials, community leaders, industry, and researchers.
- To prepare better **socio-economic environment** for TMS development by community engagement.

Synergy Opportunities

- Collaboration with USGS.

- Collaboration with other DOE unconventional projects such as: University Coalition for Fossil Energy Research.

- Brining more oil and gas industry on board for collaboration: e.g. Australis Oil & Gas, EOG, ExxonMobil, Total, BakerHughes.



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MISSISSIPPI DEPARTMENT OF ENVIRONMENTAL QUALITY

USGS
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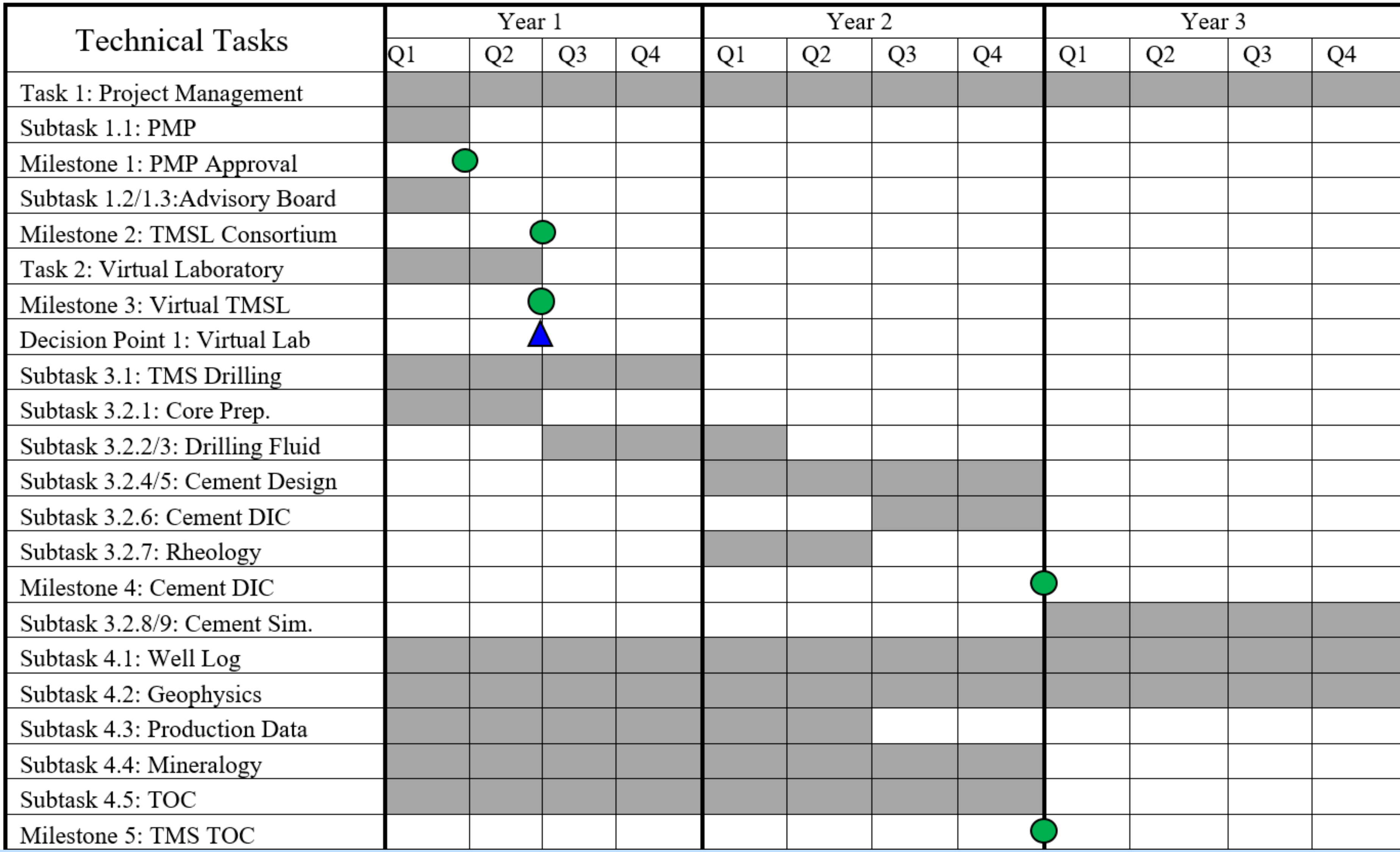
Appendix

Project Timeline



Project Timeline