10-9-2019

Proppant/Rock Interactions

Jonathan Moore

NATIONAL ENERGY TECHNOLOGY LABORATORY

Proppant / Rock Interactions

Johnathan Moore

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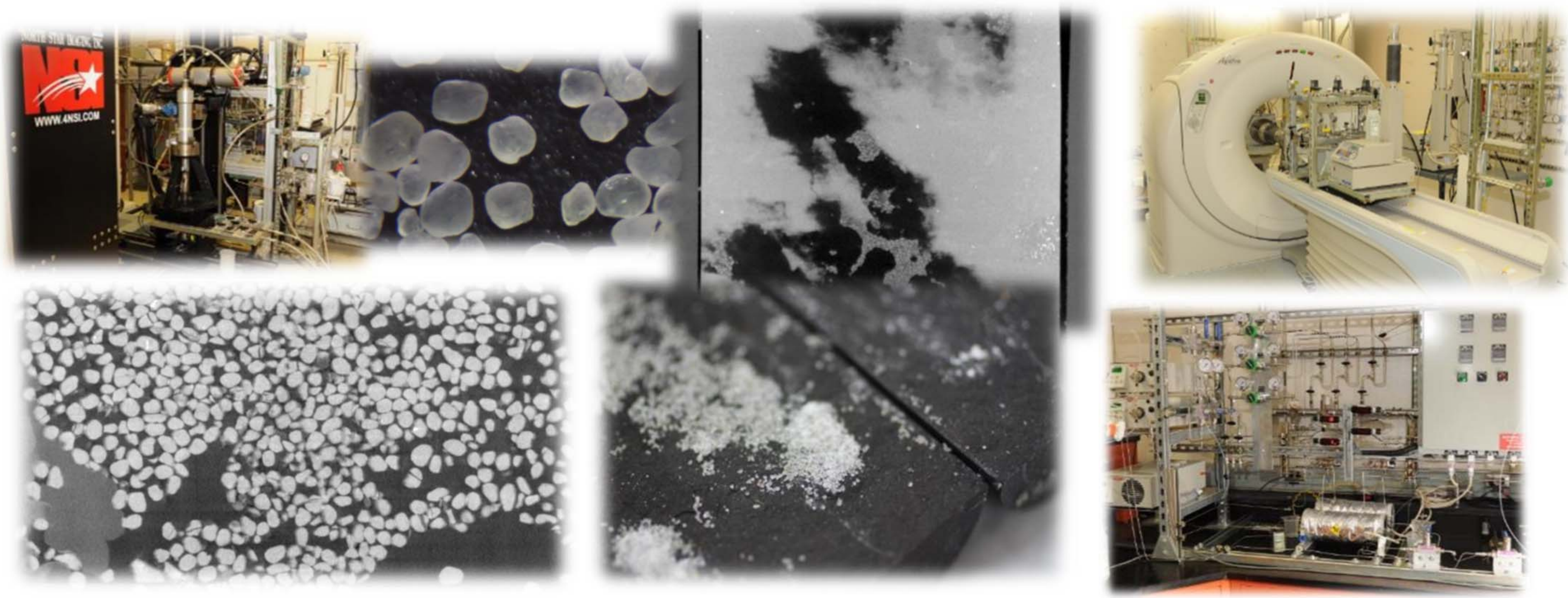
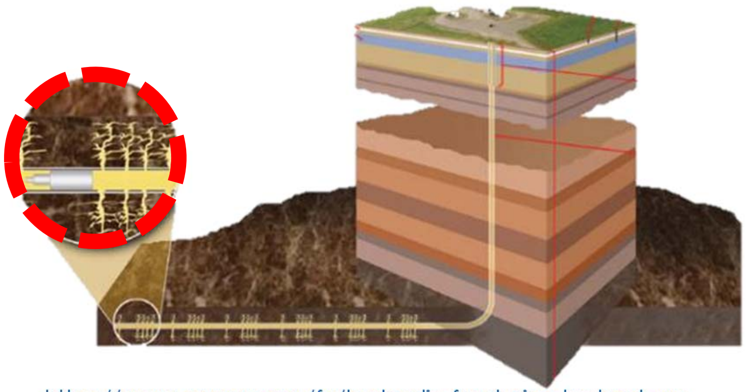
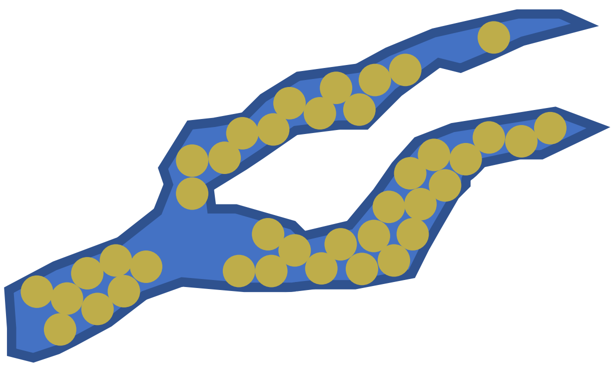


What is proppant?



https://www.energy.gov/fe/hydraulic-fracturing-technology



- Injected during hydraulic fracturing to maintain permeability following stimulation
- Intent to flow/place proppants into tributary fractures from main perforations and wellbore
- Typically sand but can be a combination of novel materials
    I. Sand, resin coated sand, ceramics, coated ceramics
- Variable mesh size and shape (sphericity & roundness)

Mesh	70/140	20/40	10/20	8/12
Screen (mm)	0.11 – 0.21	0.42 – 0.84	0.84 – 2	1.68 – 2.38

Experimental Goals & Intent

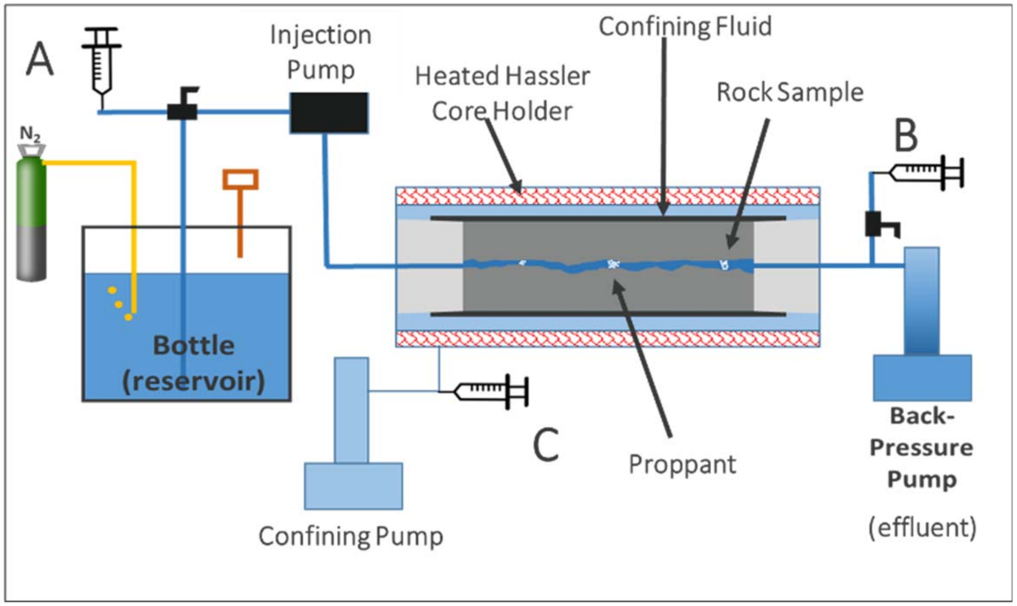
NATIONAL ENERGY TECHNOLOGY LABORATORY

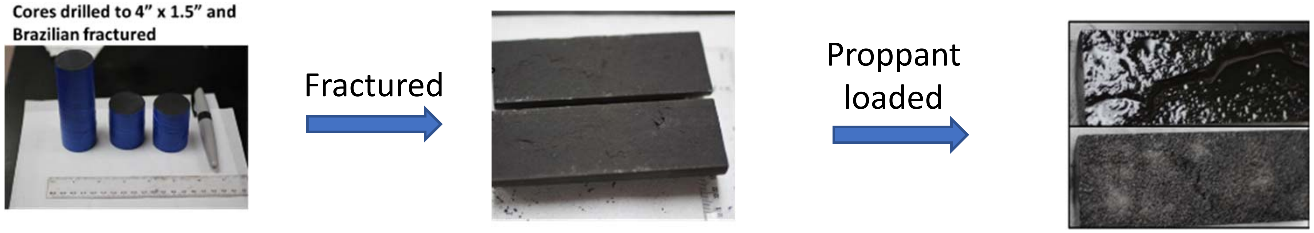
- **Geochemical interactions in fractured unconventional reservoirs**
- **Proppant embedment/impingement and the influence of hydrofracturing additives**
- **Characterization of proppant behaviors under in-situ stress regimes in unconventional reservoir rock**
- ***Time Permitting: Additional unconventional reservoir research***

Geochemical Interactions

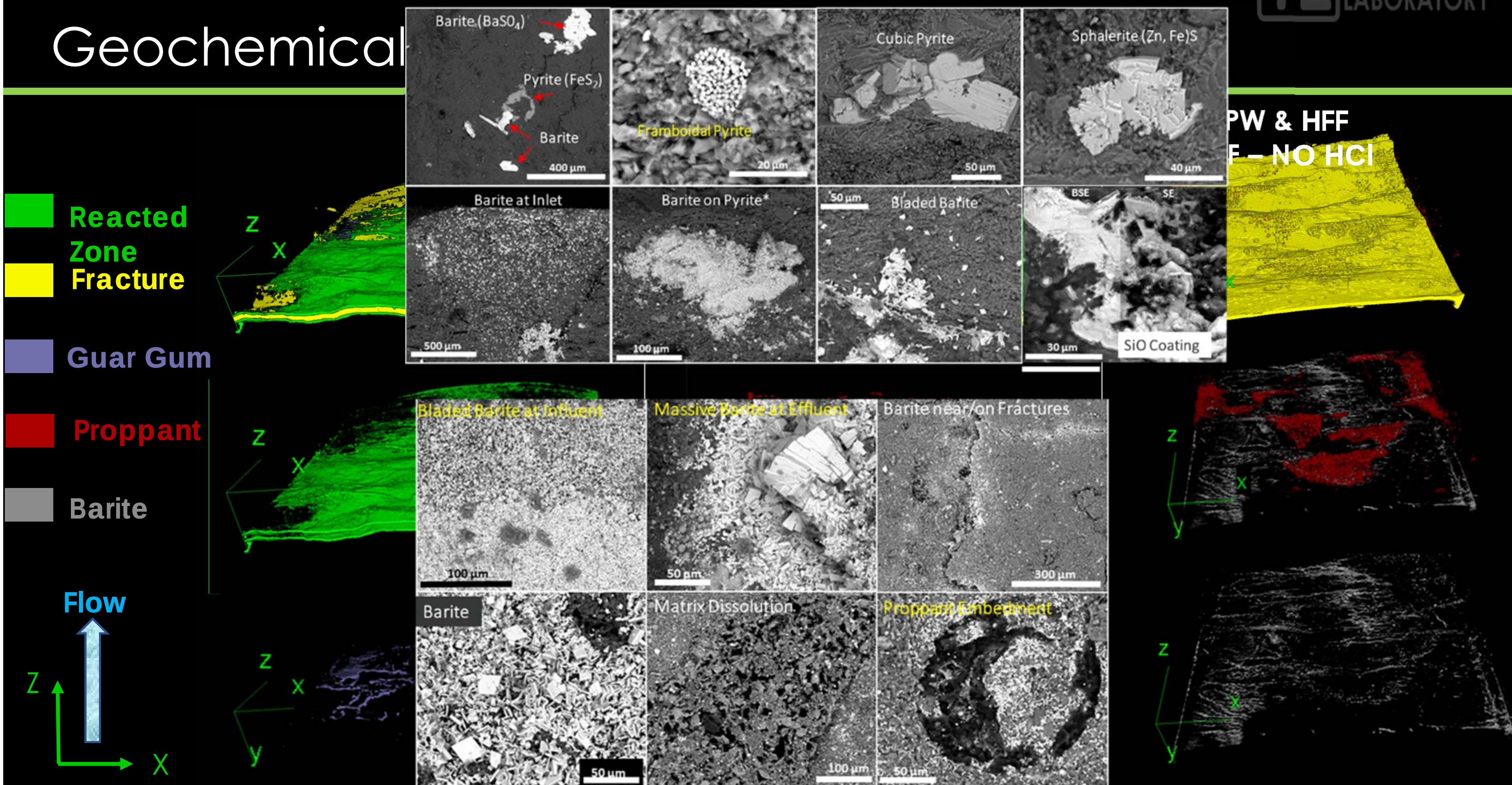
Test conditions set to approximate Marcellus shale reservoir conditions
- **Temperature 150°F (65.6°C)**
- **Confining (overburden) pressure 3,000 PSI (20.68 MPa)**
- **Pore pressure 2,800 PSI (19.3 MPa)**
- **Inject rate (Q) of 0.03 ml/min**
- **Injection bottle purged with N_2 to prevent oxidation**

Aqueous Sampling
- **Samples collected at 2, 24, 48, 72, and 96 hours after injection start**
- **Aqueous samples analyzed by/for**
  1) **Inductively Coupled Plasma Mass Spectroscopy (ICP-MS)**
  2) **Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES)**
  3) **Ion Chromatography (IC)**
  4) **pH**





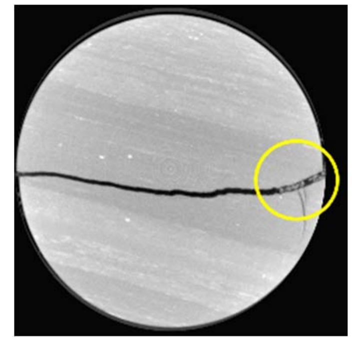
Geochemical



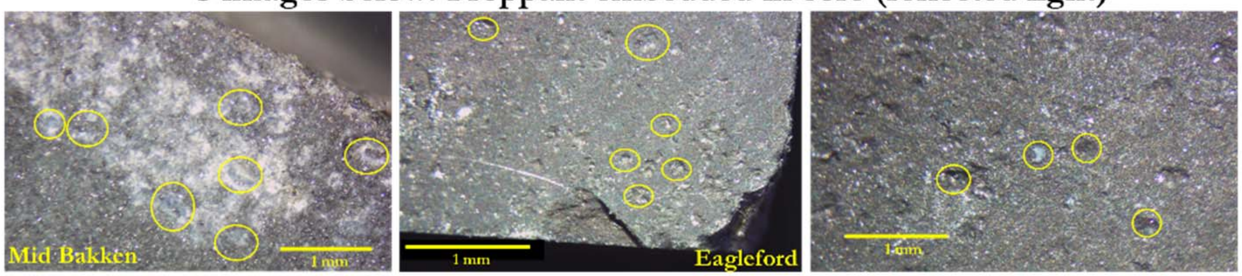
10/09/2019

Proppant Embedment

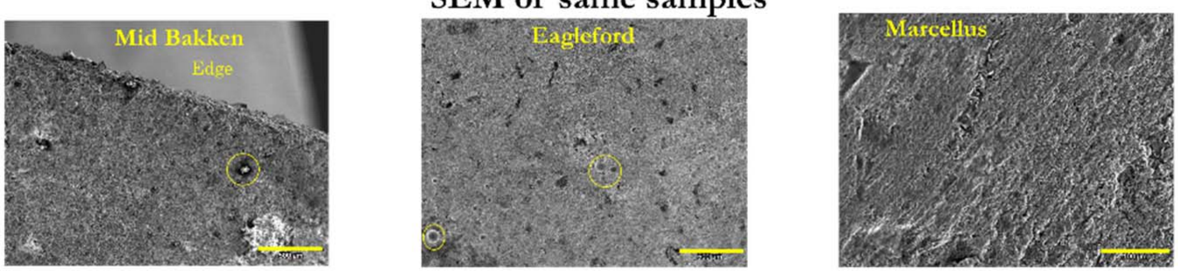
- **Marcellus shale, Bakken shale, Eagleford shale**
- **Confining pressure up to 3000 psi (20.9 Mpa), pore pressure <20 psi, room temperature, brine as pore fluid in second series with 5% KCl**
- **Tested wet and dry systems to evaluate impacts of hydration on embedment**
- **Saw cut fracture**
- **Results of dry and wet experiments show some proppant embedment in CT images and SEM**



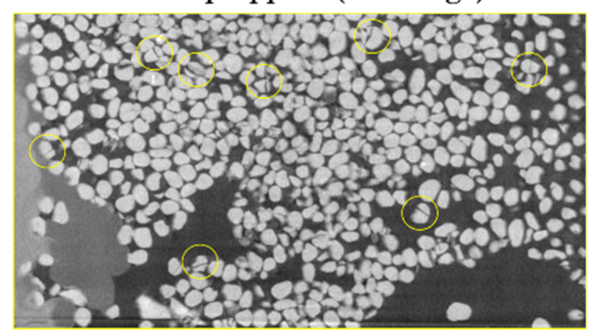
3 images below: Proppant embedded in core (reflected light)



SEM of same samples



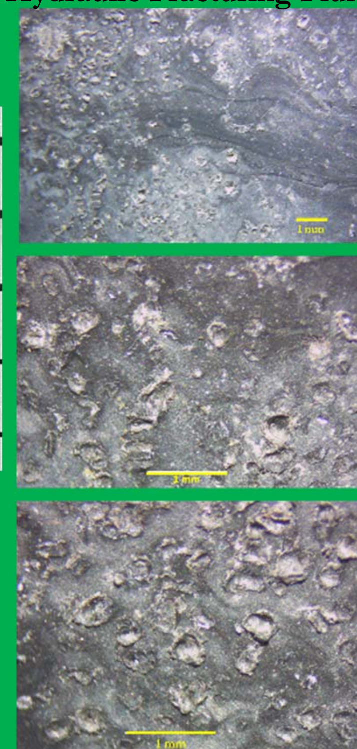
Broken proppant (CT image)



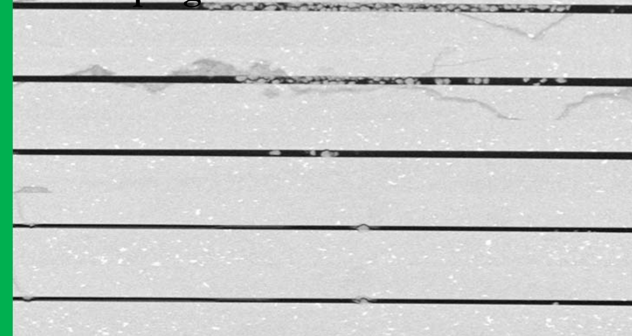
Proppant Embedment

- Marcellus shale from (MSEEL.org) MIP 3H well in Morgantown, WV, depth 7,488 feet
- Experiments under dry conditions, wet (deionized water) and exposed to fracturing fluid
- 2,400 psi (16.5 Mpa), room temperature
- Results of dry, DI wet and fracturing fluid exposure all show proppant embedment and gouging; highest density of embedment in samples exposed to fracturing fluid
- Secondary fractures form at site of proppant impingement

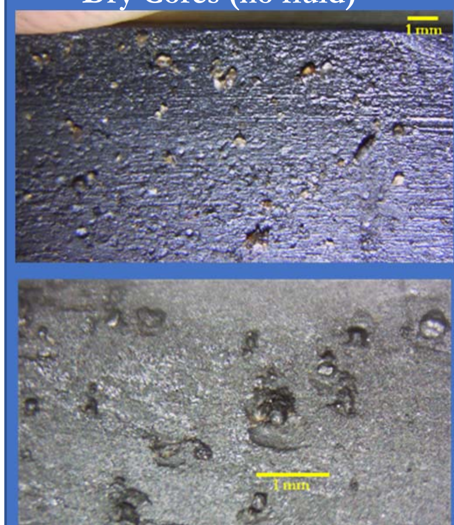
Hydraulic Fracturing Fluids



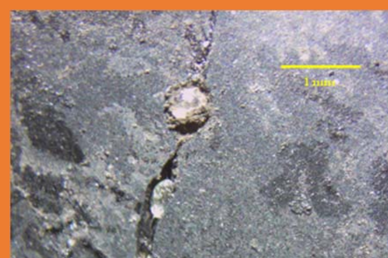
Impingement in CT cross section



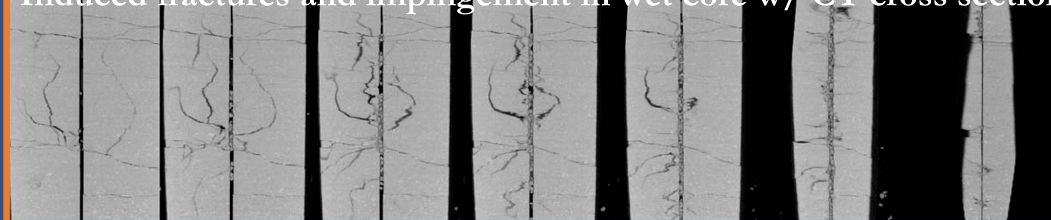
Dry Cores (no fluid)



Deionized Water

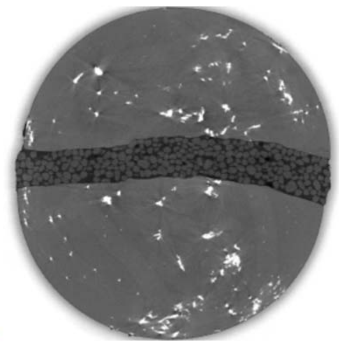


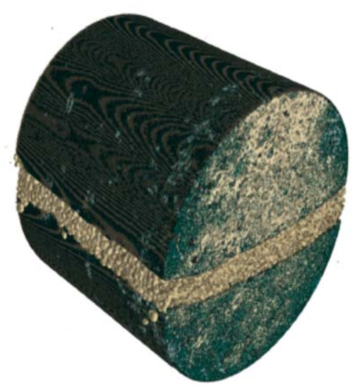
Induced fractures and impingement in wet core w/ CT cross section



Stress Effects on Proppant Behavior

- Collaborative study with LLNL to evaluate proppant movement and behavior under loading (Walsh et al. 2016)
  I. Marcellus shale was artificially fractured with Brazilian technique
  II. Resin-coated proppant 20-40 Mesh (⌀ ≈ 0.59 mm)
  III. Sample was loaded into a Hassler style core holder within the industrial CT scanner at NETL
  IV. Sample was stressed in sequential steps up to 10,000 PSI
    a. Samples were CT scanned at each step
    b. Relative slip was measured at each step (shear)
    c. Image registration and PIV was utilized to evaluate proppant movement



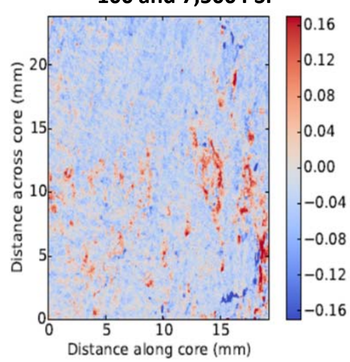


Stress Effects on Proppant Behavior Cont.

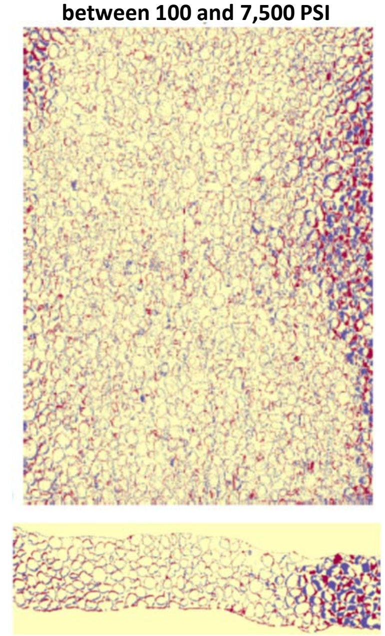
Event between 6,000 & 7,500 PSI

- **Triggered large scale proppant movement**
- **Proppant motion reflects reorganization into more stable configuration**
- **No further motion between 7,500 and 10,000 PSI**

Aperture reduction between 100 and 7,500 PSI

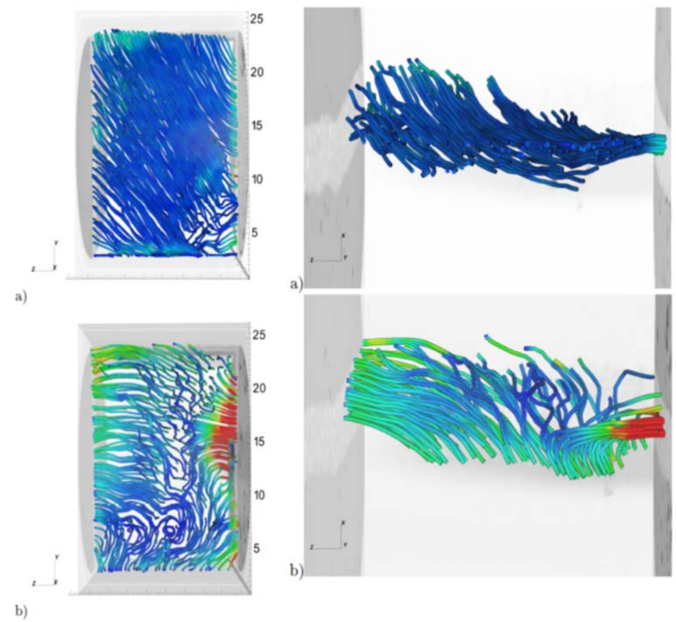


Proppant relative motion between 100 and 7,500 PSI



Relative motion vector between 100 and 7,500 PSI

Plane View (X/Z) **Side view (X/Y)**



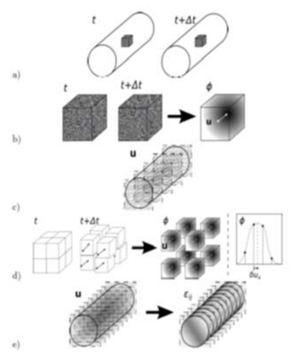


Fig. 3 Stages in the PIV analysis: a) Matching subvolumes (dark squares) are compared from the two samples. b) The cross-correlation between two matching regions is determined and a displacement vector is obtained from the position of the maximum value. c) The process is repeated for all subvolumes giving rise to a displacement field. d) The regions are sub-divided and the initial displacement field is used to improve the accuracy of subsequent cross-correlation calculations. Sub-pixel interpolation is used for further improvement. e) Strains and rotations may be determined from the displacement field gradients.

Images modified from (Walsh et al. 2016)

Enhancing Hydrocarbon Recovery through Fundamental Knowledge of the Reservoir and Well System

Improve Fundamental Understanding of Shale to Enable Decision-Making for Enhanced Hydrocarbon Recovery

Ensure Wellbore Integrity during Drilling, Completions, and Production

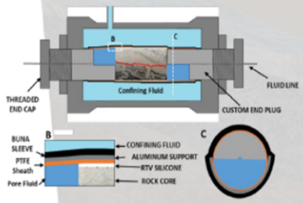
Enhanced Recovery

- Review of existing literature characterized data gap for laboratory experimental data needed to predict field performance of enhanced oil recovery techniques in shales

- How effective are CO_2 and natural gas in enhancing oil recovery from the Wolfcamp Shale (HFTS 1)?

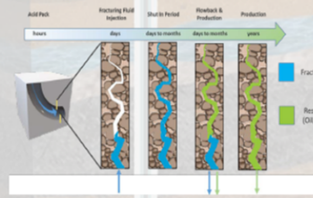
Understanding the Reservoir

Geomechanics



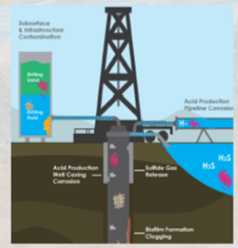
- How do geomechanical processes affect flow through fractures?
- Laboratory-based studies to address –
  - What is the impact of shale microfabric on sheared fracture alteration?
  - How do proppant embedment and clay/kerogen content influence shale fracture closure?
- Core characterization and cataloguing

Geochemistry



- How can geochemical processes affect flow through fractures?
- Laboratory-based studies to address-
  - What geochemical species (isotopes, organics) and parameters (redox, pH) can be applied to quantify impactful changes?
- Field-based studies to address relationship between laboratory results and field observations

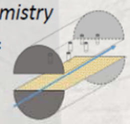
Geobiology



- What role does geobiology play in unconventional reservoir performance?
- Laboratory and field-based studies to address –
  - What is the microbial ecology and biological function in unconventional wells?
  - Can DNA be applied as an effective marker for reservoir and well processes?

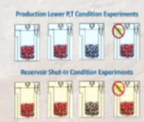
Coupled Effects of Mechanics + Chemistry

- Which micro-scale geochemical processes affect reservoir-scale processes (focus on HFTS1)?
- Multilab Project – LBNL, LLNL, SLAC, NETL



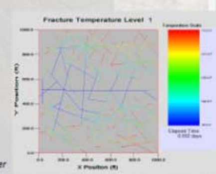
Coupled Effects of Chemistry + Biology

- When do geochemical and geobiological processes take precedence – during hydraulic fracturing or production (focus on HFTS II)?
- Collaboration with GTI



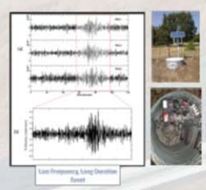
Fracture Modeling

- How can dynamic pressure and temperature changes during hydraulic fracturing and primary production be incorporated into Nflow?



Hydraulic stimulation of hot reservoir with cold water

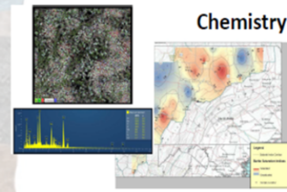
Geophysics



- How can geophysical signals be better leveraged to develop an improved understanding of near-well fracture networks and hydrocarbon recovery?

Understanding the Wellbore

Chemistry



- What biogeochemical processes control mineral scale precipitation within wellbore steel casing?
- Laboratory-based experiments and characterization of field samples to address –
  - Where, and under what conditions, will mineral scale form on wellbore steel casing?
  - Can techniques be developed to prevent problematic mineral scale from forming?

Mechanics

- What processes affect wellbore mechanics across the life cycle of the well?
- Laboratory-based experiments and modeling to address –
  - How does wellbore cement strength develop under conditions relevant to onshore unconventional reservoirs?
  - How do dynamic changes in pressure and temperature affect steel-cement-rock interfaces during the well's lifetime?

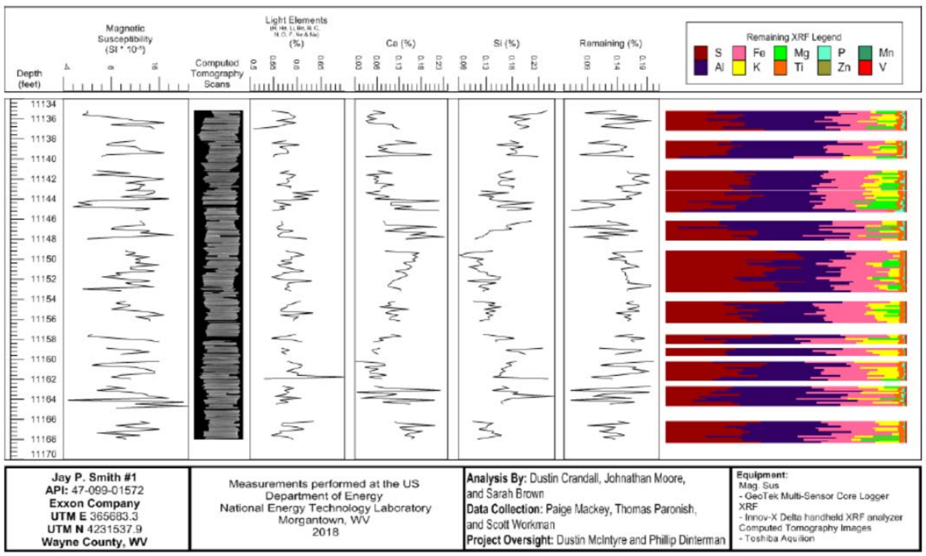
Maximizing Hydrocarbon Value and Produced Water Beneficial Use

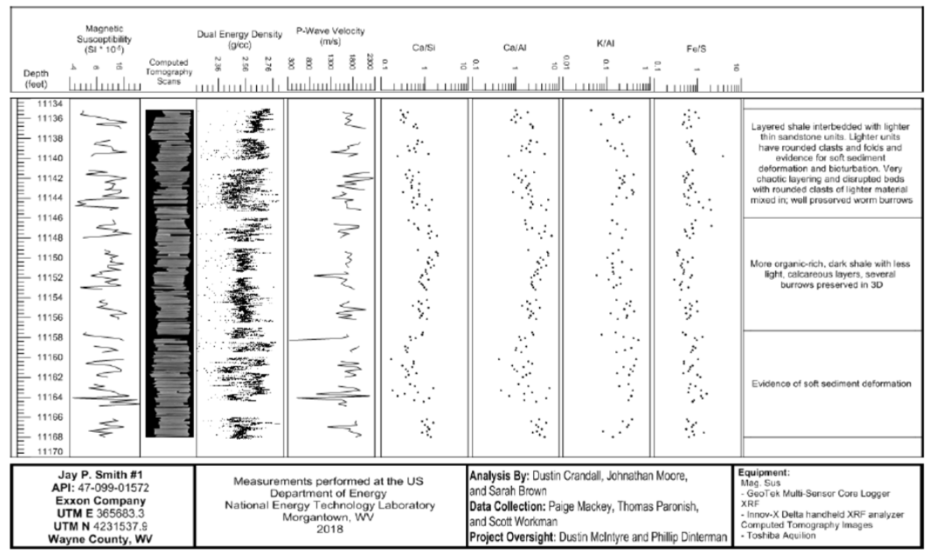
Current: Application of systems analysis to evaluate successful end-use strategies for hydrocarbons and water produced from the well.

Future: Leverage experimental and field capabilities to confirm results.

Resulting Data

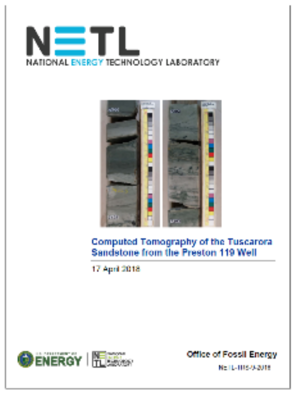
Combined logs

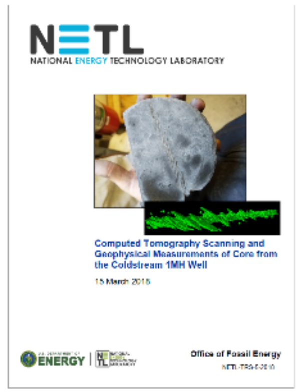


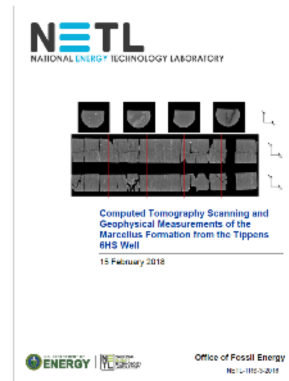


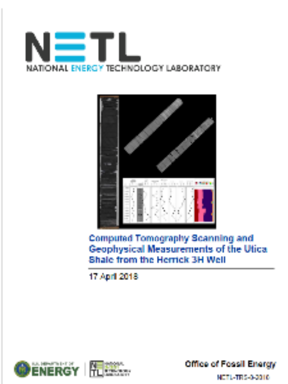
Technical Report Series

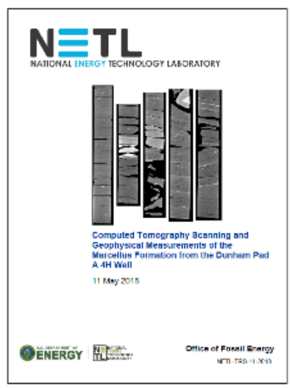
Internally reviewed grey literature

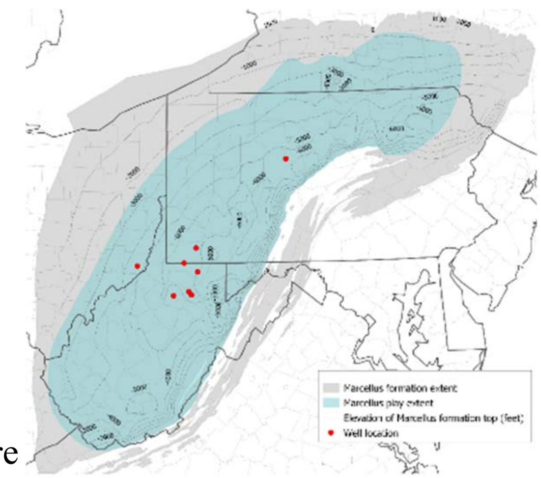












In progress - Salina Fm, MSEEL, and FutureGen Core

Collaboration Opportunities

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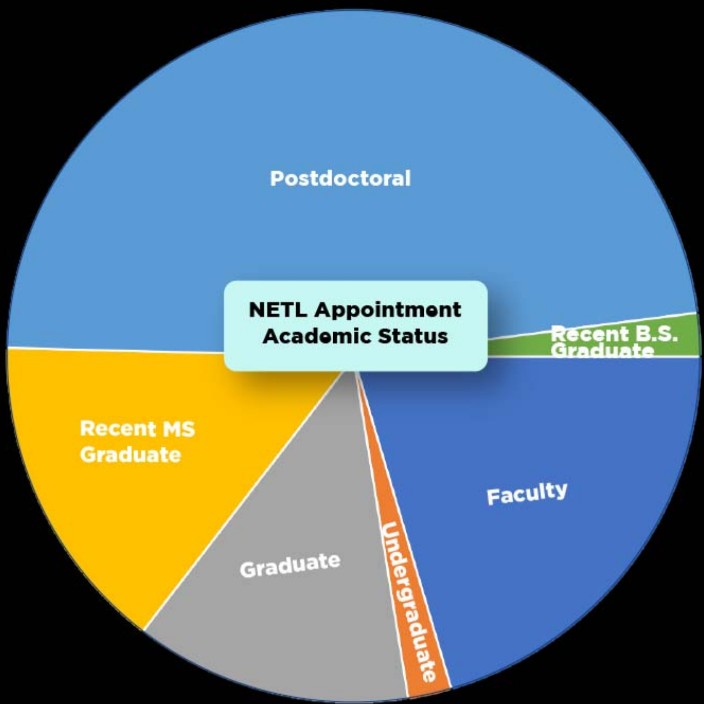

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