Understanding and Controlling Sustainability of Hydraulic Fracture Permeability in Ductile Shales

FP00008114

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U.S. Department of Energy
National Energy Technology Laboratory
Addressing the Nation's Energy Needs Through Technology Innovation – 2019 Carbon Capture, Utilization, Storage, and Oil and Gas Technologies Integrated Review Meeting
August 26-30, 2019

Acknowledgment

This research is supported by

- Assistant Secretary for Fossil Energy, Office of Natural Gas and Petroleum Technology through the National Energy Technology Laboratory

  Under the U.S. DOE, Contract No. DE-AC02-05CH11231

- Chevron Energy Technology Company (advisor)
- Tuscaloosa Marine Shale Laboratory (through collaboration)

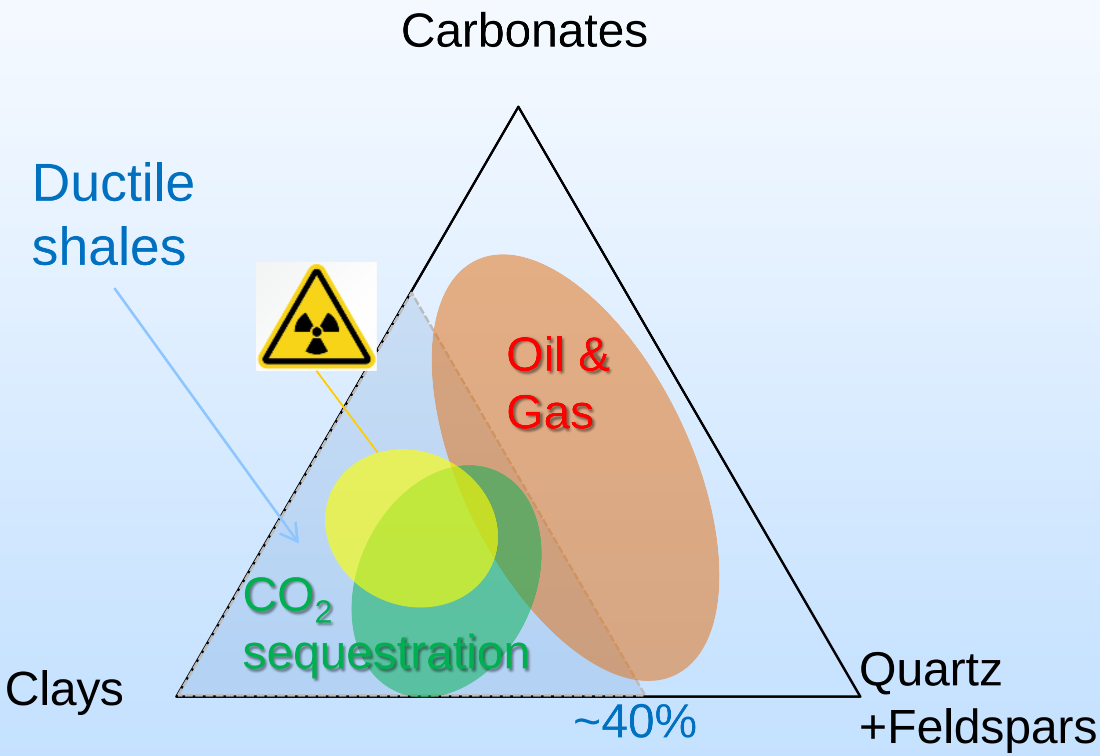
Presentation Outline

- Technical Status
  - Motivation & Background
  - Goal and Objectives
  - Anticipated Products and Impacts
  - Project Tasks and Activities
  - **Results so far**
- Accomplishment to Date
- Lesson Learned
- Synergy Opportunities
- Project Summary

Technical Status

Motivation and Background

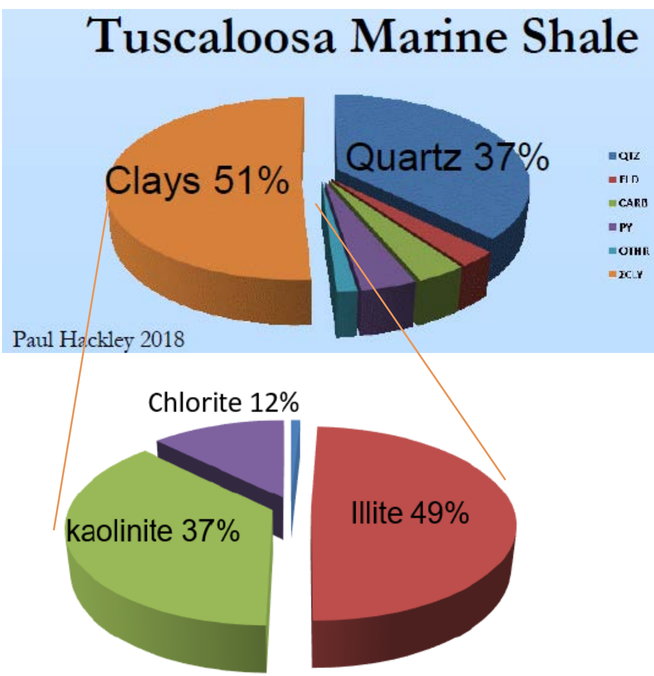
- Research focus on fracture closure and permeability loss in ductile shale.
- Normally, ductile, clay-rich shales **are not** oil/gas source rock

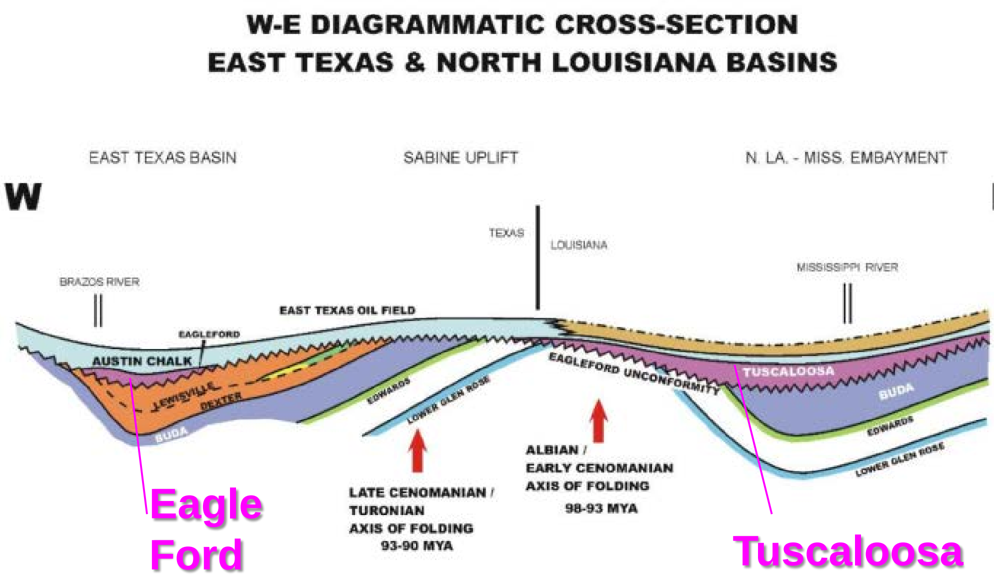


Motivation and Background

- Research focus on <u>fracture closure and permeability loss</u> in ductile shale.
- Normally, ductile, clay-rich shales **are not** oil/gas source rock
- **But** there are producing reservoirs consisting of ductile “problematic” shale.

For example….. [Tue. 10:45am SUBSURFACE PLENARY]





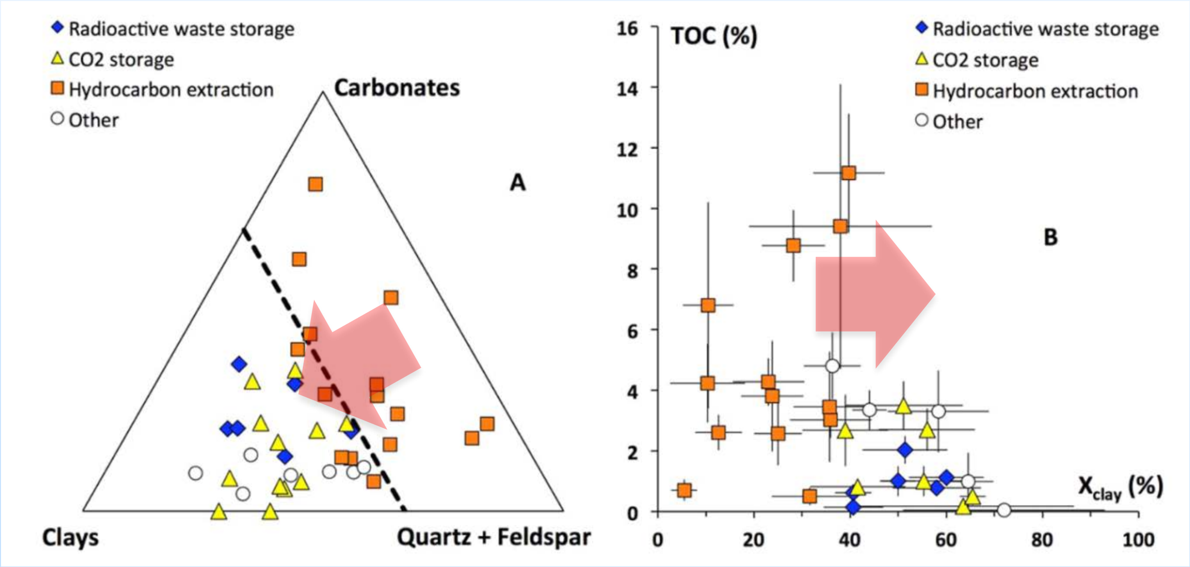
(M. Mokhtari, U. of Louisiana)

Motivation and Background

- Pristine, high-TOC, low-clay-content oil and gas shale formations will be less available

  →Expected increasing needs to produce from shales in which hydraulic fractures are difficult to induce and sustain

- Need to understand the behavior of ductile/swelling shales for efficient and economical production—Particularly for the long-term sustainability of fractures
- Need to develop/improve a technology



Shifts in available source shale

Ductile shales with high clay content (>~40%) are currently difficult to exploit as a resource rock although hydrocarbons can still be found in them (Modified from Bourg, 2015).

Project Goals/Objectives

2016-2018 Objectives

1. Understand how the proppant deposition characteristics affect the sustainability of the fracture conductivity
2. Predict how hydraulic fractures in brittle and ductile shales behave over time to reduce their aperture and permeability

Understand the process via long-term, in-situ visualization

2018-2020 (current) Objectives

1. Investigate how temperature and fluid chemistry affect short and long-term compaction of ductile shale fractures (clays+organics)

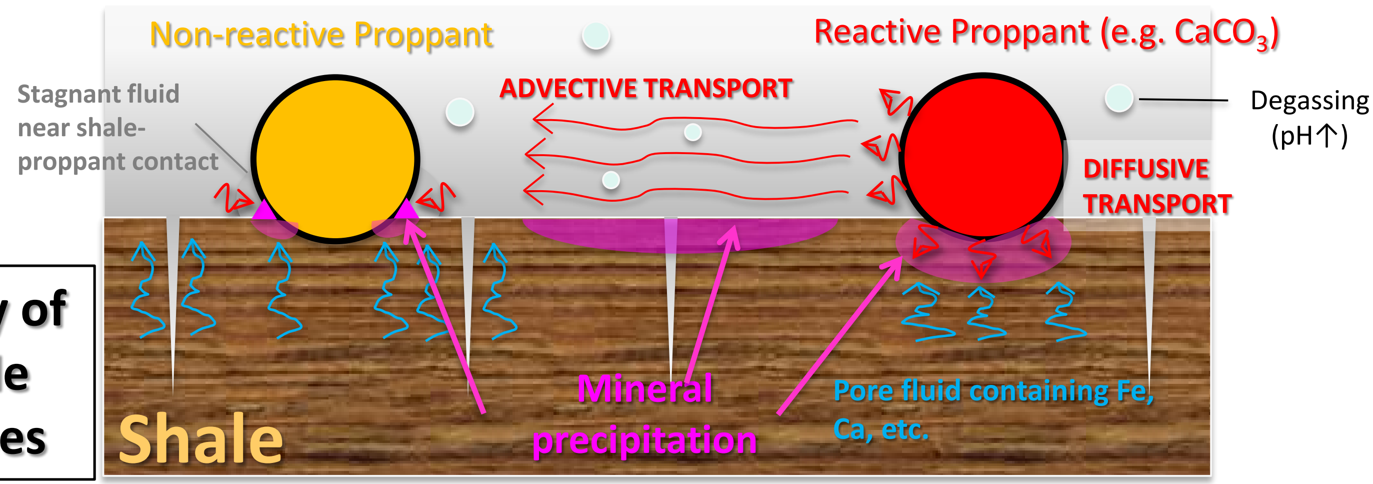
   ←Not fully investigated by our previous project scope

2. **Develop a technology for controlling the rate of fracture compaction** by manipulating the THMC processes (with an emphasis on chemistry)

Project Goals/Objectives

Key-Concept: Chemical control of fracture sustainability

A variety of possible processes



Reduce fracture deformation and proppant embedment via mineral precipitation

- Precipitation around proppant-shale contacts (within stagnant flow zone)
- Precipitation beneath proppant (direct proppant-shale contact)
- Precipitation directly on fracture surface
- Trade-off with near-fracture permeability reduction→ Needs optimization

Anticipated Products and Impacts

Anticipated products/Expected outcomes

- **Experimental tool** for investigating ductile shale fracture compaction under elevated temperature and with active fluid/proppant/shale chemical reaction
- **Numerical modeling tools** and the simulation methodology for coupled thermal-hydrological-mechanical-chemical (THMC) processes, based upon ToughReactMech code
- **Laboratory and modeling data** correlating fluid/proppant/shale properties, time-dependent compaction, and permeability changes
- **Methodologies for improving sustainability of fractures in ductile shales, based upon chemical manipulation of shale fractures**

Impacts (our ultimate goals)

- Increase economically producible hydrocarbon resources in ductile shale reservoir
- Help oil and gas production from currently existing reservoirs/formations in ductile shales

Project Tasks and Activities

Key Project Tasks

1. Experimentally **measure** long-term, single-grain-scale and core-scale **ductile shale fracture deformation** for a range of temperature and chemistry (fluid chemistry and shale type) using previously developed and newly fabricated tools
2. Investigate the possibility of long-term **fracture compaction reduction via mineral precipitation** from reservoir fluids and tailored proppant mineralogy and additives
3. Use **coupled THMC modeling** (incl. reactive transport) to identify candidates for ideal fluid+proppant+shale combinations. Verify and demonstrate the results by lab. experiments.

Project Tasks and Activities (FY2019)

Laboratory Tasks	• **Acquisition of shale core samples and baseline property characterization (Subtask 2.1)** Ductile, clay-rich samples are acquired from the field. Currently, core samples from MSEEL and TMSL are being used • **Partial modification of compaction visualization system (Subtask 2.2)** Modification of the existing system in preparation for high temperature use • **Fabrication of high-temperature, harsher-chemistry test cell (Subtask 2.3)** Designing and fabrication of a new visualization test cell • **Preliminary tests using a modified high-T test system (Subtask 2.4)** Fracture compaction tests using the modified test system • **Preliminary proppant/shale-fluid reaction tests (Subtask 2.5)** Reaction between fluid, shale, and possibly proppant will be examined for possible precipitation of minerals on shale
Modelling Tasks	• **Initial selection of proppant, shale, fluid combinations and THMC model setup (Subtask 3.1)** Identify possible candidates for fluid, shale, and proppant combinations that can produce mineral precipitation on the shale surface. TREACTMECH will be set up for the modeling. • **Single indenter/proppant-scale shale deformation modeling using TREACTMECH (Subtask 3.2)** Functions in TREACTMECH will be extended for varying elastic moduli and permeability as a function of mineralogical and porosity changes in shale.

Project Tasks and Activities (FY2020)

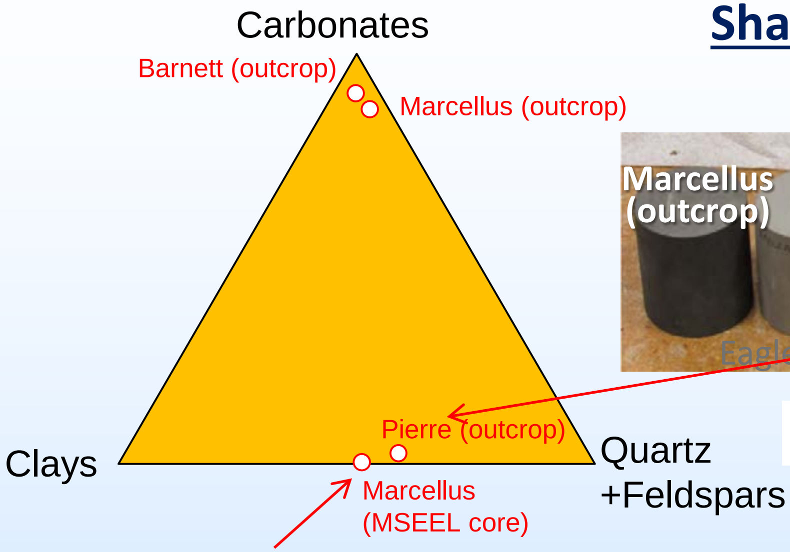
Laboratory Tasks	**Higher-temperature, long-term shale fracture compaction/proppant embedment tests (Subtask 2.6)** o Long-term compaction (+visualization) tests with mineral precipitation o Post-mortem local hardness measurement via indentation tests o SEM, mineralogical characterization tests
Modelling Tasks	**Multi-grain/asperity simulations of proppant-embedment/asperity deformations (Subtask 3.3)** o Multi-grain model development based upon the single-grain model in Year 1 o Predictive THMC modeling of laboratory experiments **THMC modeling of laboratory-observed fracture closure (Subtask 3.4)** o Prediction and comparison of proppant-containing fracture closure with the lab experiments

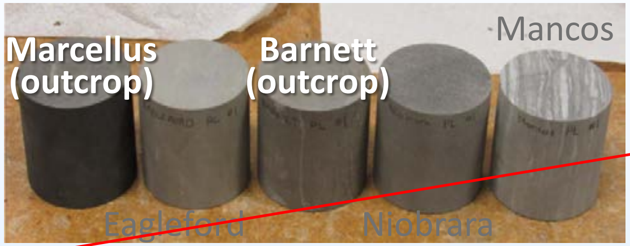
Results (Aug. 2018—Aug.2019)

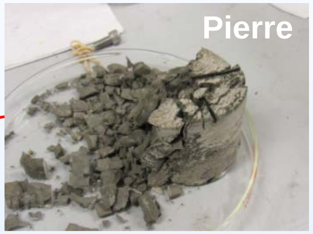
Laboratory Experiment

Results (Aug. 2018—Oct.2018)

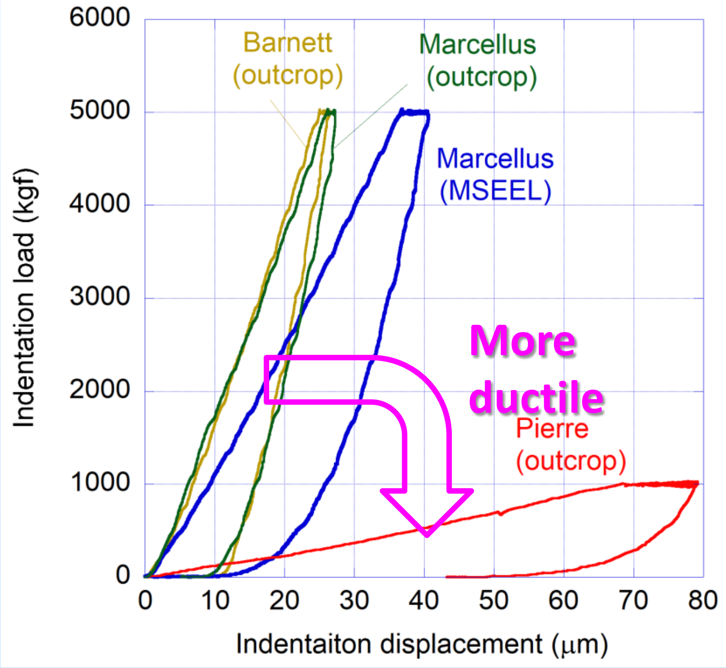
Shale samples and baseline characterization





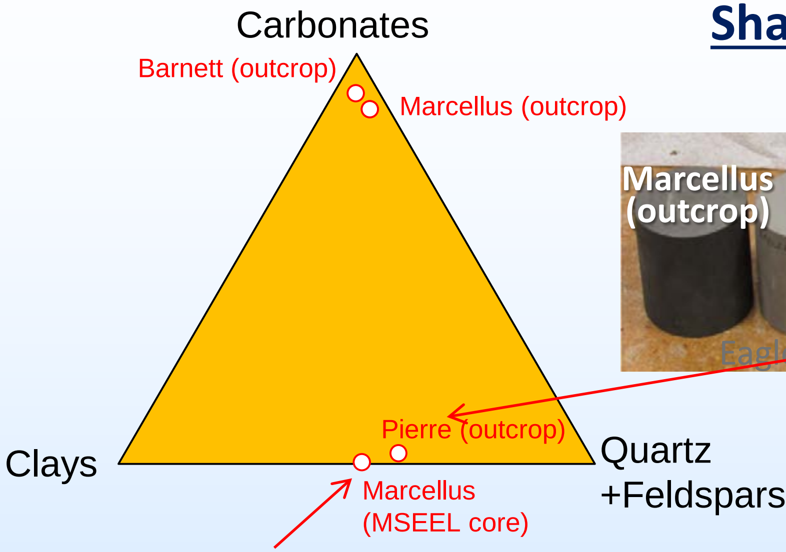


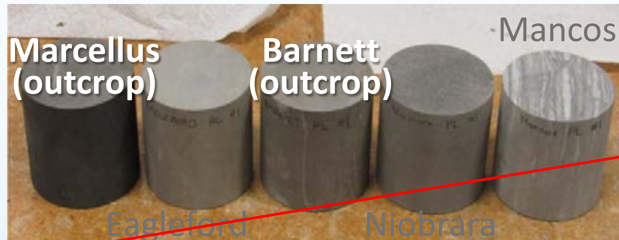
Short-term (30 min hold) indentation creep tests

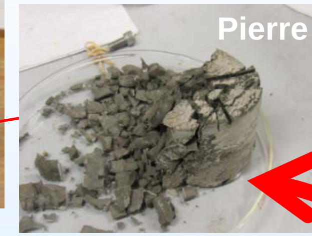


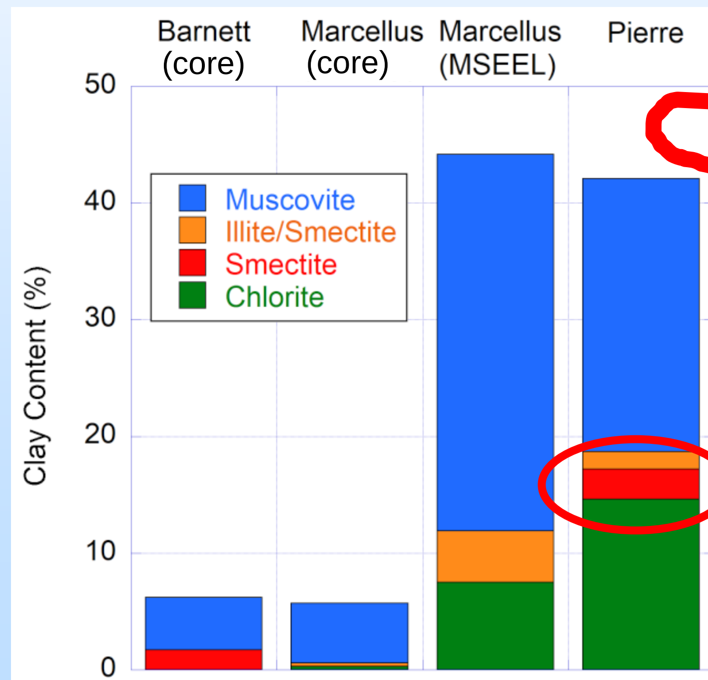
Results (Aug. 2018—Oct.2018)

Shale samples and baseline characterization



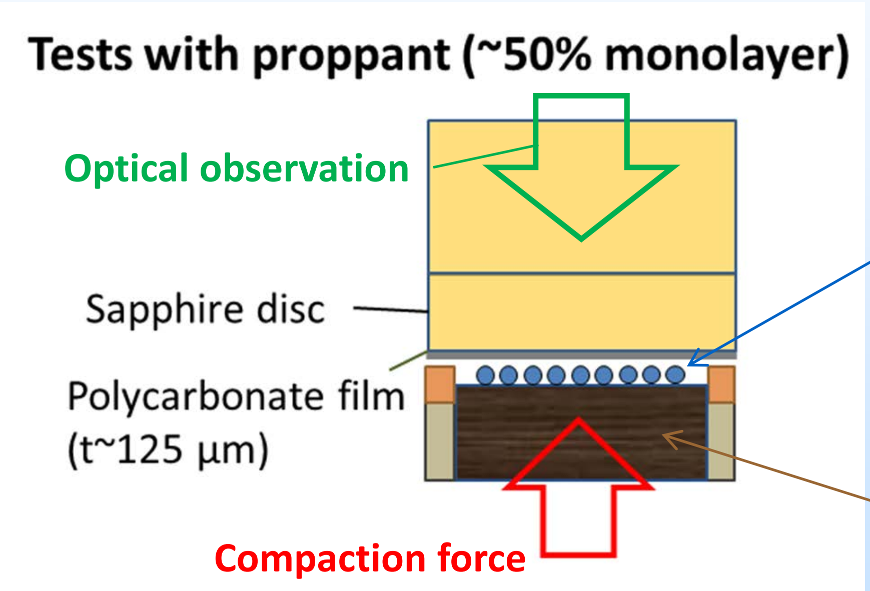




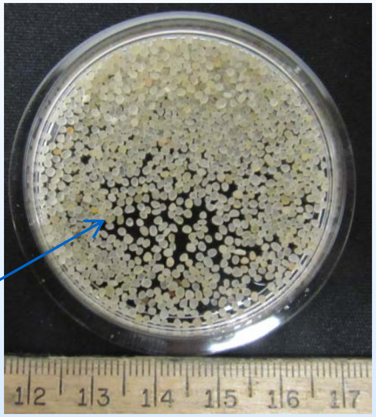


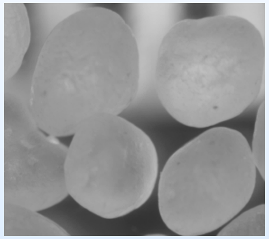
Results (Aug. 2018—Oct.2018)

Fracture closure and proppant crushing/embedment visualization experiment



Quartz sand (dia.~1 mm)

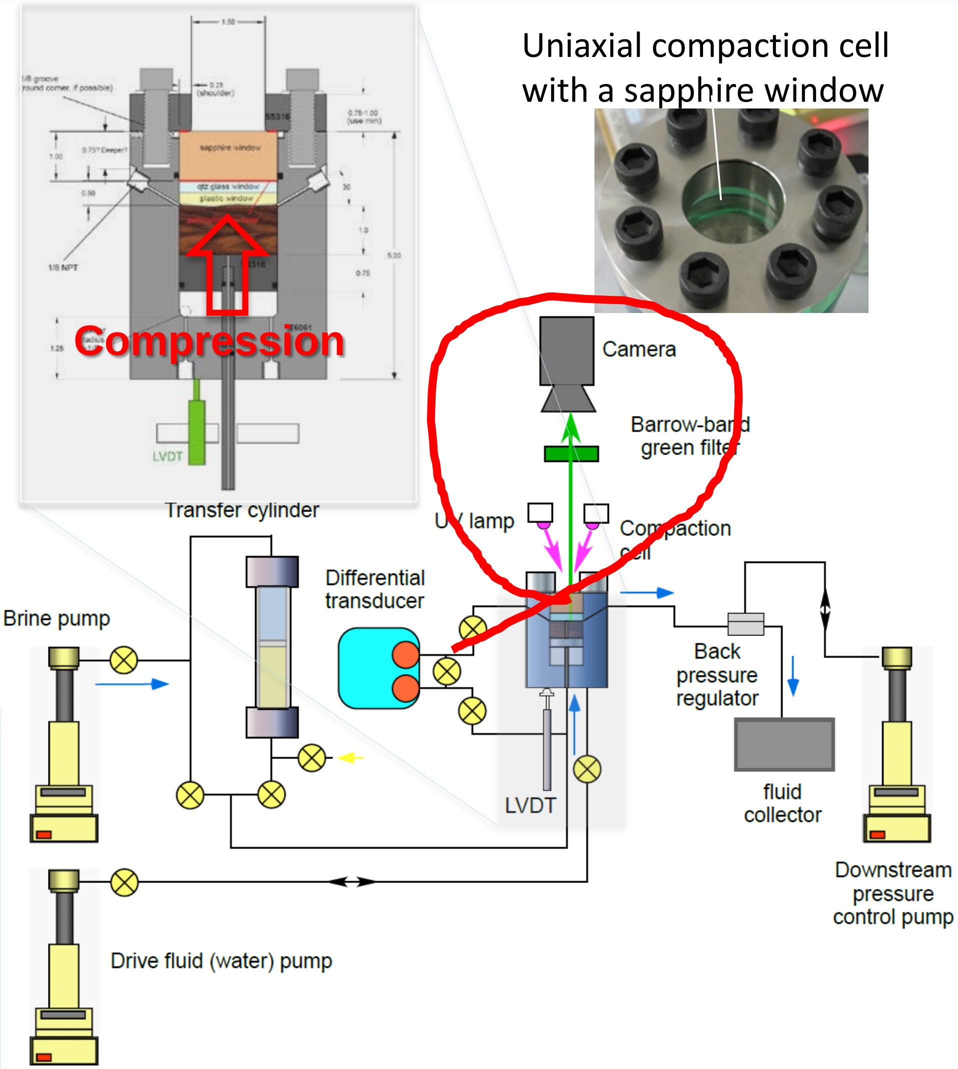


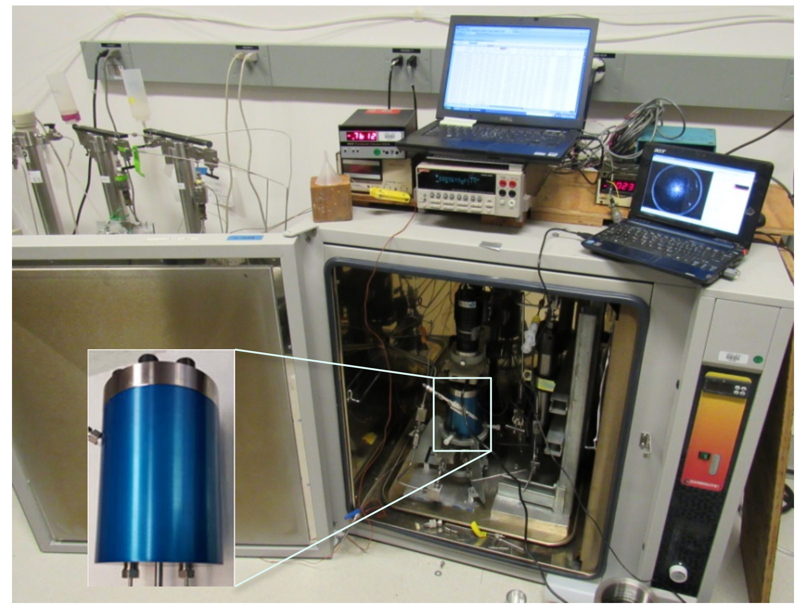


Shale disc (dia. ~44 mm)

Results (Aug. 2018—Oct.2018)

Fracture closure and proppant crushing/embedment visualization experiment





Current test conditions

Axial effective stress: 3,920 psi (27 MPa)

Pore pressure: 1,500 psi (10.3 MPa)

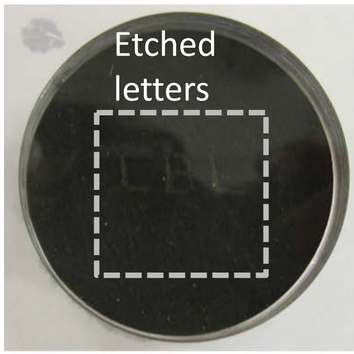
Test temperature: Ambient and 60˚C

Fluid: Brine (5%wt NaCl aq.)

Results (Aug. 2018—Oct.2018)

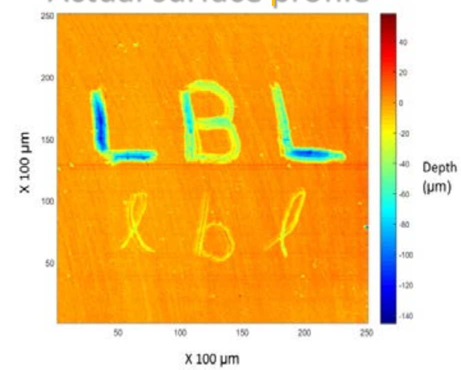
(Semi-)Quantitative fracture aperture measurement via UV-induced fluorescence

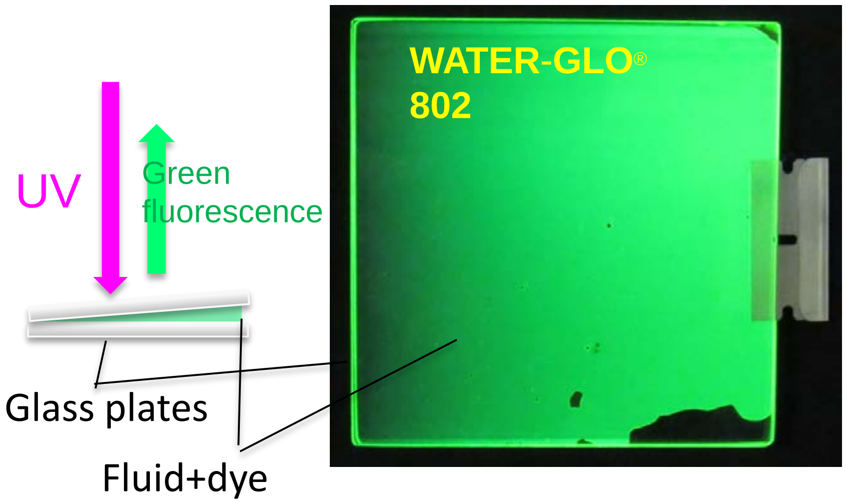
- UV-induced fluorescence was used to obtain quantitative fracture aperture distribution

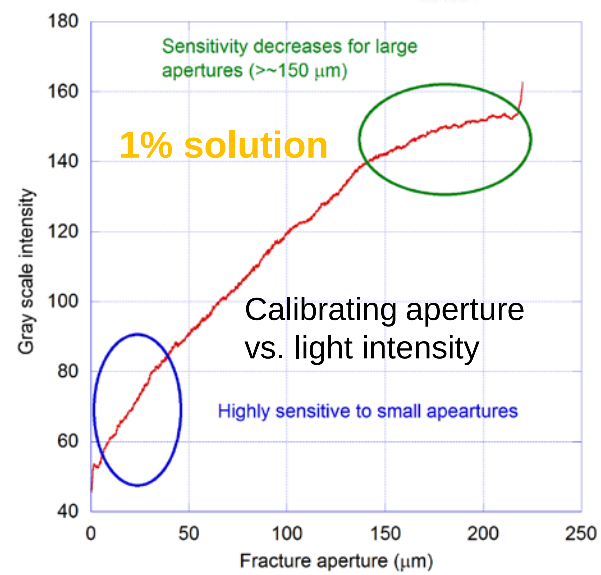


a. Cover glass only

Actual surface profile

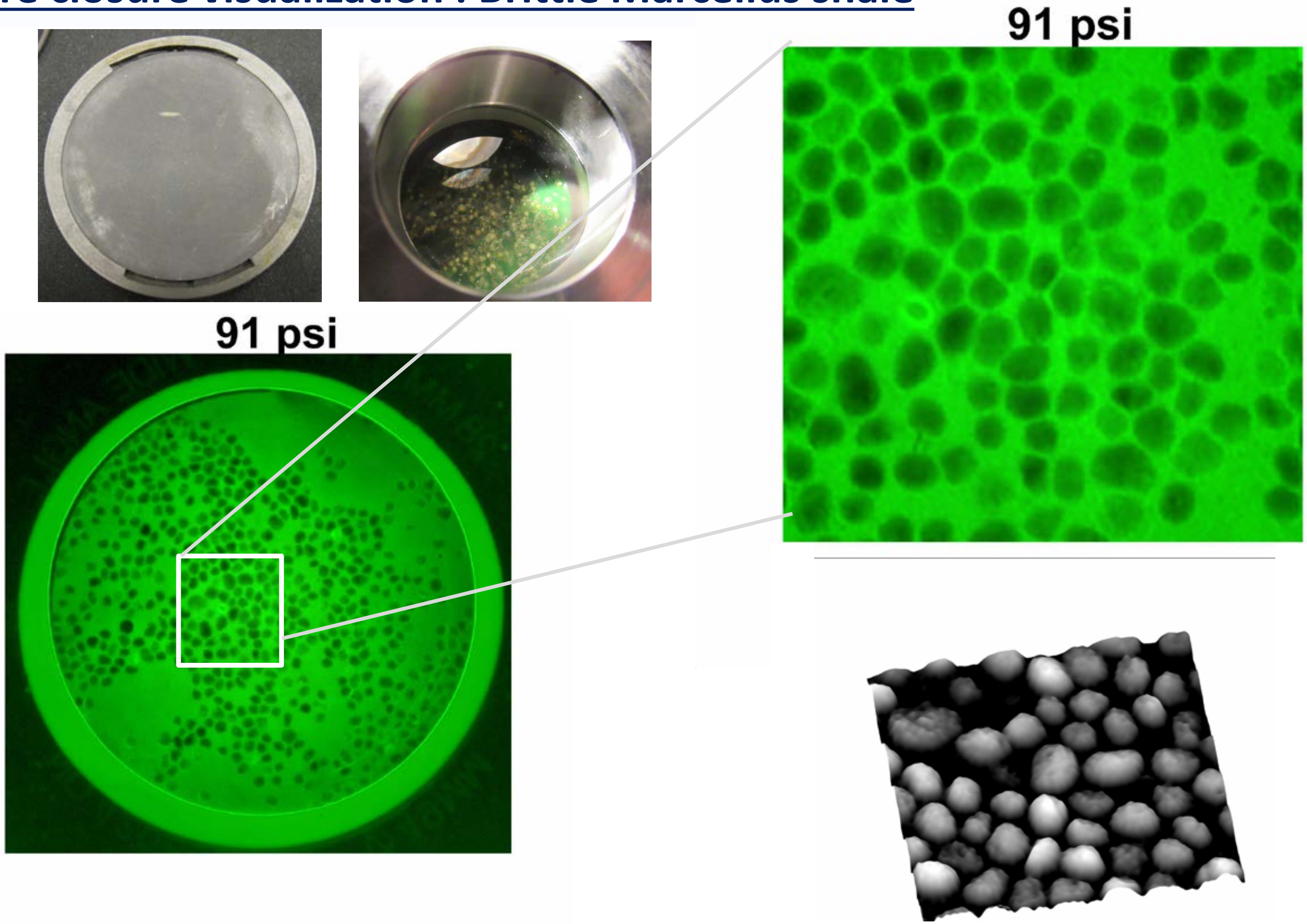






Results (Aug. 2018—Oct.2018)

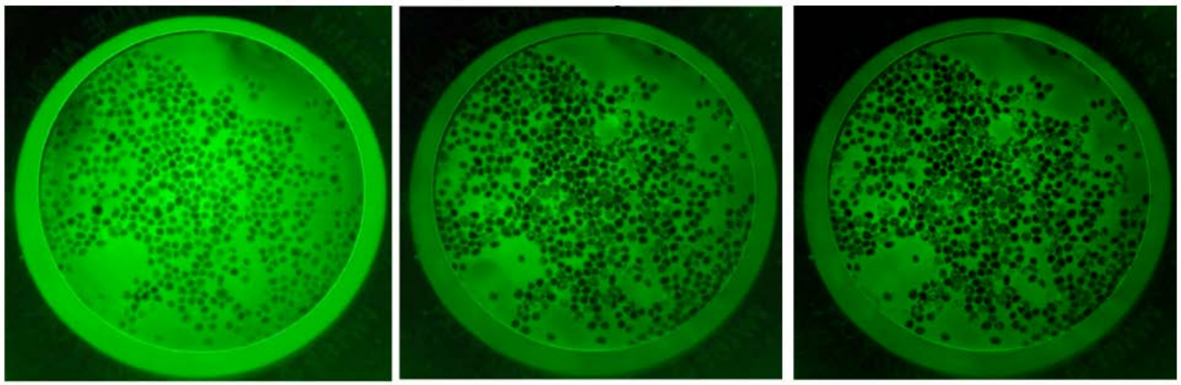
Fracture closure visualization : Brittle Marcellus shale

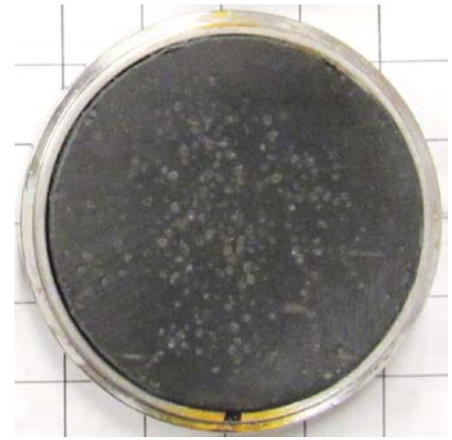


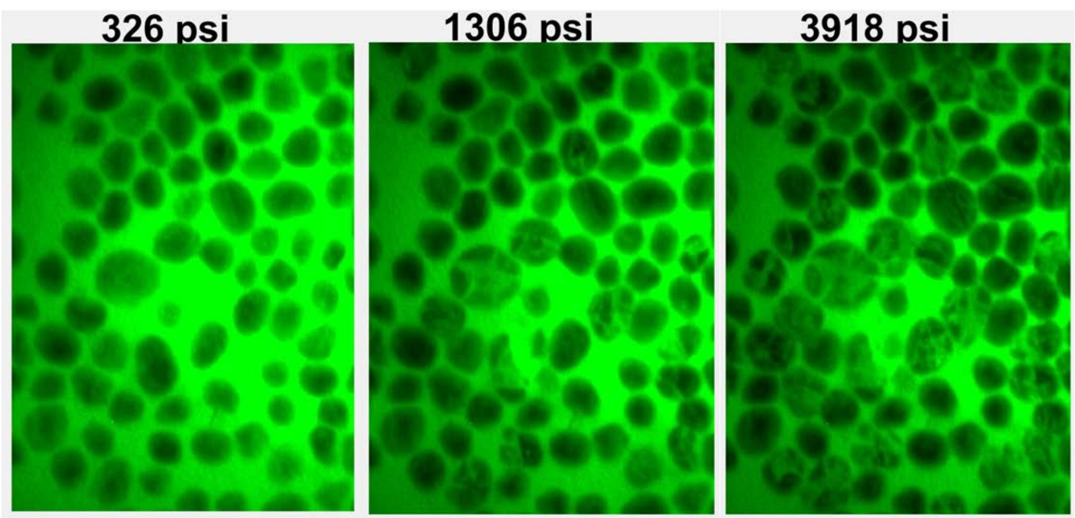
(Backup slide 1)

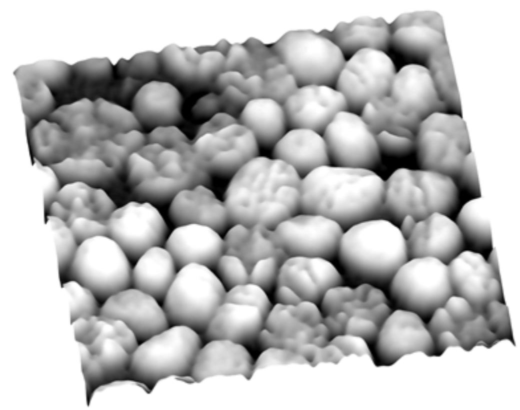
Fracture closure visualization : Brittle Marcellus shale

196 psi | T=0/3984 psi | T=15 days



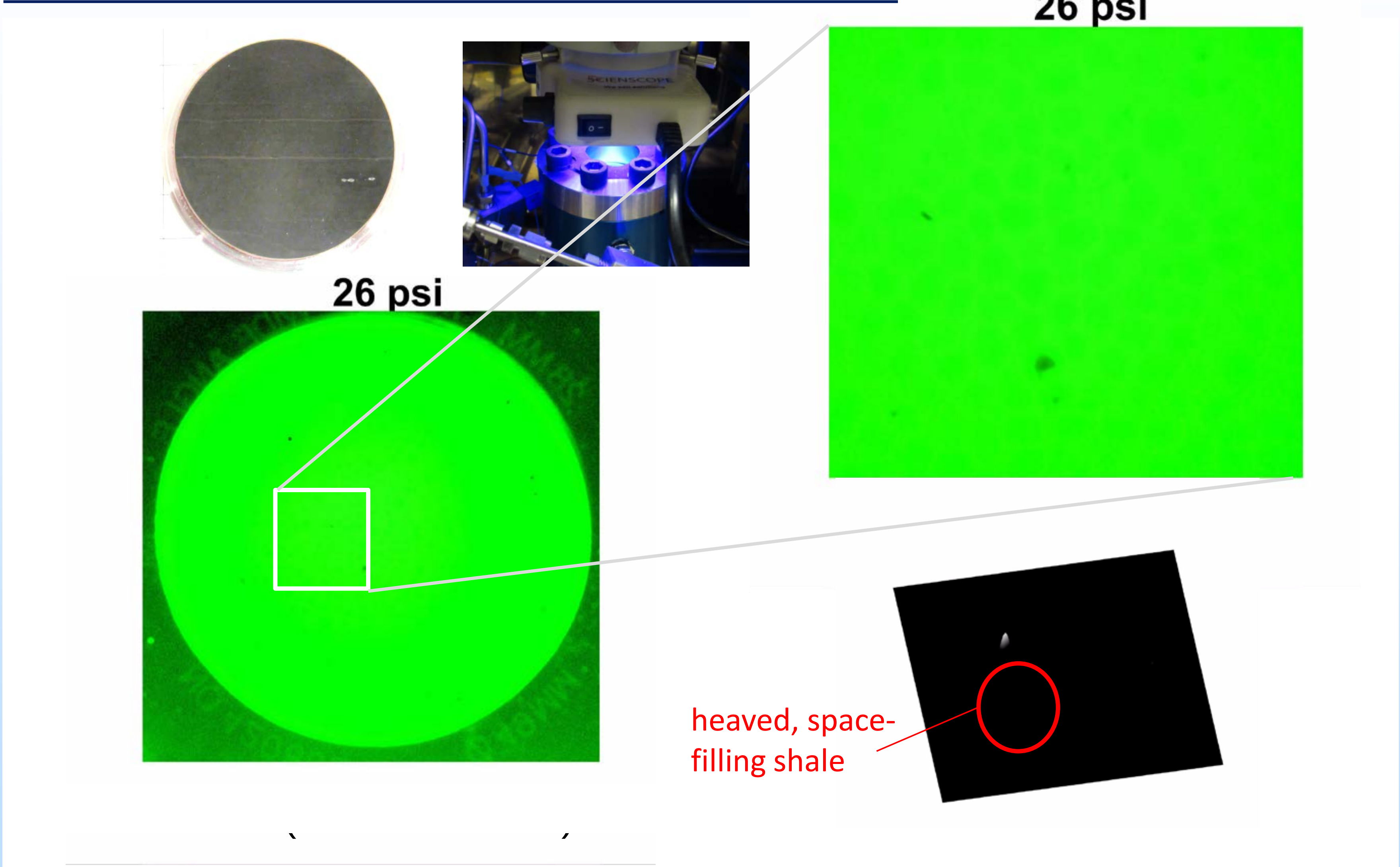






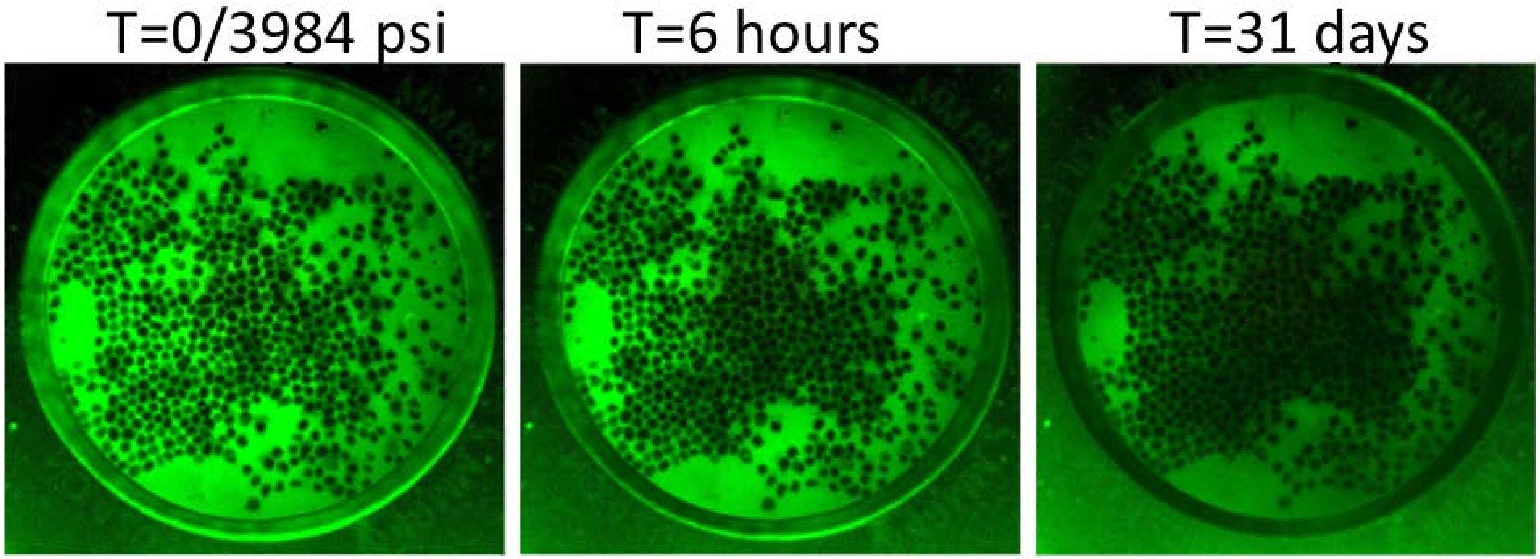
Results (Aug. 2018—Oct.2018)

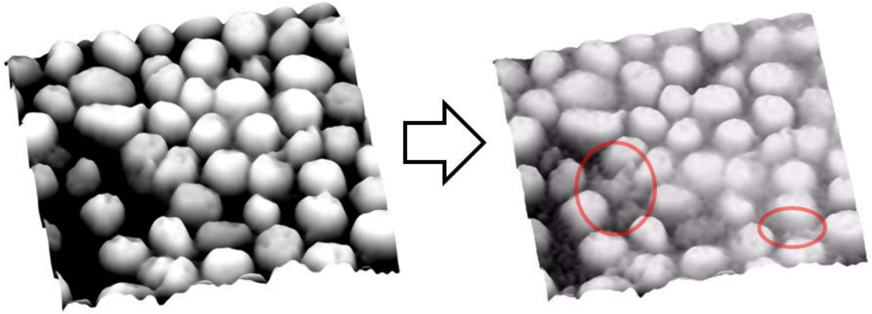
Fracture closure visualization : Ductile MSEEL shale

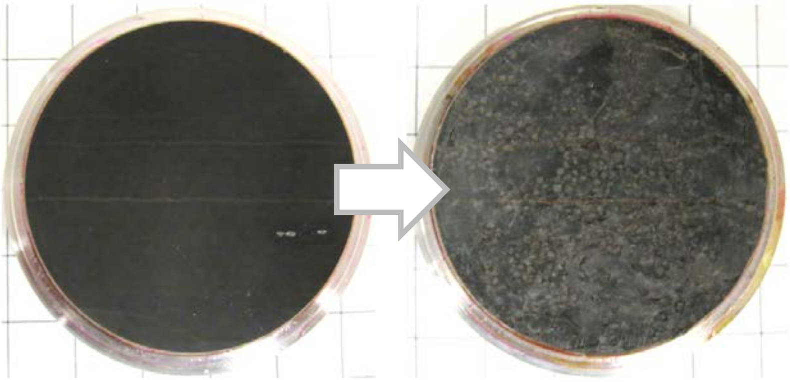


(Backup slide 2)

Fracture closure visualization : Ductile MSEEL shale

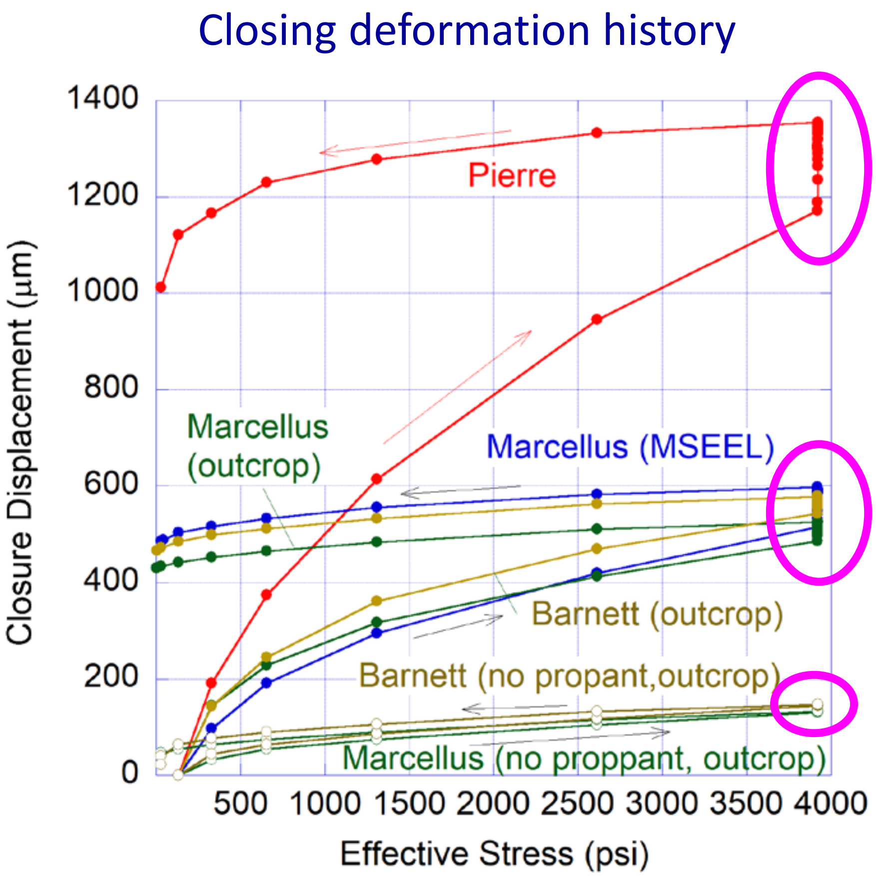




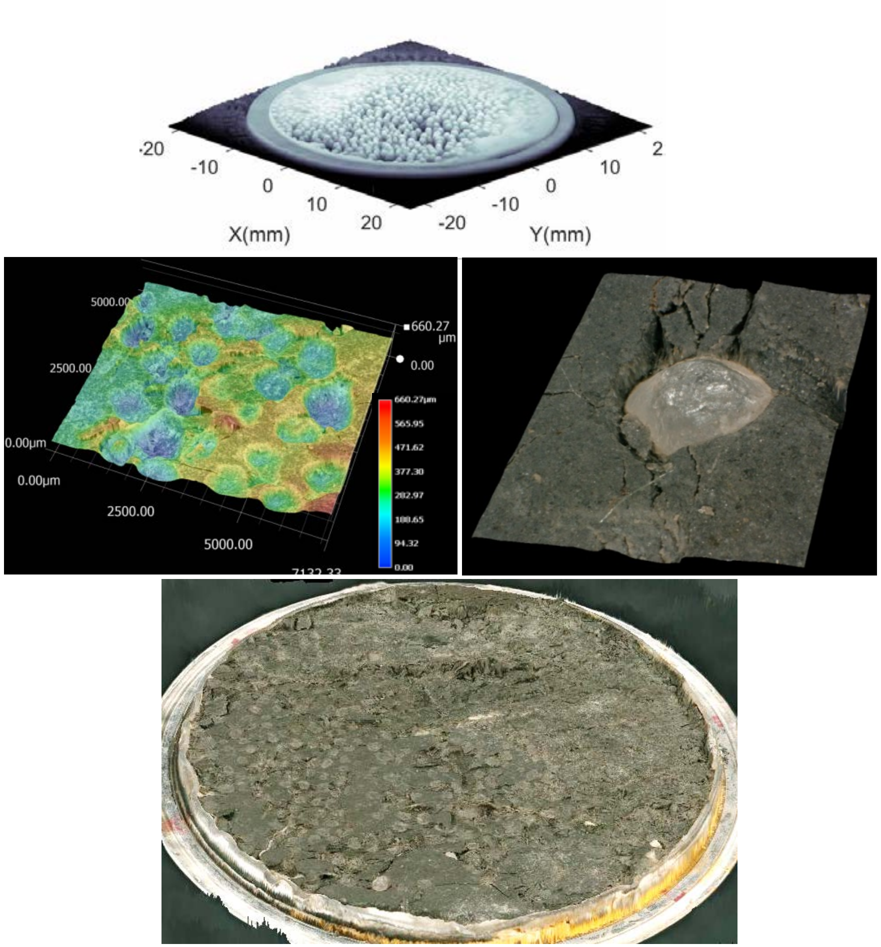


Results (Aug. 2018—Oct.2018)

Stress-fracture closure history for various shale samples



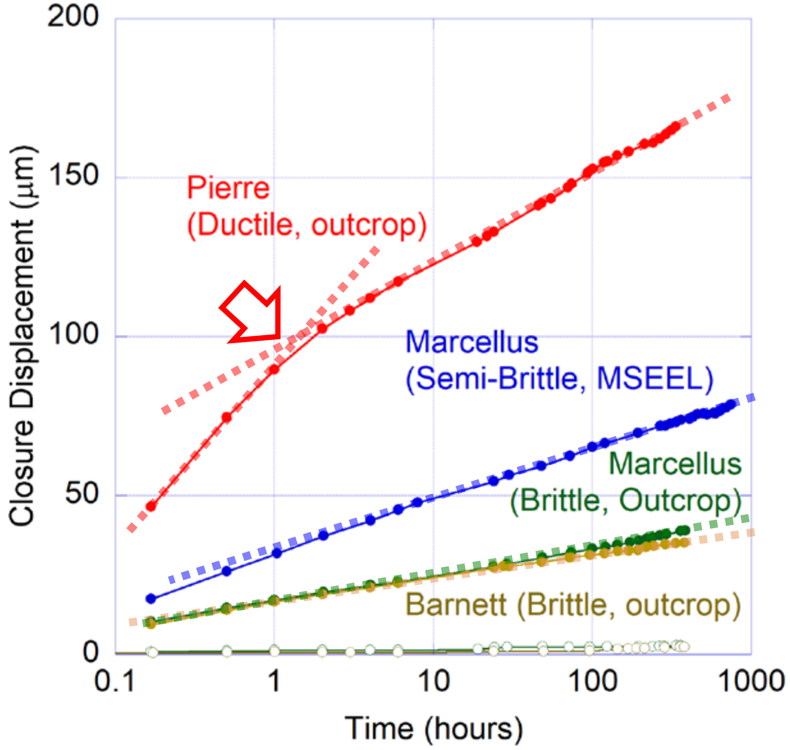
Pierre shale with proppant (15 days)



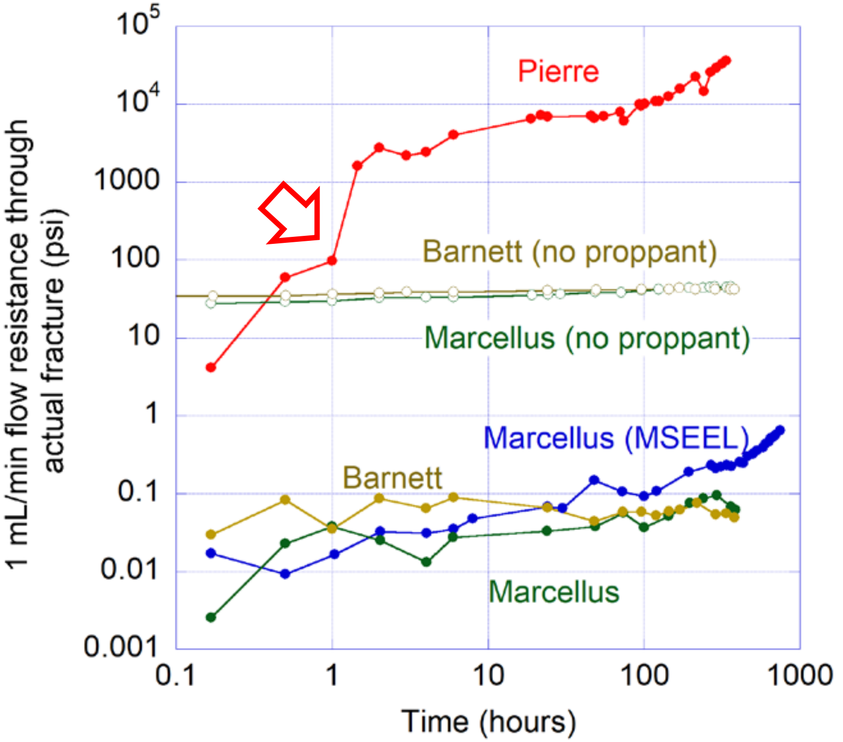
Results (Aug. 2018—Oct.2018)

Fracture closure and permeability reduction

Closure displacement (creep)



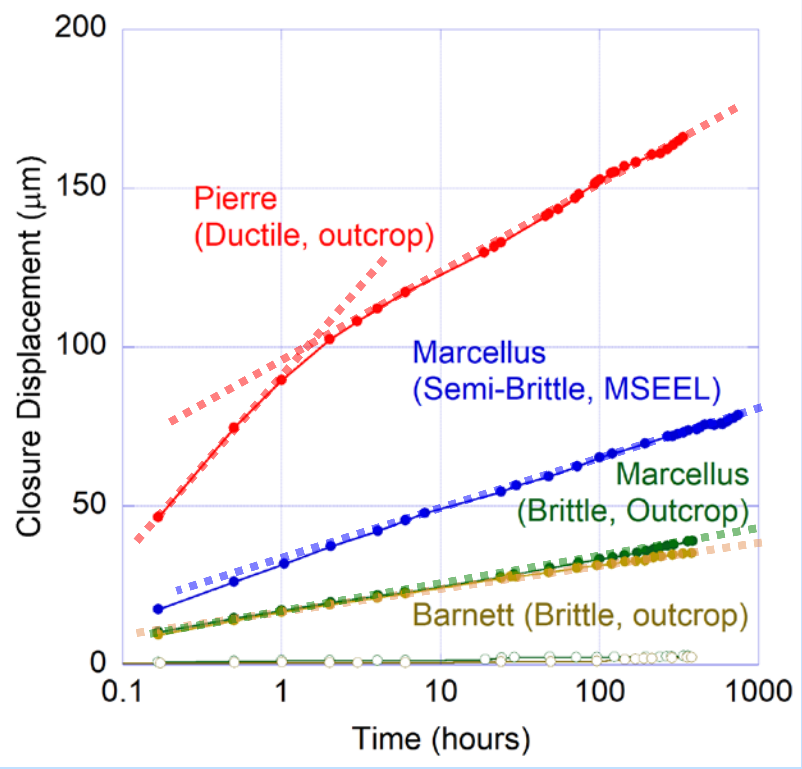
Flow resistance
(Permeability reduction)



Results (Aug. 2018—Oct.2018)

Fracture closure and permeability reduction

Closure displacement (creep)



$$\boxed{\Delta d = a \log T + b}$$

Hypothesized "universal law" of healing geological media (e.g., Schnieder, 2016) also applies to hydraulic fracture closure, for a wide range of proppant embedment behavior media

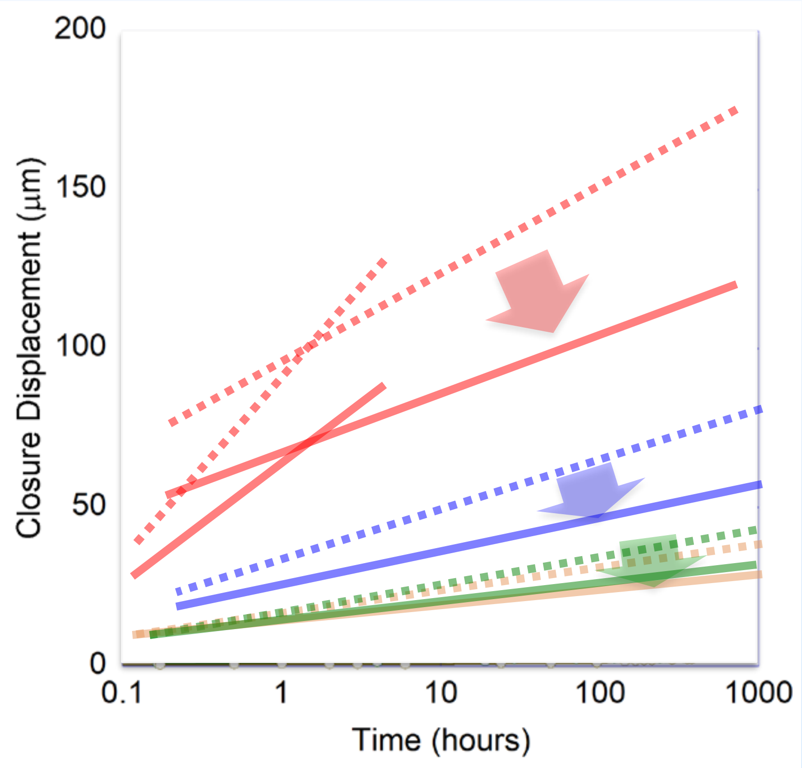
Changes in slope "*a*"
→ Different relaxation processes

Can be a very useful too for simple parameterization of sustainability of propped fracture, for a wide range of ductility

Results (Oct. 2018—Aug.2019)

Fracture closure and permeability reduction

Closure displacement (creep)



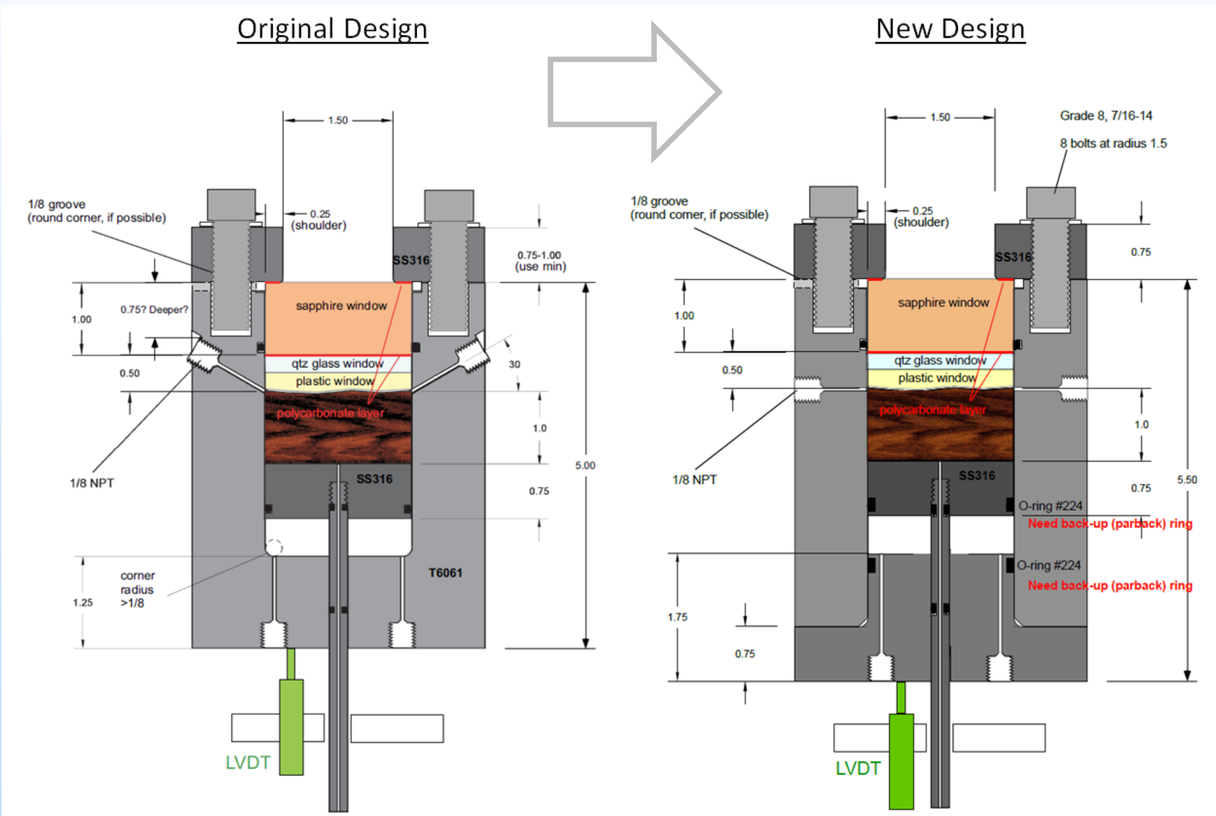
$$\Delta d = a \log T + b$$

How can we reduce the '*a*" coefficient?

The main objective of the current (2018-2020) research

Results (Oct. 2018—Aug.2019)

New shale fracture test cell development



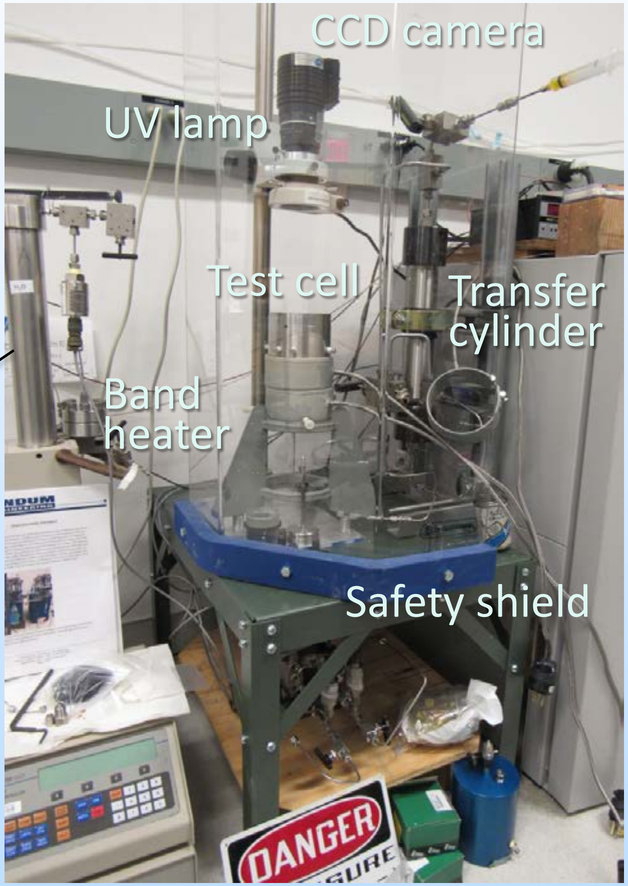
Previous aluminum T6061T6 test cell

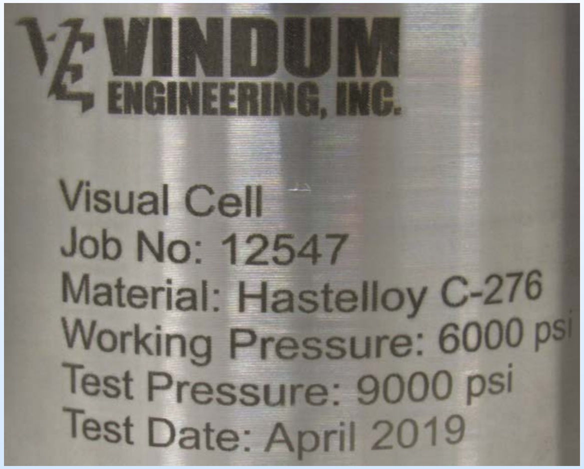
New Hastelloy C276 test cell

Results (Oct. 2018—Aug.2019)

New shale fracture test cell development

Syringe pump (1 of many)



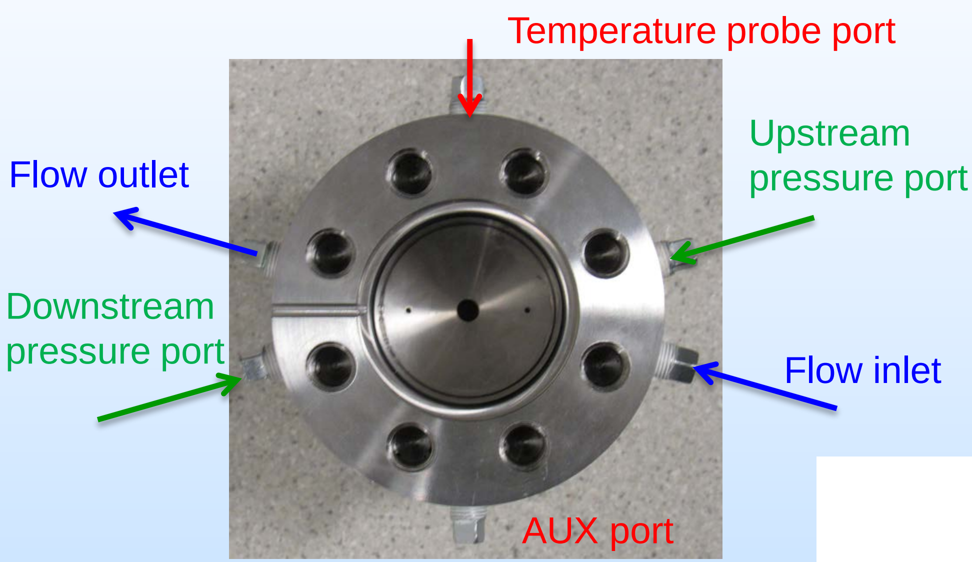


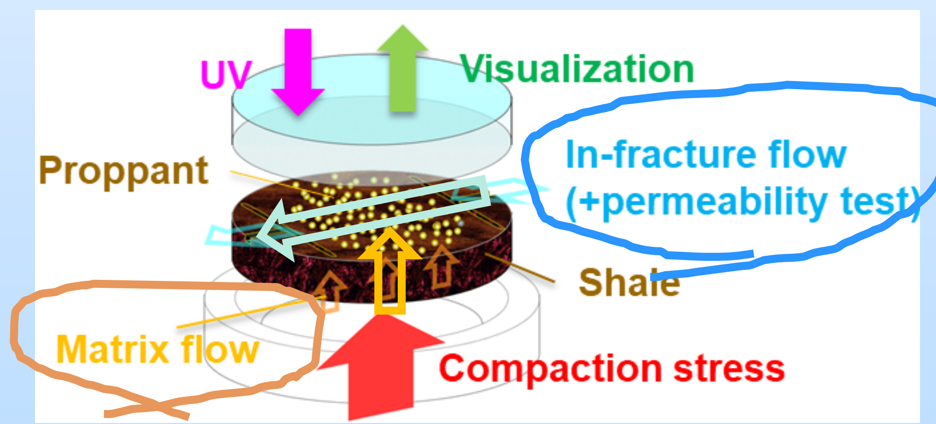
Test capability:

- Axial stress: 6000 psi
- Pore pressure: 1500 psi
- Temperature: 150˚C
- Chemistry : Low/high pH (that HC276 can withstand)

Results (Oct. 2018—Aug.2019)

New shale fracture test cell development

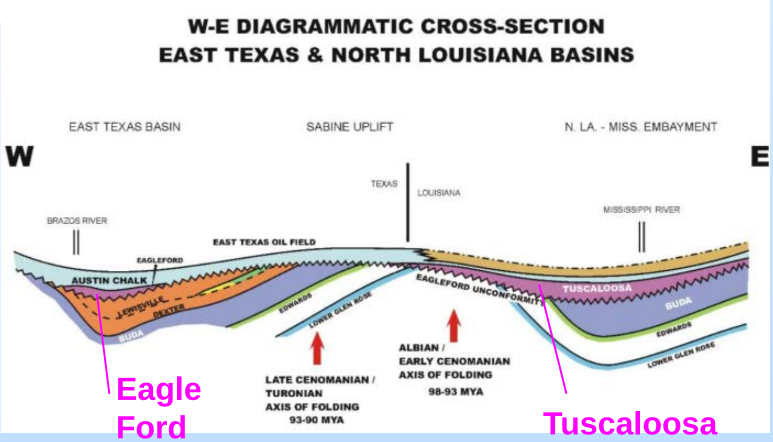




Results (Oct. 2018—Aug.2019)

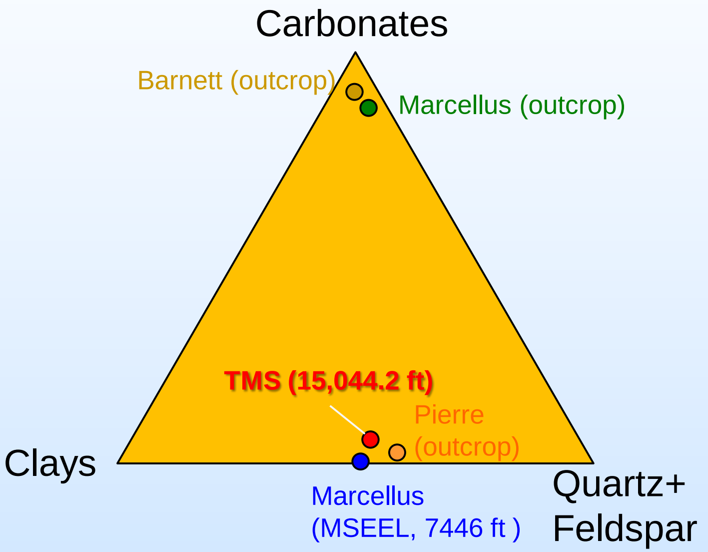
New ductile shale samples for lab experiment

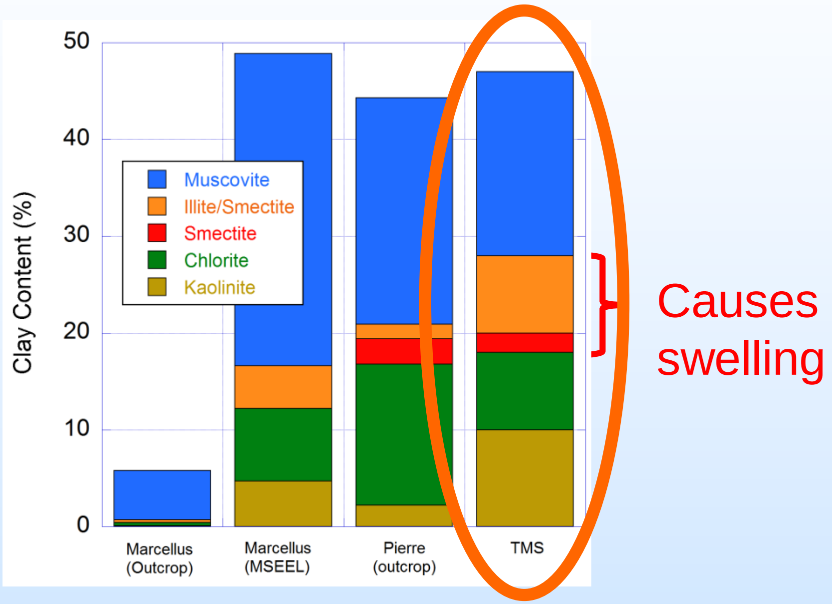
- **Collaboration with TMSL/UL**



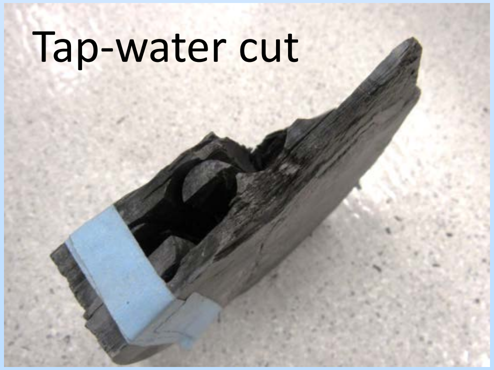
Results (Oct. 2018—Aug.2019)

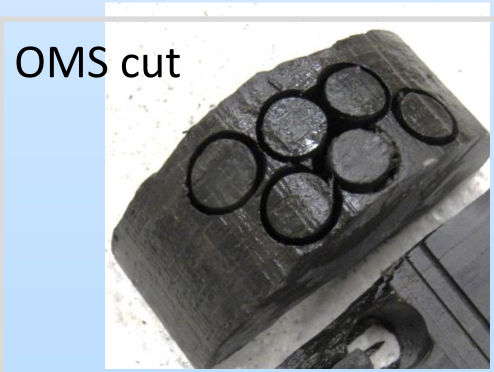
New ductile shale samples for lab experiment





*Sample is organic-poor

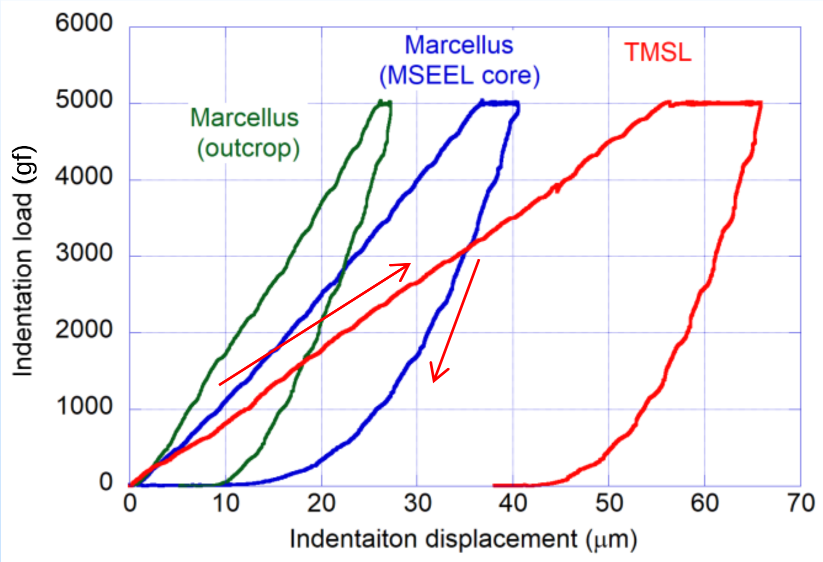




Results (Oct. 2018—Aug.2019)

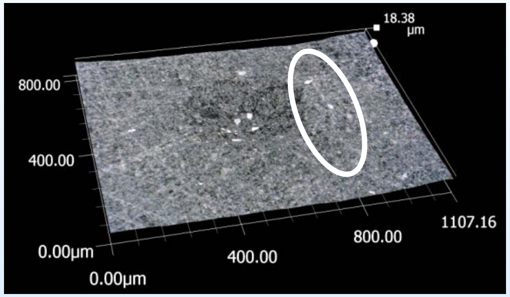
New ductile shale samples for lab experiment

Short-term grain-scale indentation tests

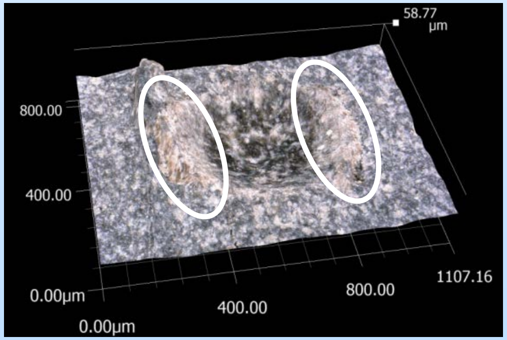


*Kept in brine (NaCl+$CaCl_2$ aq.) for 48 hrs.

MSEEL



TMSL

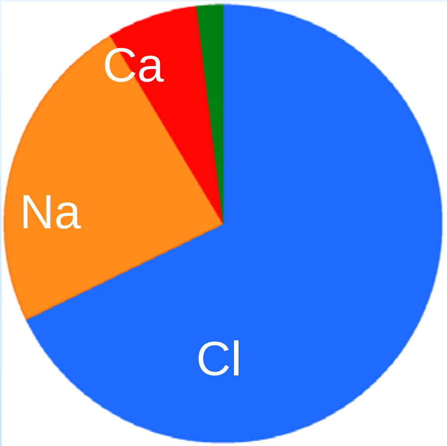


Results (Oct. 2018—Aug.2019)

Preliminary proppant/shale-fluid reaction tests

Question: For given formation fluid (TMSL brine is used), what minerals shall we target for precipitation?

Solid composition of TMS in-situ brine



Model brine used in experiments

$CaCl_2 \bullet 2H_2O$	4.03 g/100g
NaCl	9.66 g/100g

Possible requirements are:

- **To form hard cement via reaction with formation fluids**
- **To be abundant and cheap**
- **To precipitate relatively quickly (hours to months)**

Results (Oct. 2018—Aug.2019)

Preliminary proppant/shale-fluid reaction tests

TMSL Reservoir Fluid

TMSL Pore Water Chemistry
(Modified from Hoffman & Borrok (pers. comm.))

Abundant ions

	TMSL	Notes
T (C)	[redacted]	speciation temp.
pH	[redacted]	
Na+	[redacted]	ppm
K+	[redacted]	ppm
Ca+2	[redacted]	ppm
Mg+2	[redacted]	ppm
Fe+2	[redacted]	ppm
Sr+2	[redacted]	ppm
Al+3	[redacted]	ppm (est)
H4SiO4	[redacted]	eq. with quartz
Ba+2	[redacted]	ppm
HCO3-	[redacted]	ppm
Cl-	[redacted]	ppm
F-	[redacted]	ppm
SO4-2	[redacted]	ppm
O2 (aq)	[redacted]	ppm (est)

*Confidential

TMSL Calculated Saturation Indices

Minerals	log(Q/K)
halite	[redacted]
gypsum	[redacted]
strontianite	[redacted]
barite	[redacted]
dolomite	[redacted]
calcite	[redacted]
siderite	[redacted]
albite(low)	[redacted]
microcline	[redacted]
quartz(alpha)	[redacted]
clinochlore	[redacted]
chamosite(daphnite)	[redacted]
muscovite(ordered)	[redacted]
annite	[redacted]
phlogopite	[redacted]
montmorillonite(mgca)	[redacted]
montmorillonite(mgmg)	[redacted]
montmorillonite(mgna)	[redacted]
montmorillonite(mgk)	[redacted]
kaolinite	[redacted]
illite(feii)	[redacted]
hematite	[redacted]
magnetite	[redacted]
pyrite	[redacted]

Super-saturated minerals

Results (Oct. 2018—Aug.2019)

Preliminary proppant/shale-fluid reaction tests

Carbonates

	Solubility in water	Comment
Na_2CO_3	34.1g/100mL (27.8 °C), 43.6g/100mL (100 °C)	Too soluble
$MgCO_3$	13.9 mg/100mL(25 °C) 6.03 mg/100mL(100 °C)	Magnesite
$CaCO_3$	1.5 mg/100mL (25°C)	Target mineral

Sulfates

	Solubility in water	Comment
$MgSO_4$	35.1g/100mL (20 °C), 50.2g/100mL (100 °C)	Too soluble
$CaSO_4$	210 mg/100mL (20°C)	anhydrous
	240 mg/100mL (20 °C)	Target mineral, di-hydrous
$Al_2(SO_4)_3$	13.9 mg/100mL(25 °C) 6.03 mg/100mL(100 °C)	Too insoluble
$BaSO_4$	0.2448 mg/100mL (20 °C)	Too insoluble

Results (Oct. 2018—Aug.2019)

1st candidate $MgCO_3 + Ca^{2+} + 2Cl^- \rightarrow Mg^{2+} + 2Cl^- + CaCO_3$ **(Aragonite?)**

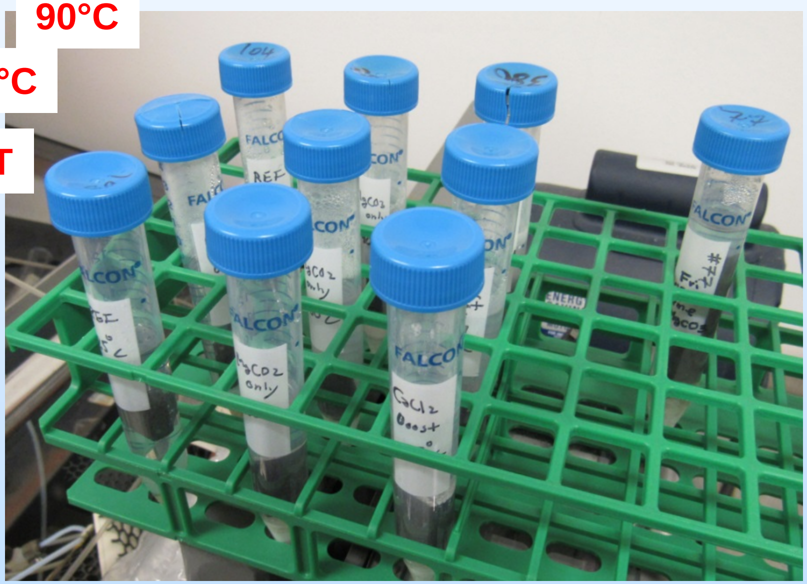
Magnesite

Reference (brine only) | **Brine $+MgCO_3$** | **Brine $+MgCO_3$ $+CaCl_2$**

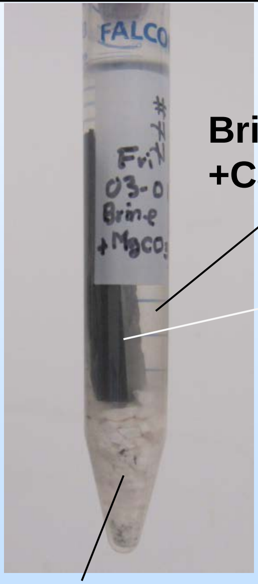
90°C

60°C

Room T



90°C 48hrs no change….



Brine $+CaCl_2$

TMSL shale chip

Magnesite chips

4 Days….

$MgCO_3$ powder

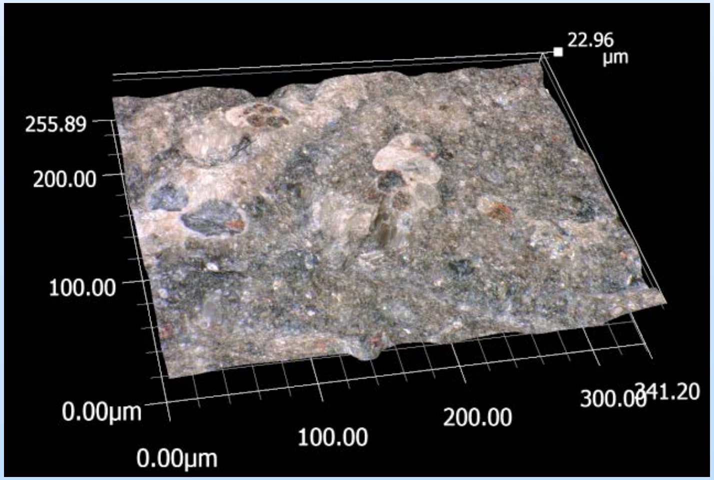
Reference (brine only) | **Brine $+MgCO_3$** | **Brine $+MgCO_3$ $+CaCl_2$**

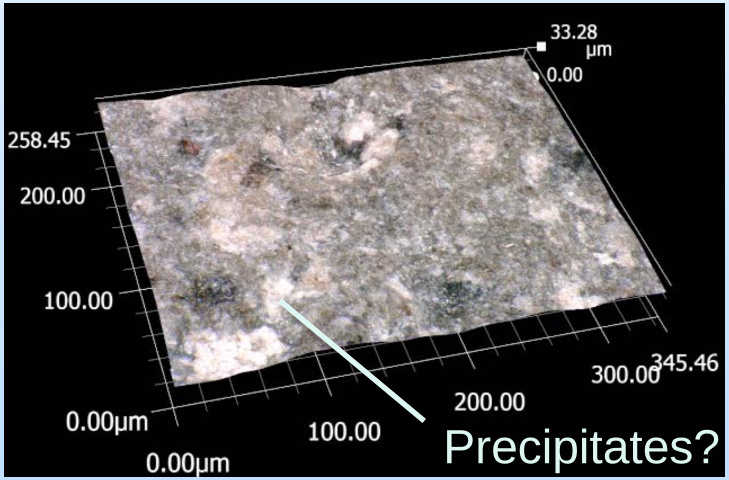
Results (Oct. 2018—Aug.2019)

1st candidate $MgCO_3 + Ca^{2+} + 2Cl^- \rightarrow Mg^{2+} + 2Cl^- + CaCO_3$ **(Aragonite?)**

In 60˚C TMSL brine only
(2 months)

In 60˚C TMSL brine+MgCO3 powder
(2 months)



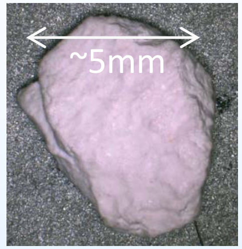


After 2 months, no clear indications of mineral ($CaCO_3$) precipitation

Results (Oct. 2018—Aug.2019)

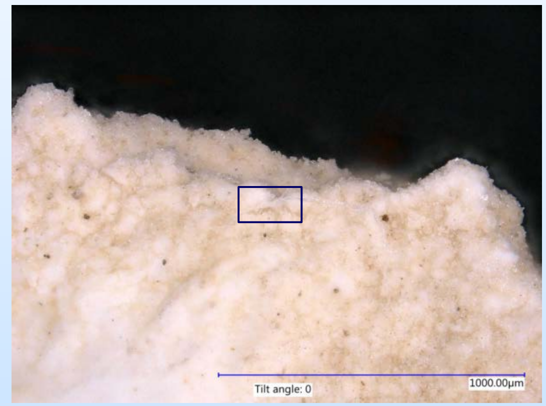
1st candidate $MgCO_3 + Ca^{2+} + 2Cl^- \rightarrow Mg^{2+} + 2Cl^- + CaCO_3$ **(Aragonite?)**

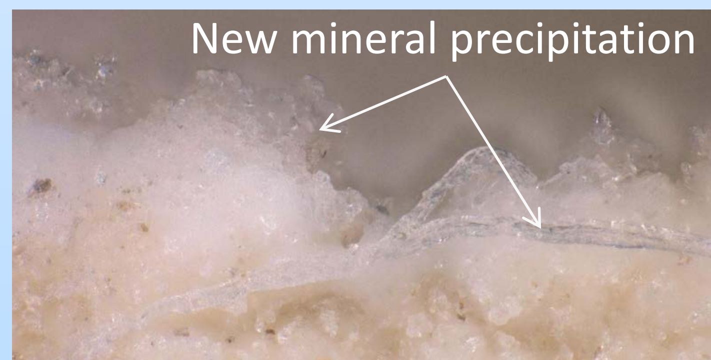
Magnesite chips



90°C 48hrs

*Not same sample



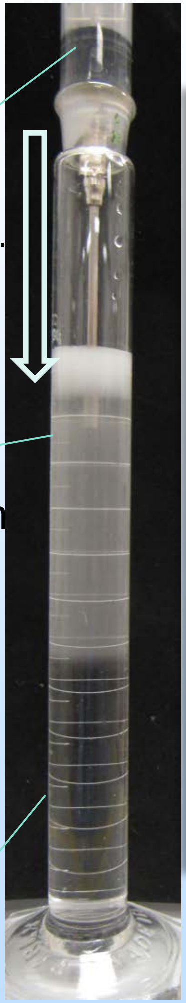


Results (Oct. 2018—Aug.2019)

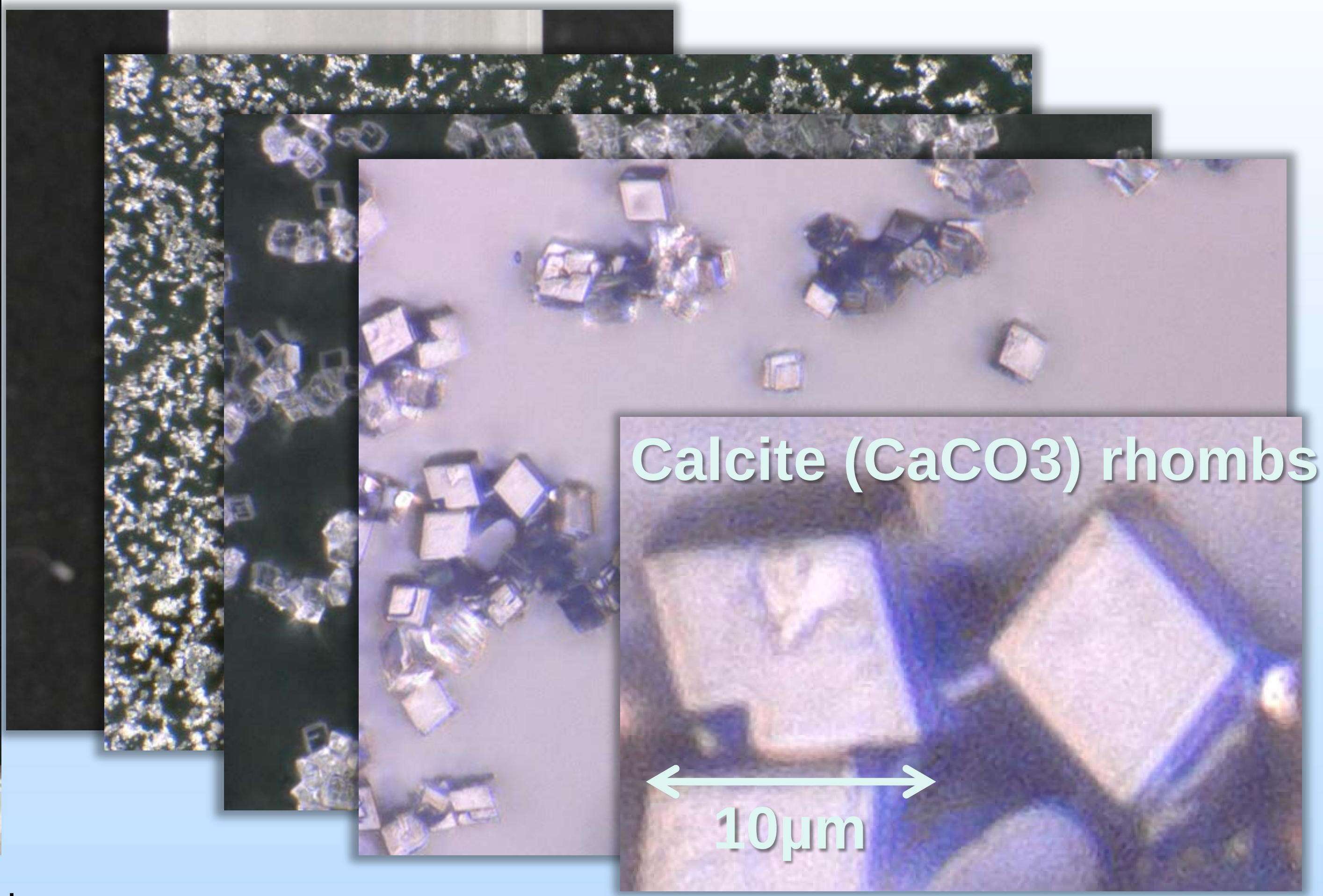
2nd candidate $CaCl_2 + 2NaHCO_3\,(aq) \rightarrow CaCO_3\downarrow + 2NaCl(aq) + H_2O + CO_2\uparrow$

NaHCO3 aq.

Instant precipitation



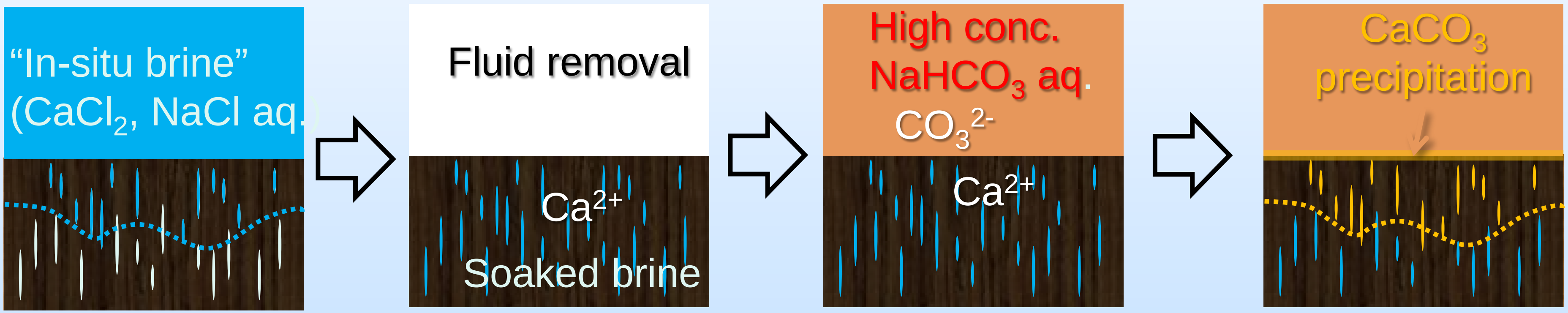
TMSL reservoir fluid ($CaCl_2$+NaCl)



Results (Oct. 2018—Aug.2019)

2nd candidate $CaCl_2 + 2NaHCO_3\,(aq) \rightarrow CaCO_3\downarrow + 2NaCl(aq) + H_2O + CO_2\uparrow$

How sodium bicarbonate ($NaHCO_3$) may induce carbonate precipitation on/in shale (instead of in the fluid)

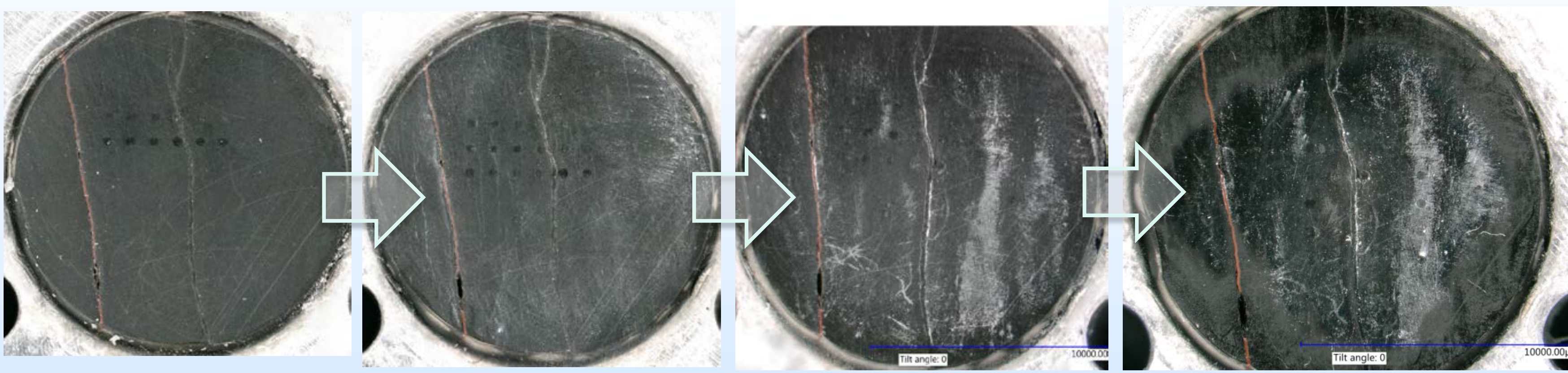


Strategy: Use the brine (Ca^{2+}) in the shale matrix to precipitate minerals (Not in the fracture!)

Results (Oct. 2018—Aug.2019)

2nd candidate $CaCl_2 + 2NaHCO_3\,(aq) \rightarrow CaCO_3\downarrow + 2NaCl(aq) + H_2O + CO_2\uparrow$

MSEEL core sample (Marcellus shale)

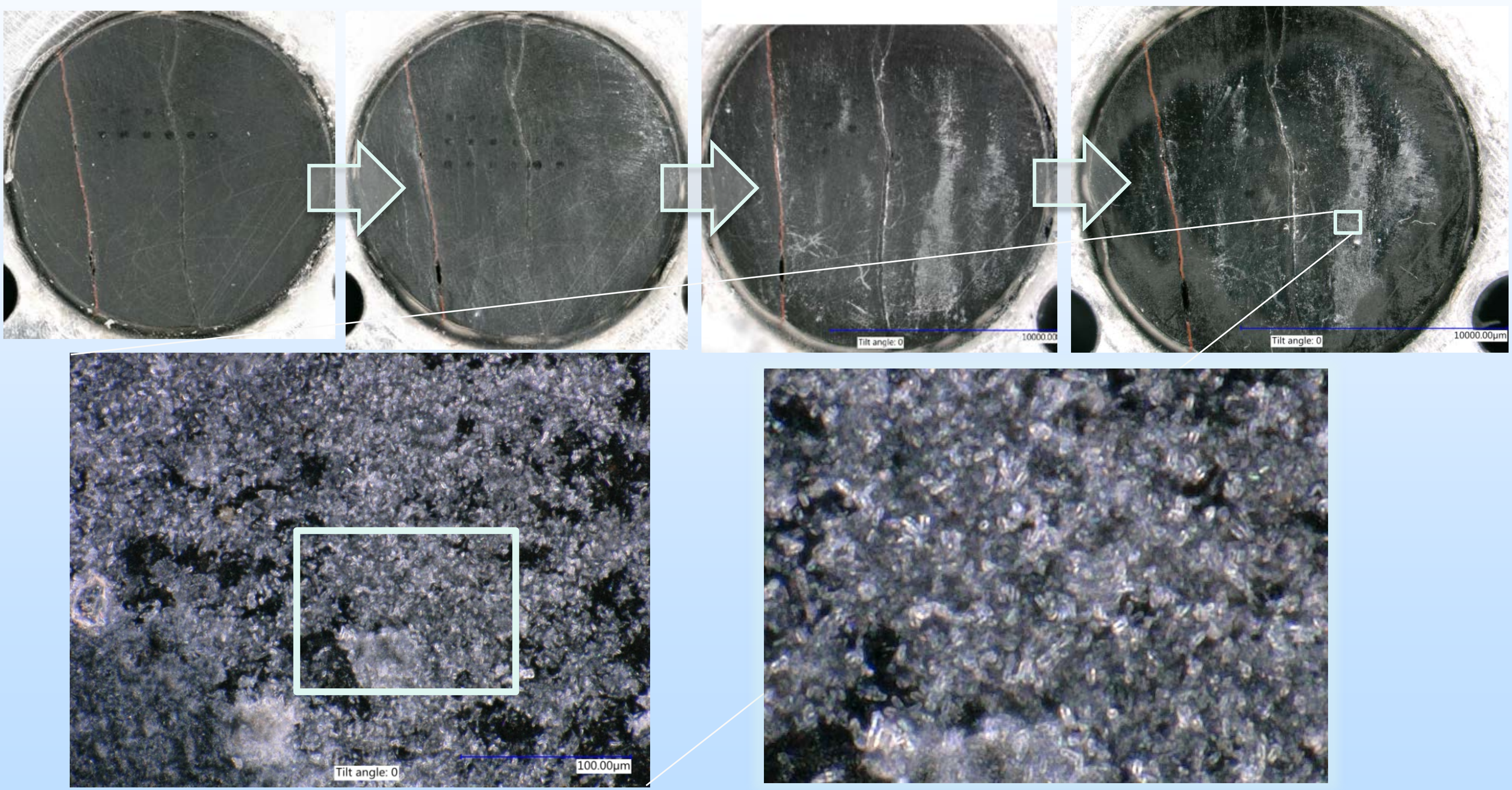


Initial 3 days 6 weeks 4 months

Results (Oct. 2018—Aug.2019)

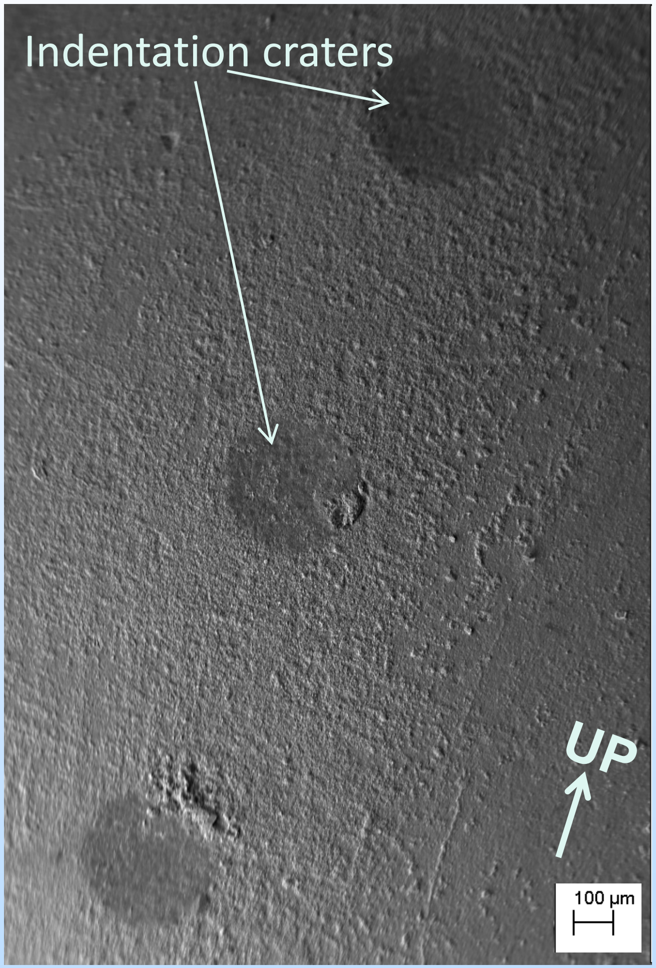
2nd candidate	$CaCl_2 + 2NaHCO_3\,(aq) \rightarrow CaCO_3\downarrow + 2NaCl(aq) + H_2O + CO_2\uparrow$

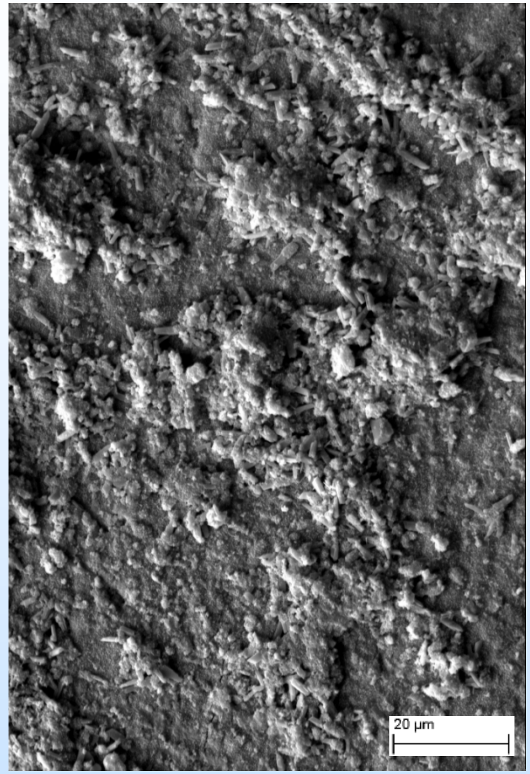
MSEEL core sample (Marcellus shale)

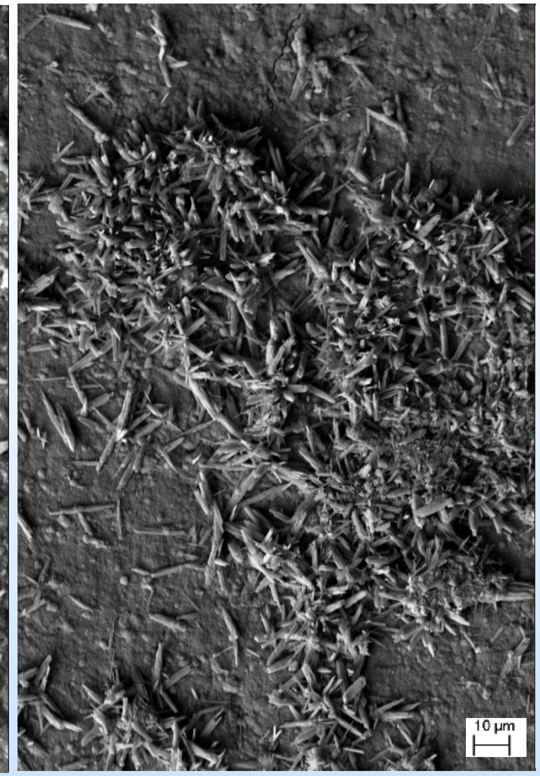


Results (Oct. 2018—Aug.2019)

SEM Images



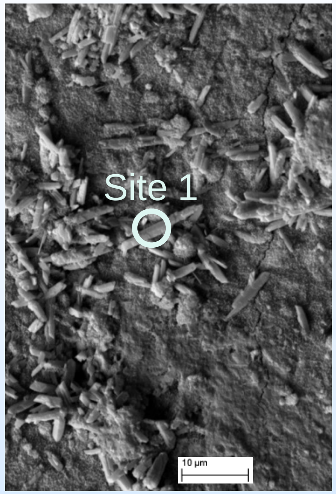


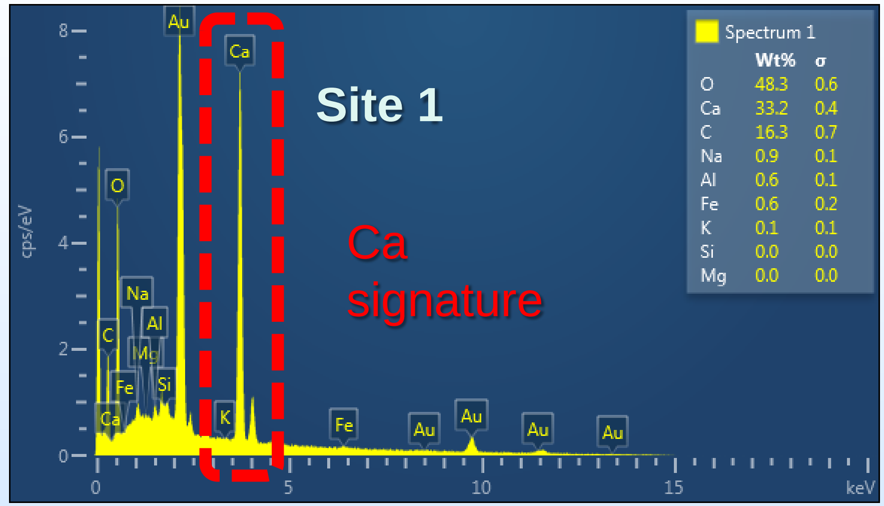


Results (Oct. 2018—Aug.2019)

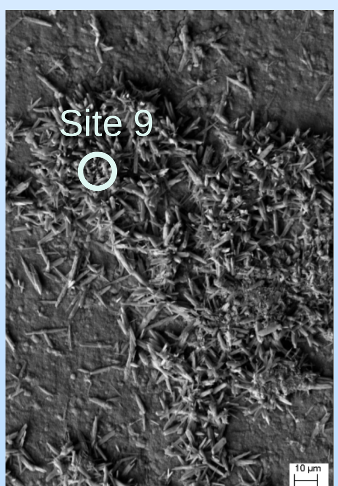
EDX analysis

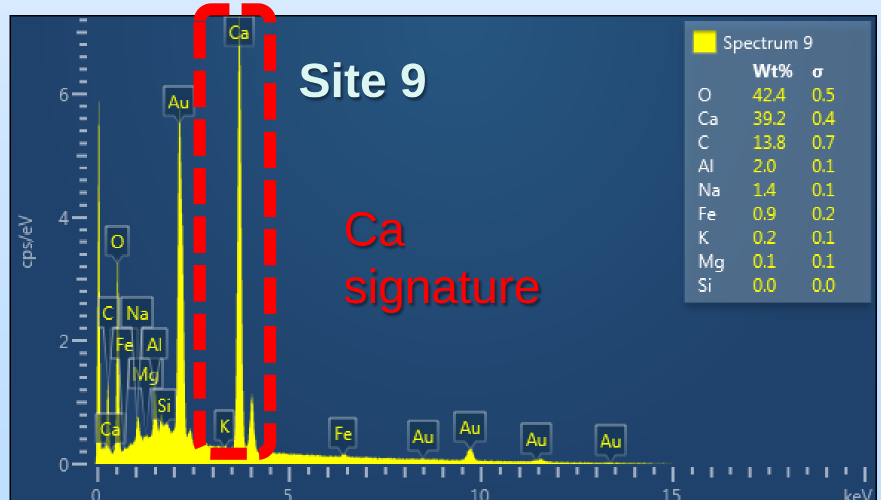
Prismatic crystals





Acicular crystals

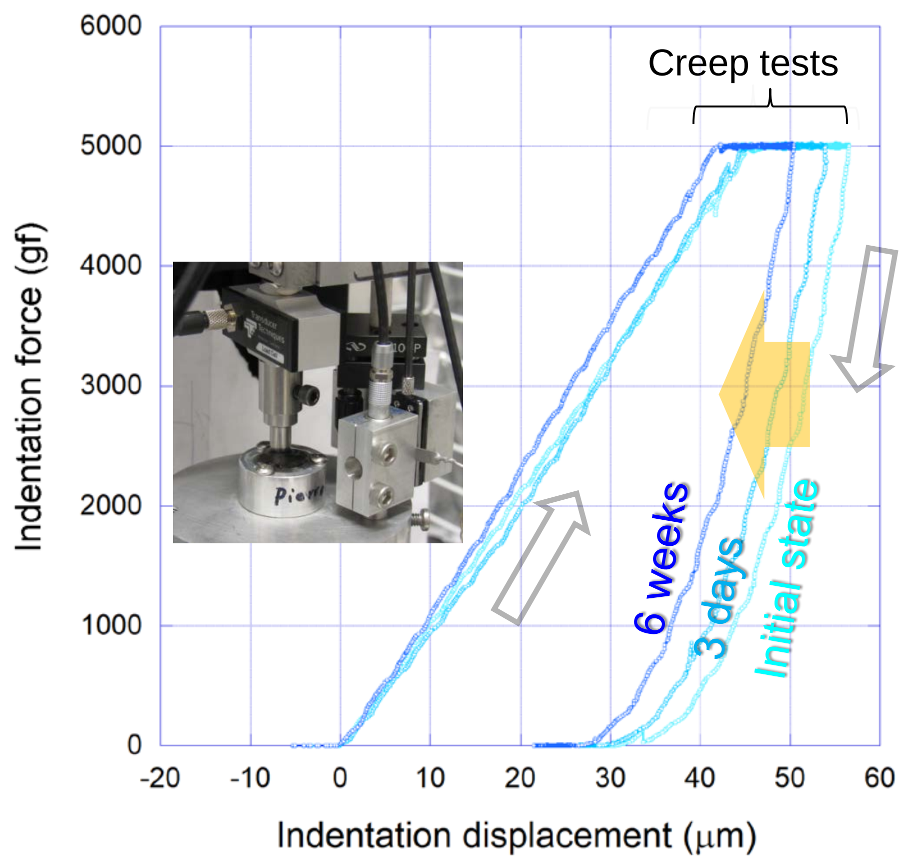




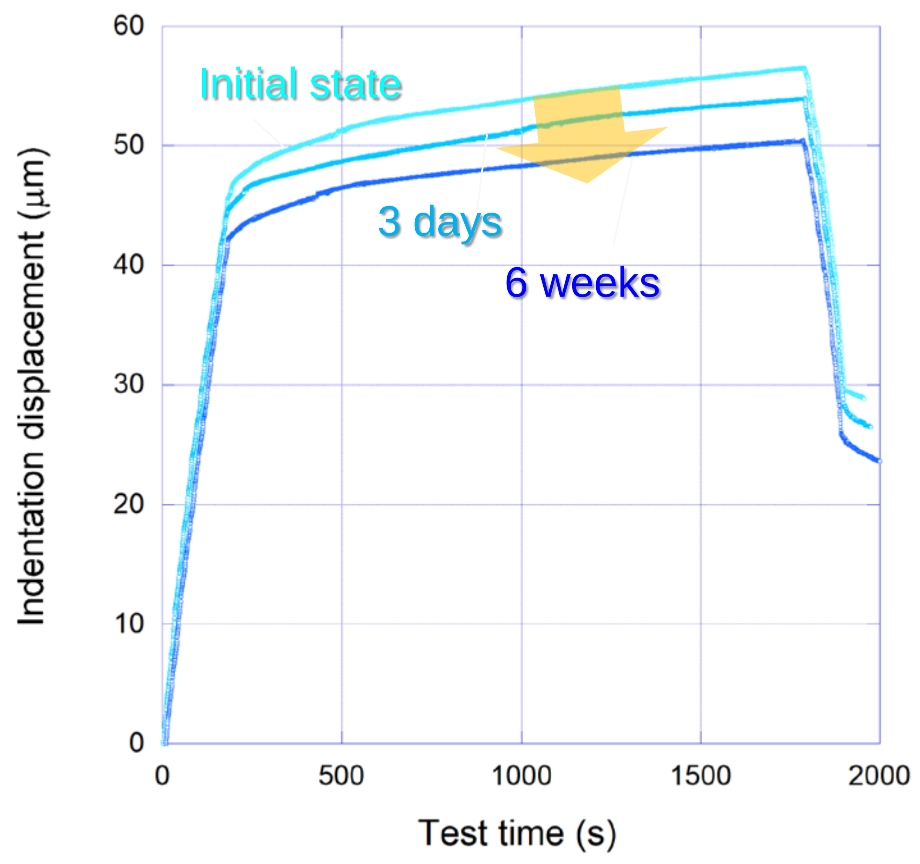
Results (Oct. 2018—Aug.2019)

Proppant-scale instrumented indentation tests and short-term creep tests

Indentation load-displacement



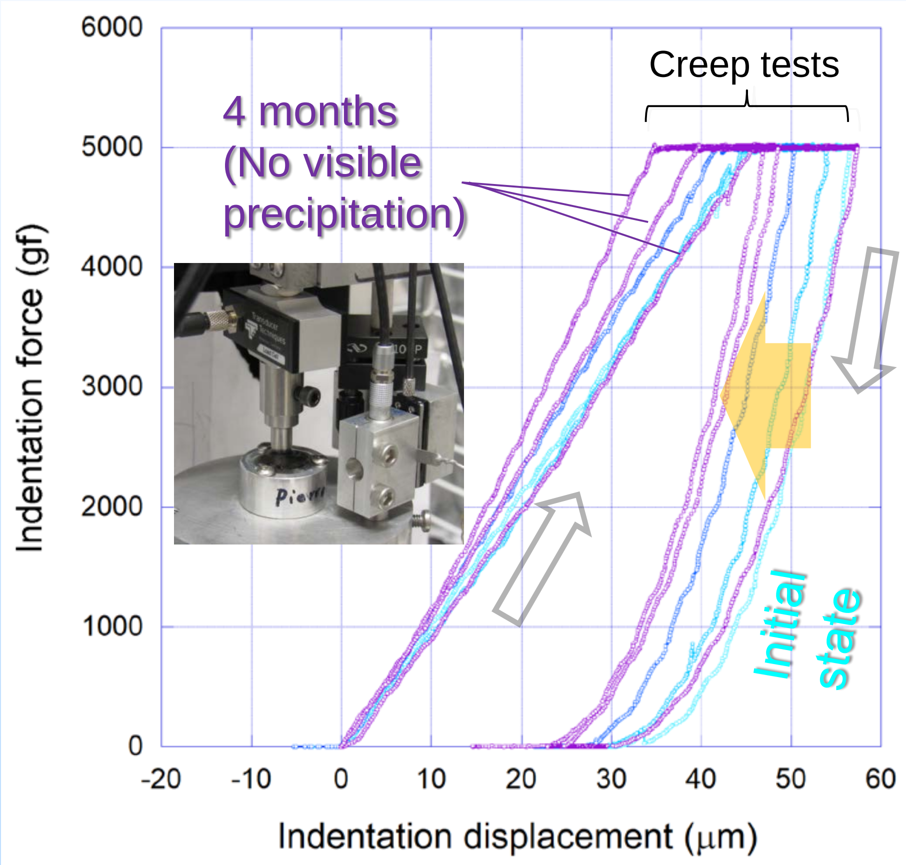
30 min creep test histories



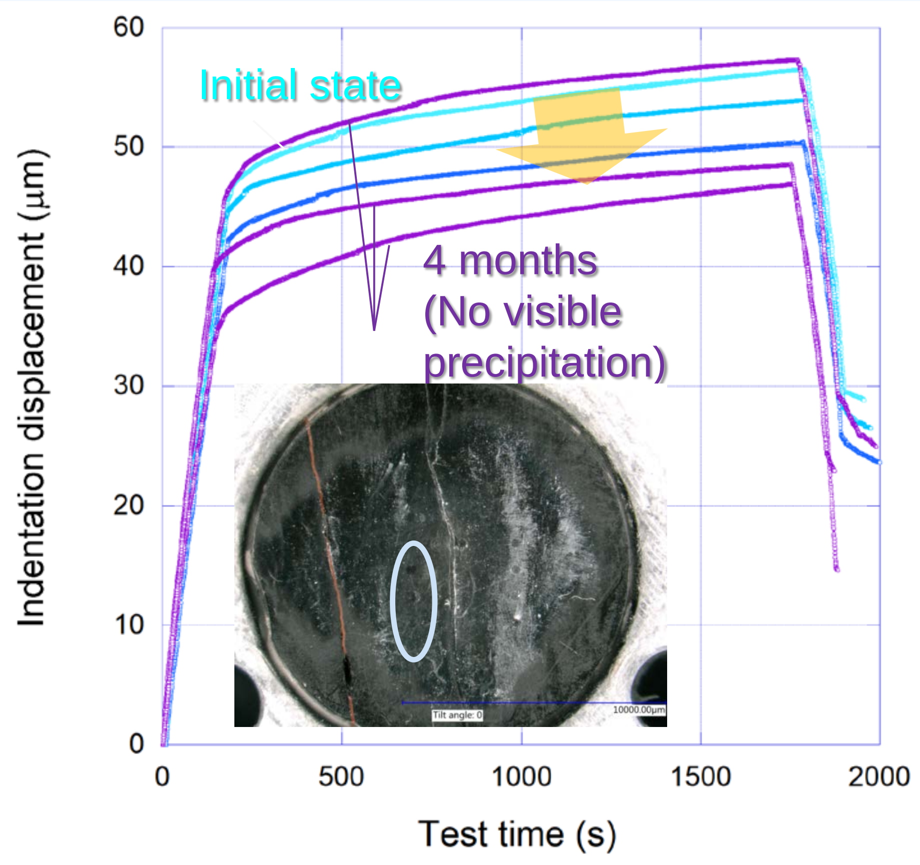
Results (Oct. 2018—Aug.2019)

Proppant-scale instrumented indentation tests and short-term creep tests

Indentation load-displacement



30 min creep test histories



Results (Oct. 2018—Aug.2019)

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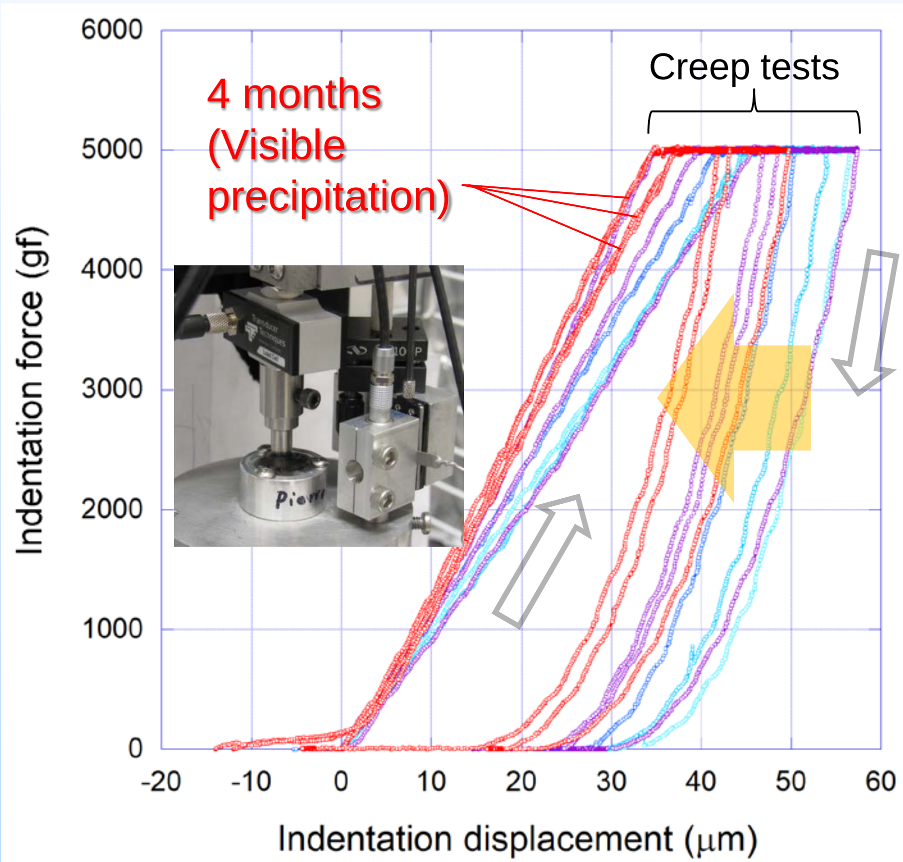
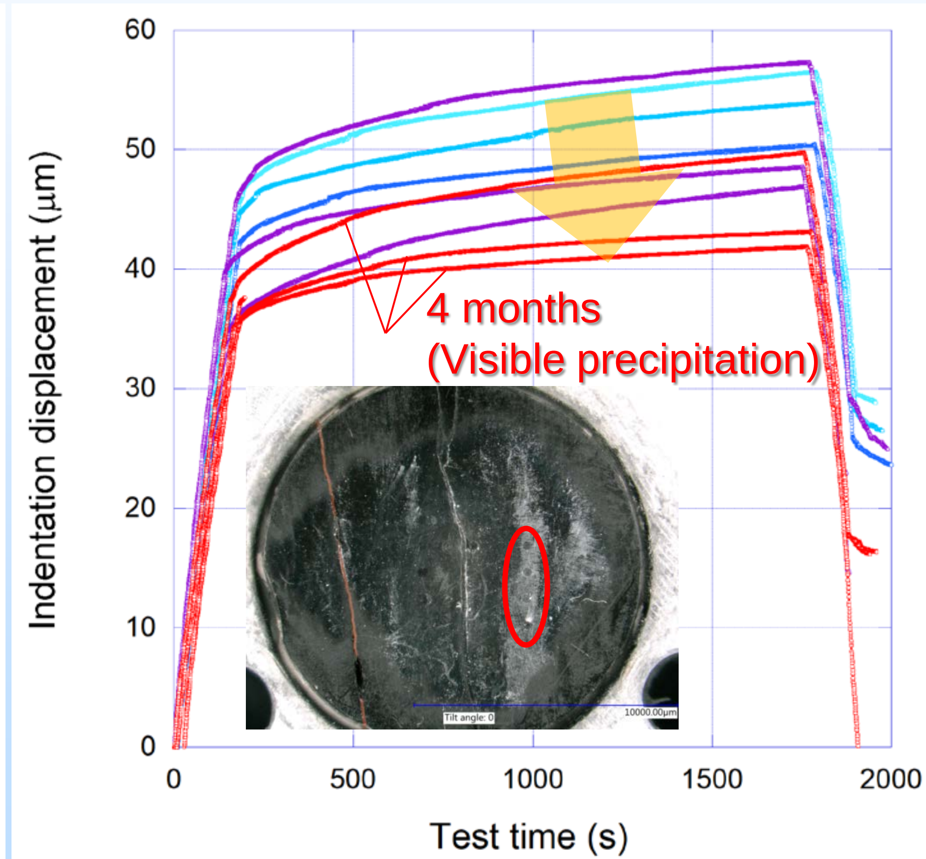
Indentation load-displacement



30 min creep test histories

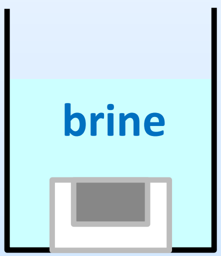


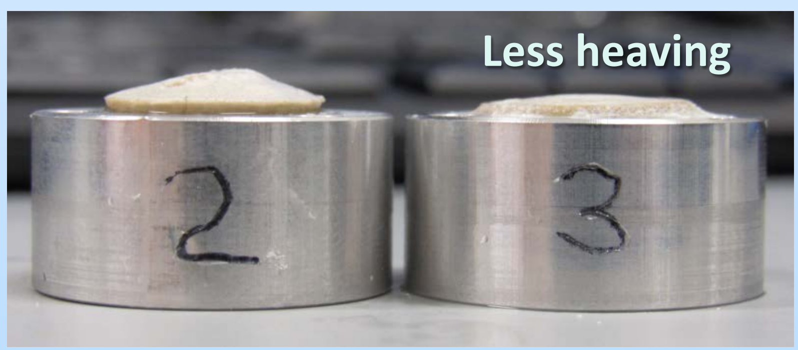
Results (Oct. 2018—Aug.2019)

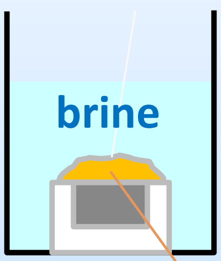
Ok, then, can we control the **location** of precipitation?
(e.g. around proppant)

Reference: In TMSL brine
(Direct contact)

In TMSL brine
(Covered with guar gum +$NaHCO_3$)







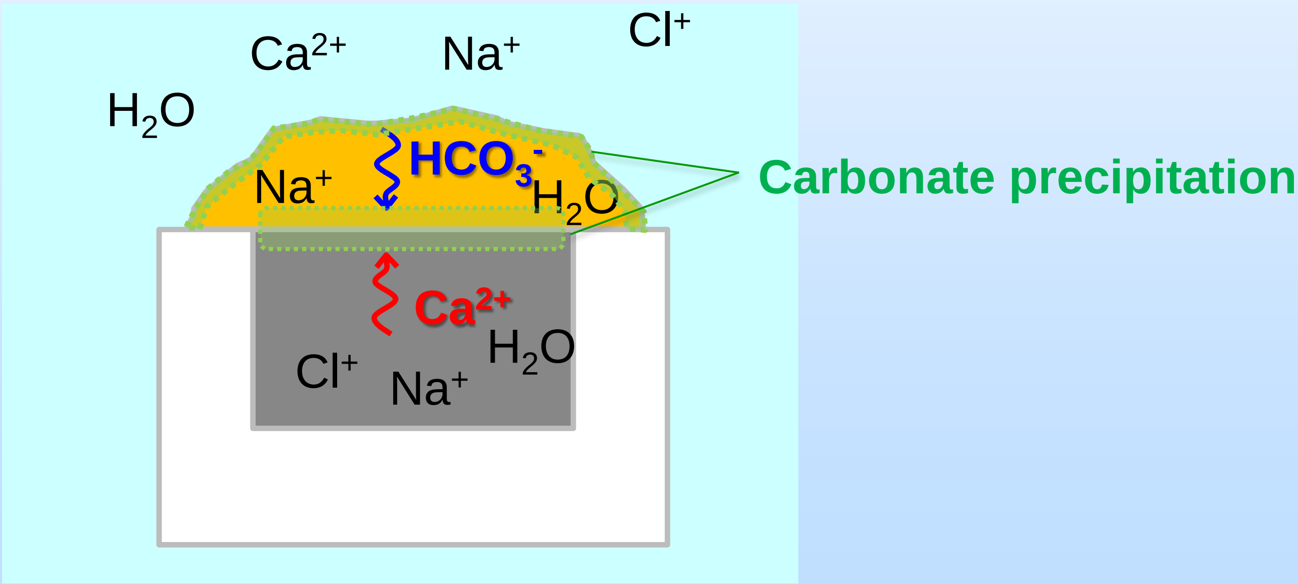
Guar gum+NaHCO3

Synthetic “shale”
Kaolinite +TMSL
brine mixture

Results (Oct. 2018—Aug.2019)

Benefit of using a protective medium (e.g. guar gum)+$NaHCO_3$+proppant mixture

- Keeps precipitation **away from the fracture fluid**
- Keeps precipitation to **nearby proppant**
- **Assures delivery** of high concentration of the reactive chemical
- Create **heterogeneous patches** of precipitation, rather than uniform precipitation which may harm permeability of the shale matrix



Results (Oct. 2018—Aug.2019)

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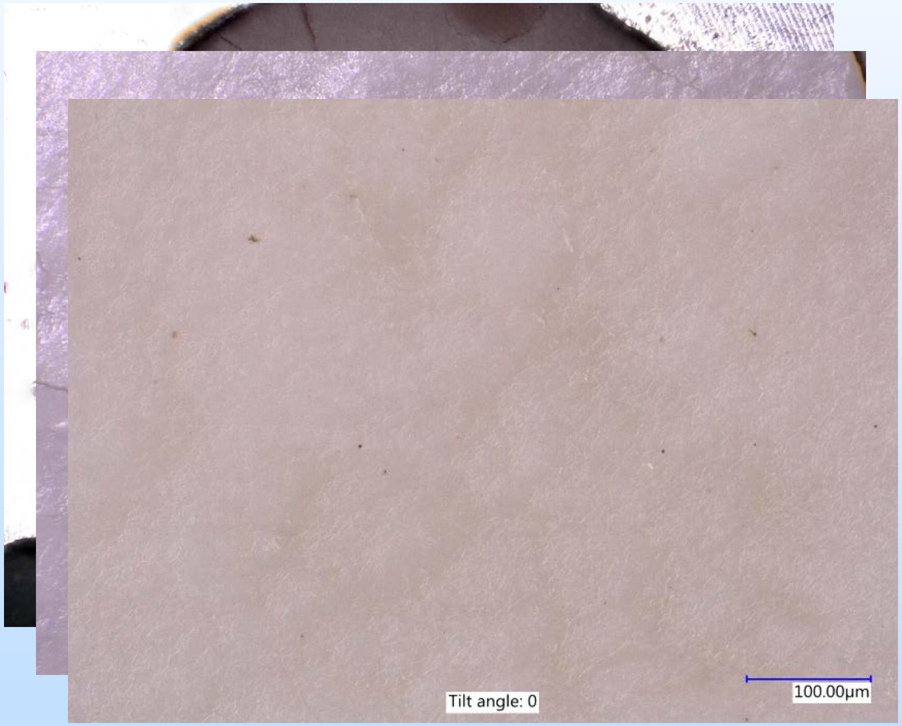
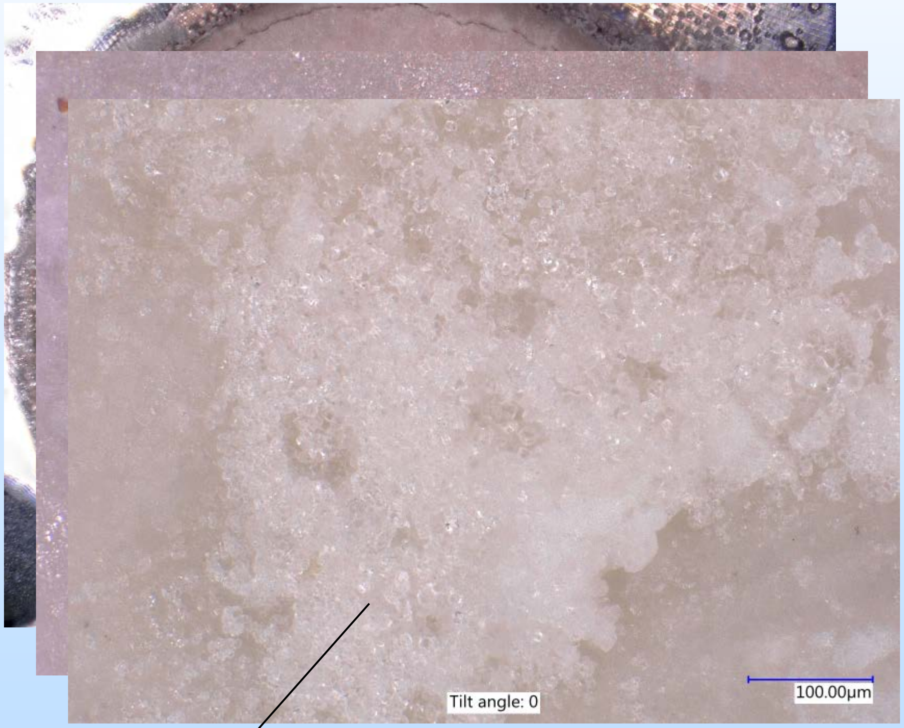
(Direct contact)



In TMSL brine
(Covered with **guar gum +$NaHCO_3$**)



Possible $CaCO_3$ crystals (aragonite?)

Results (Oct. 2018—Aug.2019)

Numerical Modeling

Results (Oct. 2018—Aug.2019)

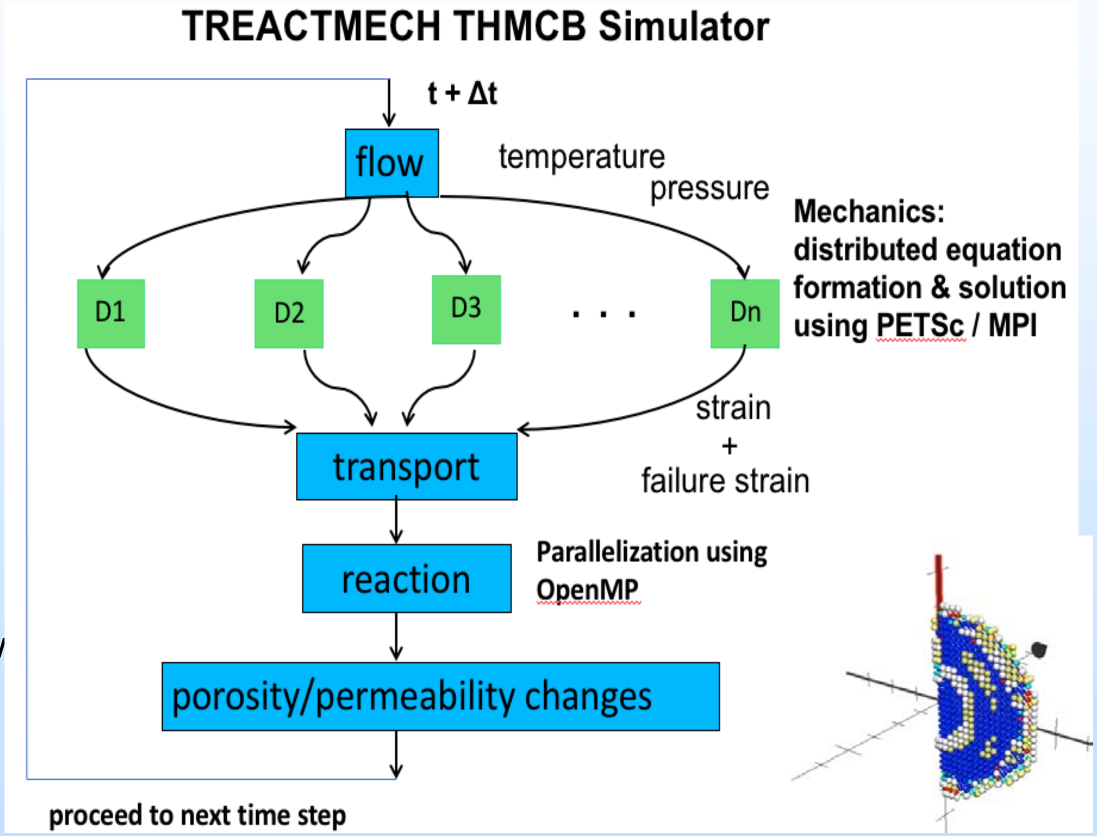
Modeling Approaches

- Porosity-dependent elastic moduli added to THMCB code TReactMech V3.88mpi
- Allows for changes in elastic moduli as a function of mineral precipitation/dissolution and/or compaction/dilation
- Allows for modifying fracture elastic moduli (for discrete fractures) as a function of proppant fraction
- Allows for proppant dissolution and re-precipitation
- Effective continuum model implemented to allow for separate fracture and matrix permeability changes (and laws) owing to mechanical deformation (e.g., shale matrix compaction, fracture closure/opening, tensile and shear failure) in a single-continuum flow (and reactive-transport) model
- THMC models under development using preliminary TMSL water chemistry

Results (Oct. 2018—Aug.2019)

TReactMech Simulation Approach

- Hybrid Parallel Coupled THMCB Simulator
- Multiphase Fluid-Heat Flow (Modified TOUGH2)
- Parallel Petsc/OpenMPI Mechanics (Poro-Thermo-Elastic & Plastic Strain)
- Parallel (OpenMP) Reactive Chemistry (TOUGHREACT core)
- Couples Mechanical-Chemical Aperture-Porosity-Permeability to Flow



Kim et al. 2012, 2015; Smith et al., 2015; Sonnenthal et al., 2015, 2018, 2019, Xu et al., 2011

Results (Oct. 2018—Aug.2019)

Modeling precipitation-induced elastic moduli and permeability changes

Bulk Modulus

$$K = K_0 \left[A_k + B_k\sqrt{\phi_{crit} - \phi} + C_k(\phi_{crit} - \phi) + D_k(\phi_{crit} - \phi)^2 \right]$$
$$/\left[A_k + B_k\sqrt{\phi_{crit} - \phi_0} + C_k(\phi_{crit} - \phi_0) + D_k(\phi_{crit} - \phi_0)^2 \right]$$

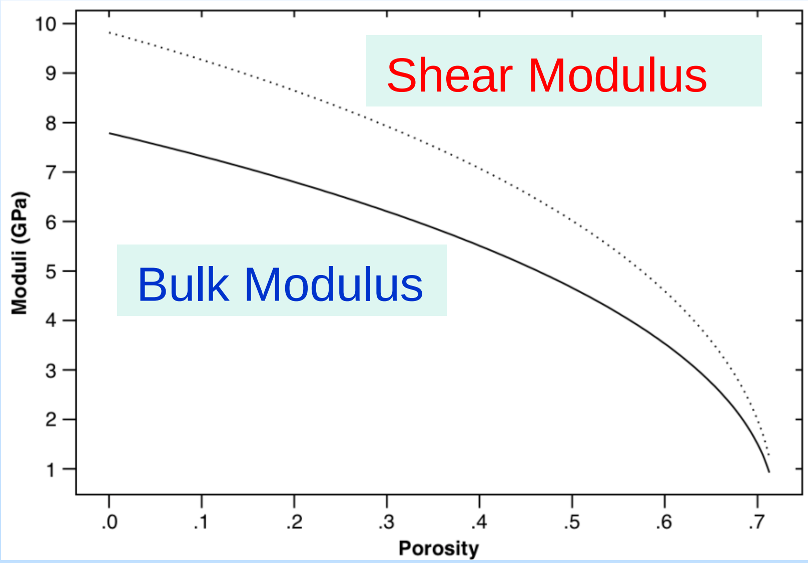
Shear Modulus

$$G = G_0 \left[A_{sh} + B_{sh}\sqrt{\phi_{crit} - \phi} + C_{sh}(\phi_{crit} - \phi) + D_{sh}(\phi_{crit} - \phi)^2 \right]$$
$$\left[A_{sh} + B_{sh}\sqrt{\phi_{crit} - \phi_0} + C_{sh}(\phi_{crit} - \phi_0) + D_{sh}(\phi_{crit} - \phi_0)^2 \right]$$

ϕ current porosity

ϕ_0 reference (initial) porosity

ϕ_{crit} critical porosity above which the rock matrix or fracture moduli decline to a minimum value (e.g., disaggregation limit)



Cementation theory (Dvorkin and Nur, 1996), with $\phi_{crit} = 0.72$

Accomplishments to Date

- **Multiple long-term (2 week to 1 month) experiments** have been conducted on fractures in different types of shales (Barnett, Marcellus [outcrop + MSEEL], Pierre), with and without proppant
- Time-lapse dataset correlating optical images of fracture aperture distribution, average fracture closure, and fracture permeability (hydraulic aperture) has been obtained. **The tests revealed very robust, semi-logarithmic fracture closure deformation behavior** with lapse time

→Possibility of long-term closure prediction from short-term experiments

Accomplishments to Date

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→**Possibility of long-term closure prediction from short-term experiments**

- Fabrication of a **new, high-temperature, chemically inert fracture compaction visualization cell** has been completed
- **A possible strategy for reduction of shale deformation/proppant embedment** via in-situ mineral precipitation has been found. This is to be tested and validated in Year 2 of the current project.
- **TReactMech code has been prepared** for conducting coupled thermal-hydrological-mechanical-chemical simulations of proppant embediment/fracture closure/permeability reduction process

Lessons Learned (and Identified Issues)

- **(As we all know…) Clay-rich shales (especially swelling clays) are much more difficult than brittle shale to prepare their samples**. These include
  - Core cutting (fluid sensitivity, choice of core cutting fluid)
  - Core stabilization (due to shrinkage-induced fractures)
  - Re-hydration of dried/semi-dried samples

  Sample preparation for the experiment, and the interpretation of the results, has to be conducted very carefully
- **The organic fluorescent dye used for imaging can produce clogging of the system when kept under high temperature**. If used in the planned experiment, the resident time in the system must be restricted (i.e. the dye-bearing brine needs to be introduced only during imaging)
- **Simple sodium bicarbonate (baking soda) appears to be surprisingly effective** in introducing relatively rapid precipitation of carbonate minerals on a fracture surface. If this material can be used, it can lead to a technology using inexpensive chemical additive to proppant/fracturing fluids

Synergy Opportunities

- Field-scale behavior of hydraulic fractures in ductile shale: Collaboration with Tuscaloosa Marine Shale Laboratory (TMSL Consortium/University of Louisiana [PI. Prof. Mehdi Mokhtari])
- Micron-scale shale-proppant interactions: Collaboration with synchrotron X-ray CT imaging of proppant embedment study (LBNL research, M. Voltolini, PI: Matt Reagan [LBNL])
- More?

Project Summary

- A new laboratory in-situ optical visualization technique for shale fracture compaction/ proppant embedment experiment was developed
- For room-T experiments, correlated datasets of time-lapse proppant crushing/embedment images and fracture deformation and permeability changes for different types of shales
- Both laboratory tools (High T test system) and modeling tools (TReactMech) are projected to be ready to conduct the planned tasks of shale fracture/fluid/proppant behavior study. Fabrication of the new, high-temperature, chemically inert fracture compaction visualization cell has been completed (Go/No-go criterion I)
- Preliminary tests seem to indicate fluid/proppant/shale-reaction-induced precipitation of hard minerals and manipulation of fracture surface property is possible! (Go/No-go criterion II)

Appendix

Benefit to the Program

Program Goals

- Identify and accelerate development of economically-viable technologies to more effectively locate, characterize, and produce natural gas and oil resources, in an environmentally acceptable manner
- Characterize emerging oil and natural gas accumulations at the resource and reservoir level and publish this information in a manner that supports effective development
- Catalyze the development and demonstration of new technologies and methodologies for limiting the environmental impacts of unconventional oil and natural gas development activities

Project Benefits

This research investigates the possibility of *manipulation the sustainability of hydraulic fractures in ductile shales*—particularly through alteration of proppant-embedment behavior—*using chemical means*. If successful, the knowledge gained and technology developed by this project will help economical production of hydrocarbons from normally avoided, resource-rich but difficult-to-develop , ductile shale formations.

Project Overview

Goals and Objectives

Project Goals and Objectives

The primary objectives of the proposed research are
(1) to understand the behavior of fractures in clay-rich, ductile (and sometimes swelling) shales and
(2) to begin to develop technologies for efficient and economical production from such shales.

(1) Identification of proppant-shale-fluid (P-S-F) combination for proppant embedment behavior in a ductile shale fracture
(2) Laboratory demonstration of the reductions in fracture-closure-induced permeability reduction of a shale fracture
(3) Predictable numerical modeling tool development based upon coupled thermal-hydrological-mechanical-chemical code (TReactMech code)

Research Activity and Products

Program Goals and Objectives

- Fracturing and re-fracturing operation optimization
- Efficient and sustainable oil and gas production
- Development of under-utilized shale resources

Success Criteria

- Demonstrate chemical reaction can be used to modify compaction behavior of proppant/fracture, improving sustainability of hydraulic fractures in ductile shale
- Identify their combinations effective for practical use

Organization Chart

Project Team

Sara Hefty
–Administrative Assistance–

Lab Experiment Team

Seiji Nakagawa (PI)
–Mechanical and hydrological testing. Optical imaging–

Tim Kneafsey
– Hydrological testing and X-ray CT imaging –

Sharon Borglin
- Laboratory assistance -

Numerical Modeling Team

Eric Sonnenthal
–TReactMech modeling, Theoretical geochemistry–

J. Torquil Smith
–TReactMech modeling–

Industry Advisor

Russell Ewy
Chevron ETC

Mehdi Mokhtari
U. Louisiana, TMSL

Field Laboratory Collaborator

Gantt Chart

Tasks	Year 1 (Oct.2018-Sep.2019)				Year 2 (Oct. 2019-Sep.2020)			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1 Project Management and Planning								
Task 2 Laboratory experiments								
Subtask 2.1 Acquisition of shale core samples and baseline sample property characterization								
Subtask 2.2 Partial modification of the fracture compaction visualization system for THMC experiment		M1						
Subtask 2.3 Fabrication of a new fracture compaction visualization cell			M3					
Subtask 2.4 Medium-temperature, short-term shale fracture compaction/proppant embedment tests				M4				
Subtask 2.5 Preliminary proppant/shale-fluid reaction tests				M5				
Subtask 2.6: Higher-temperature, long-term shale fracture compaction/proppant embedment tests					M7	M9		M10
Task 3 Numerical modeling								
Subtask 3.1 Initial selection of proppant, shale, fluid combinations and THMC model setup		M2						
Subtask 3.2 Single indenter/proppant-scale THMC modeling of shale deformation using TREACTMECH				M6				
Subtask 3.3 Multi-grain/asperity simulations of proppant-embedment/asperity deformations						M8		
Subtask 3.4 THMC modeling of laboratory-observed fracture closure								M11

Bibliography

For the current research project,

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