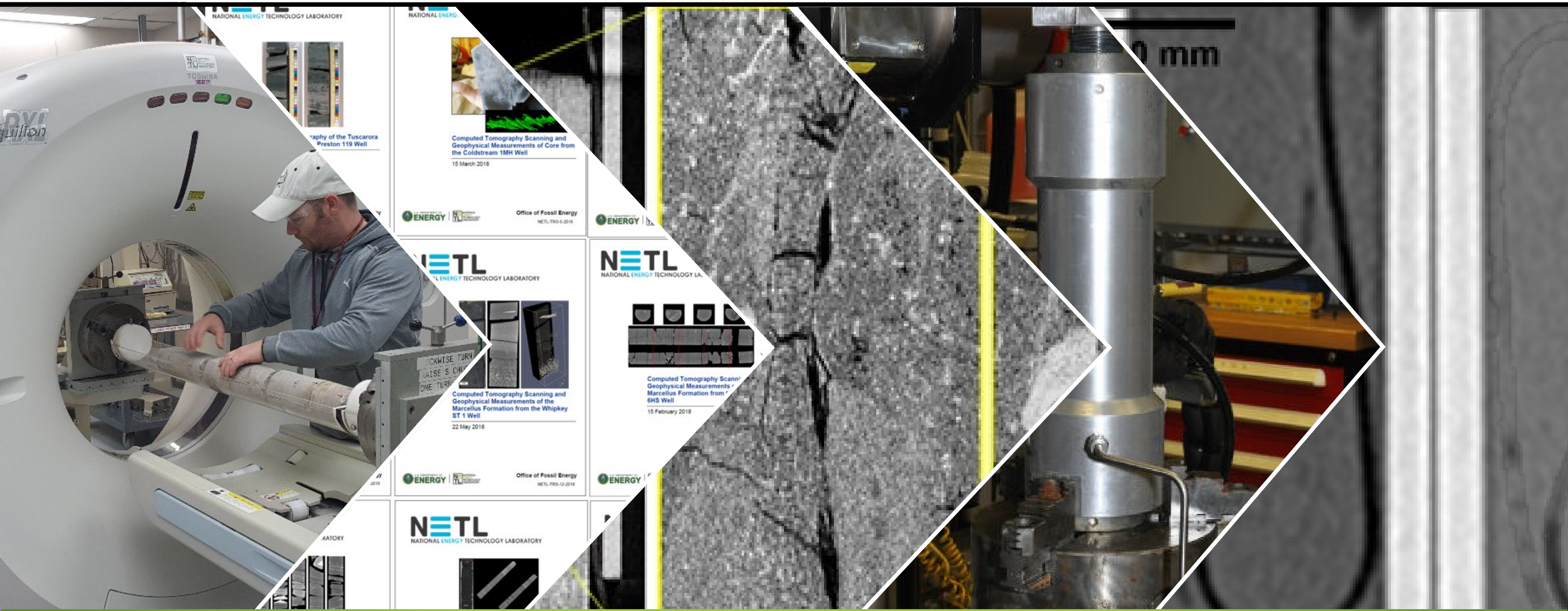
# Role of Shale Geomechanical Changes Affecting Gas and Fluid Flow

Dustin Crandall, NETL

August 25th, 2021



# Outline

## CT Scanning of Cores for Insight

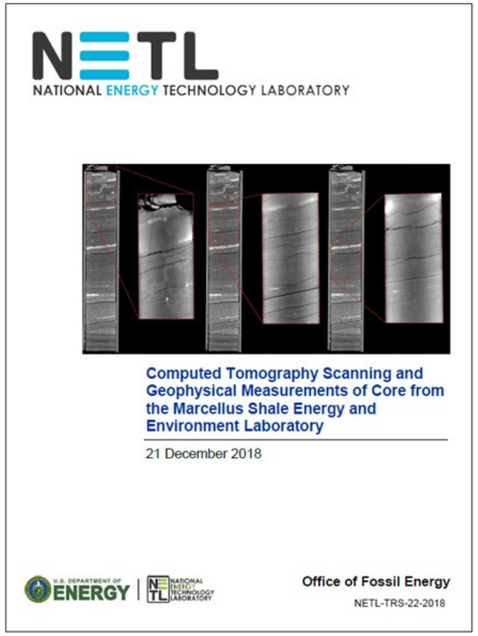
- Final year of a task that has utilized NETL's in-house computed tomography and flow systems to examine what impacts to gas/fluid migration various stressors cause.

- Building from the 'basic' CT equipment, devices to examine specific phenomena have been built and utilized
  - Shearing of fractured shale under pressure
  - Huff and puff behavior of shales under pressure
  - Near fracture direct matrix permeability measurements

- As part of this process, the scanning of relevant cores for field operations slowly became more important
  - Thousands of feet of shale cores have been scanned and made publicly available.

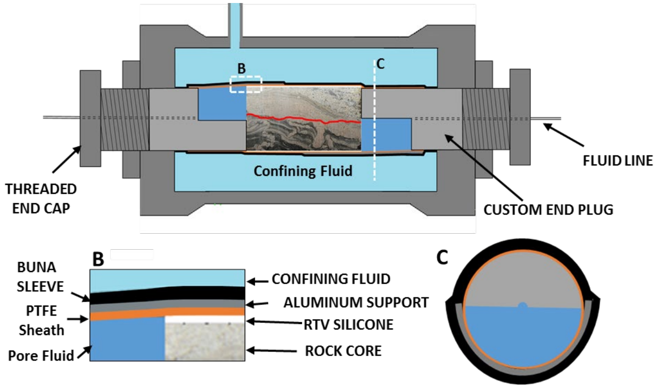
# Impact to Flow in Shales

| 2017 – 2018* | 2019 | 2020 | 2021 | Total Project (2017 – 2021) |
|---|---|---|---|---|

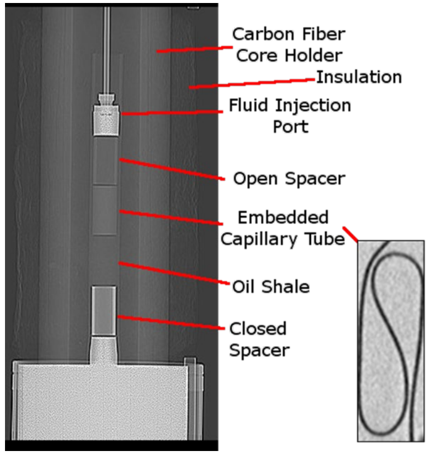



**Non-destructive core characterization for baseline reservoir information**

**Apparatus to Measure Fracture Aperture Changes under Confining Stress**

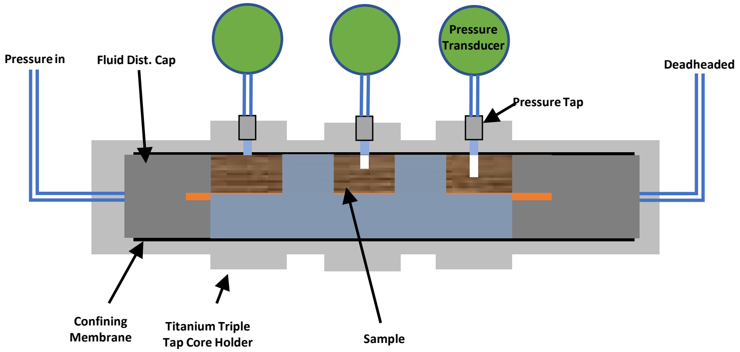



One-of-a-kind laboratory techniques developed to study mechanics and flow changes under reservoir P & T conditions.




**Apparatus to Measure Live Hydrocarbon Huff n' Puff**

**Apparatus to Measure Fracture Adjacent Matrix Permeability**




**End Products:**
Characterized reservoir core and improved relationships for model-based predictions of flow.

# Benefits of Fundamental Research

## Fundamental understandings for applied problems

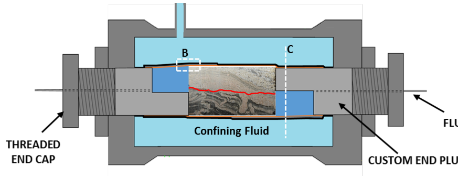
**Barriers to knowledge transfer that the project is addressing.**

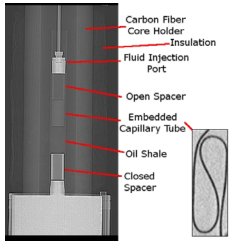
- Understanding how rocks from different basins behave, under representative subsurface conditions, is important to identify similarities and differences.
- Enabling wide distribution of characterizations and results to partners and public.

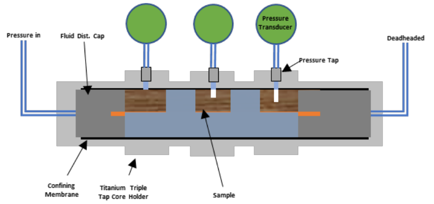
The barriers are being addressed with unique experimental equipment to *examine real rocks, under real conditions*.

The extent the barriers have been/are being addressed by the project

- Fundamental understanding of behavior increased through publications.
- Continued collaborations with industrial, academic, and national laboratory partners to ensure our fundamental measurements and understandings resonate.



# Project Objectives & 2021 Milestones

## Task 2 to end March 2022

### 2.1 Fracture Shearing

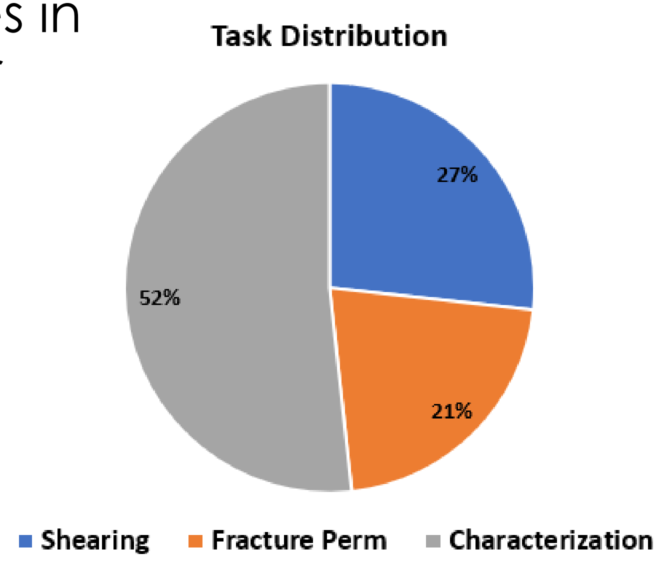
- Finalize and submit publications describing the observed relationships between changes to sheared fracture properties and shale constituents.

### 2.2 Fracture Adjacent Permeability Measurements

- Develop relationships that can be modeled to describe changes in fracture adjacent matrix permeability due to geomechanical or geochemical alterations.

### 2.3 Fundamentals of Shale/Core Characterization

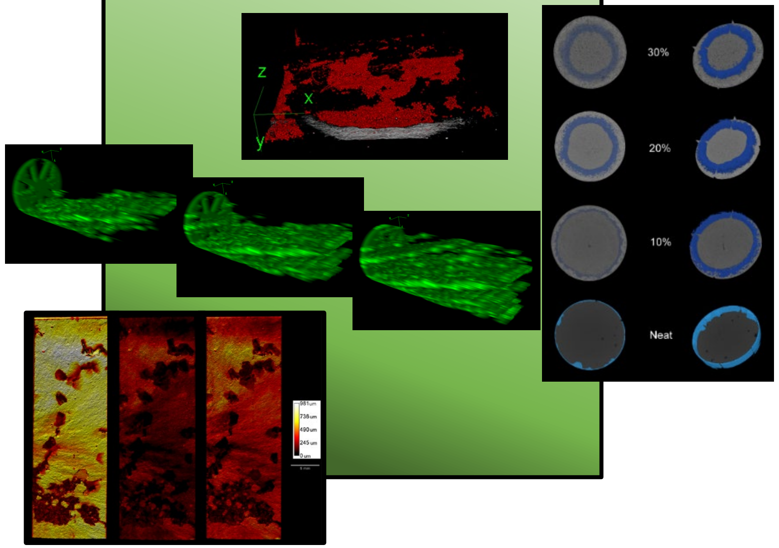
- Core collection/distribution continuing with a minimum of three core characterization reports in EY21.



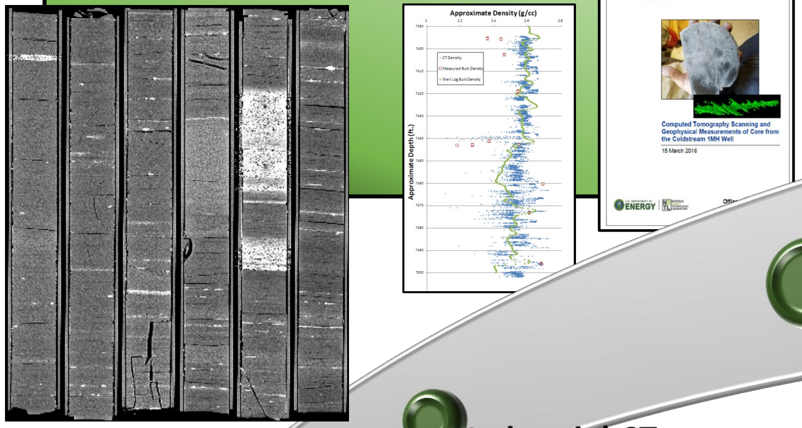
# Multi-scale CT flow and imaging facility

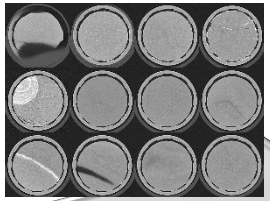


Real rocks at real conditions



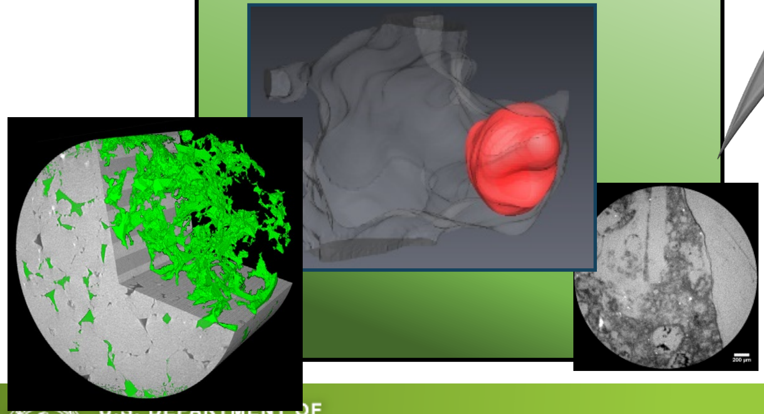

Core Logging



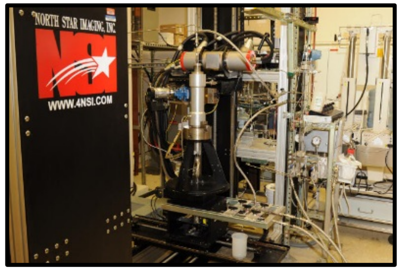
Geophysical Logging

Visualizing pore networks and trapped fluids



Micro CT Scanner
- $10^{-6}$ to $10^{-5}$ m
- Pore scale

Industrial CT Scanner
-$10^{-6}$ to $10^{-3}$m
- Pore & core scale




Medical CT Scanner
-$10^{-4}$ to $10^{-2}$m
- Core scale


Model: DynaTOM

Core flow facility

# Fracture Shearing

NATIONAL ENERGY TECHNOLOGY LABORATORY

## Marcellus, Utica, and Eau Claire Shales examined

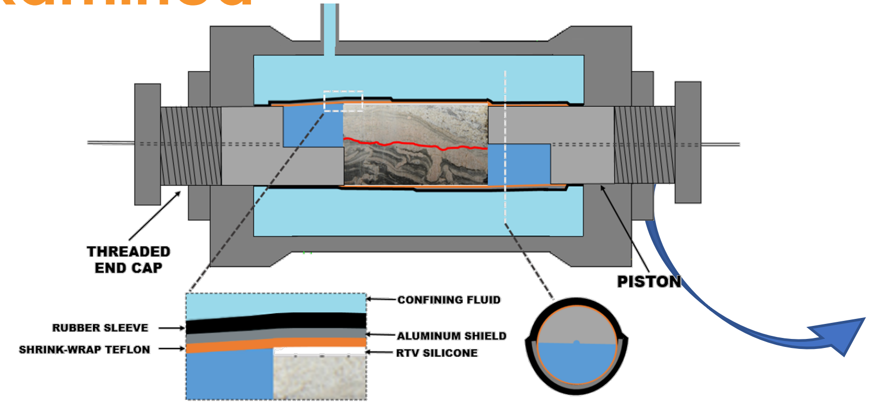
Controlled shear of fractured shale, under elevated pressure, with flow and full 3D scans

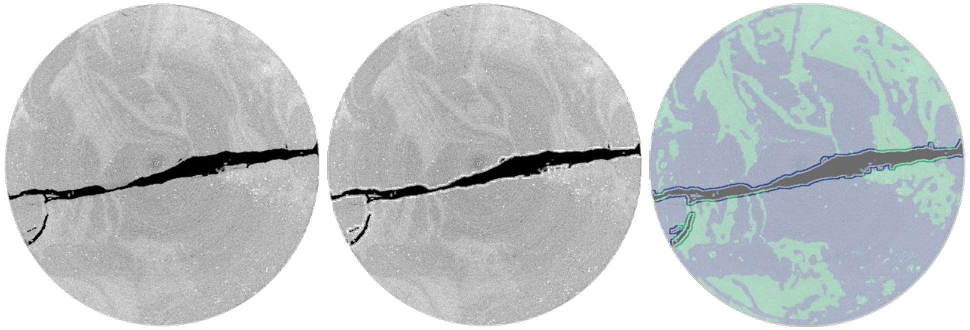
3 separate Utica shearing completed

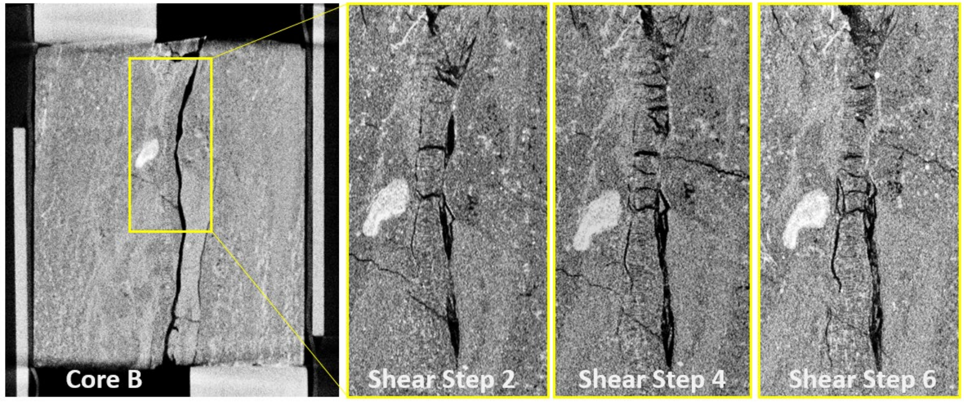
- Analysis is still underway
- Very tight fractures with low permeability

Paper describing impact of core heterogeneities submitted to Int J of Rock Mech and Mining Sciences

- Developed new image processing techniques to discern fracture adjacent materials
- Influence of local gouge creation on full fracture permeability evaluated





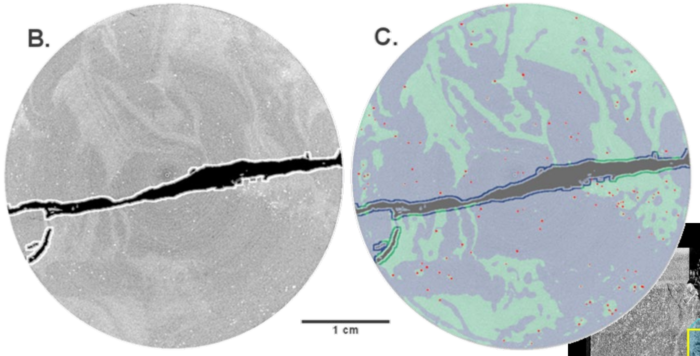
# Take Away from Recent Shearing

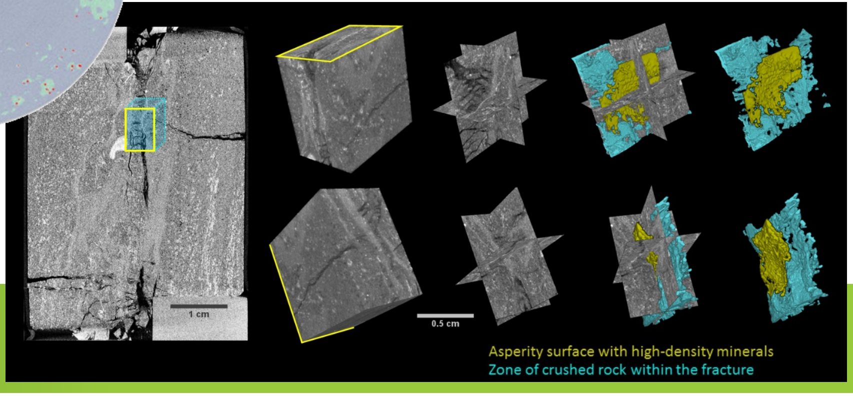
## Multiple heterogeneous shale cores examined

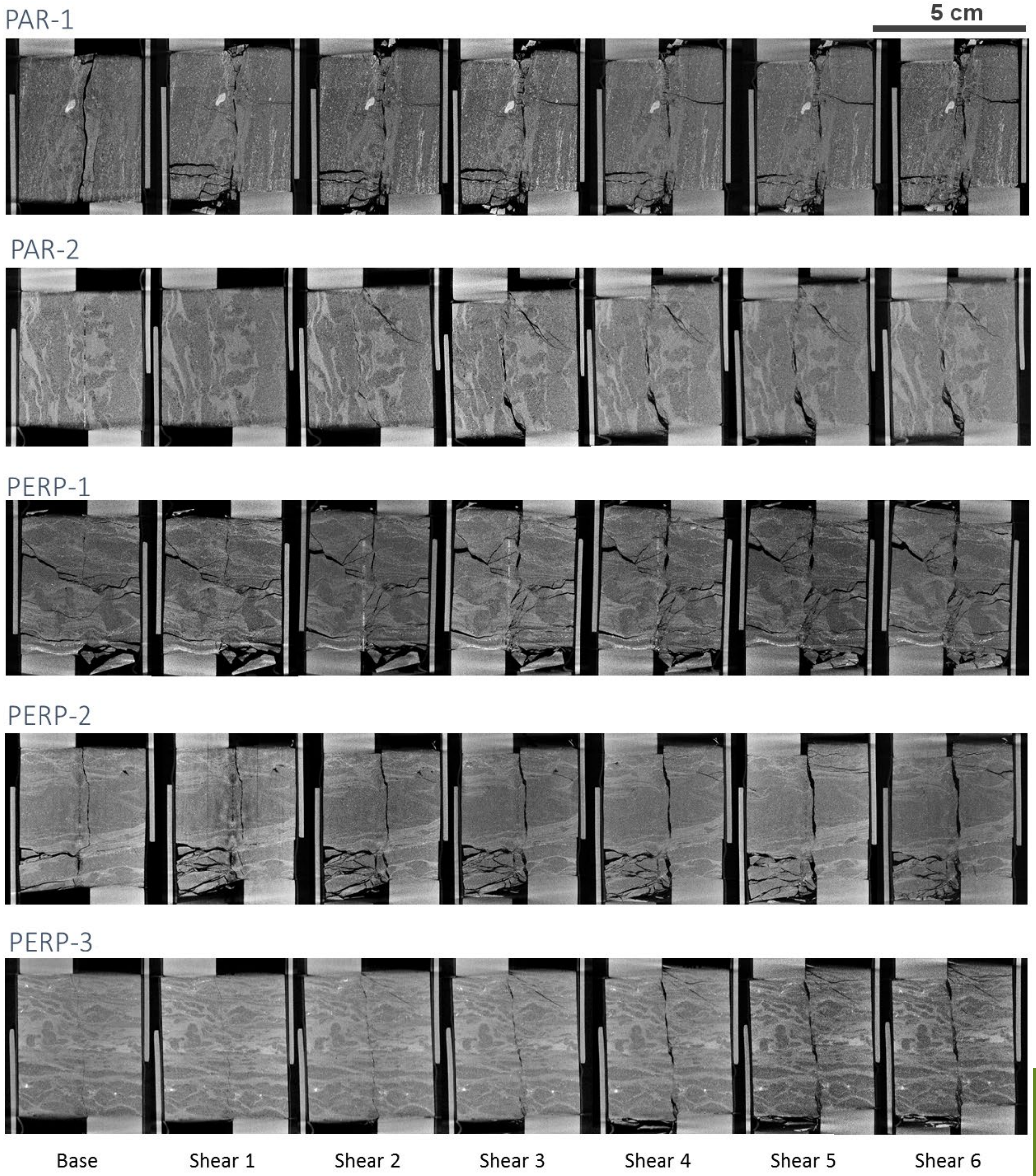
Fracture orientation to bedding matters

The material <u>adjacent</u> to the fracture plane has a significant bearing on the fracture development during shear

Small zones of gauge development can significantly reduce fracture transmissivity

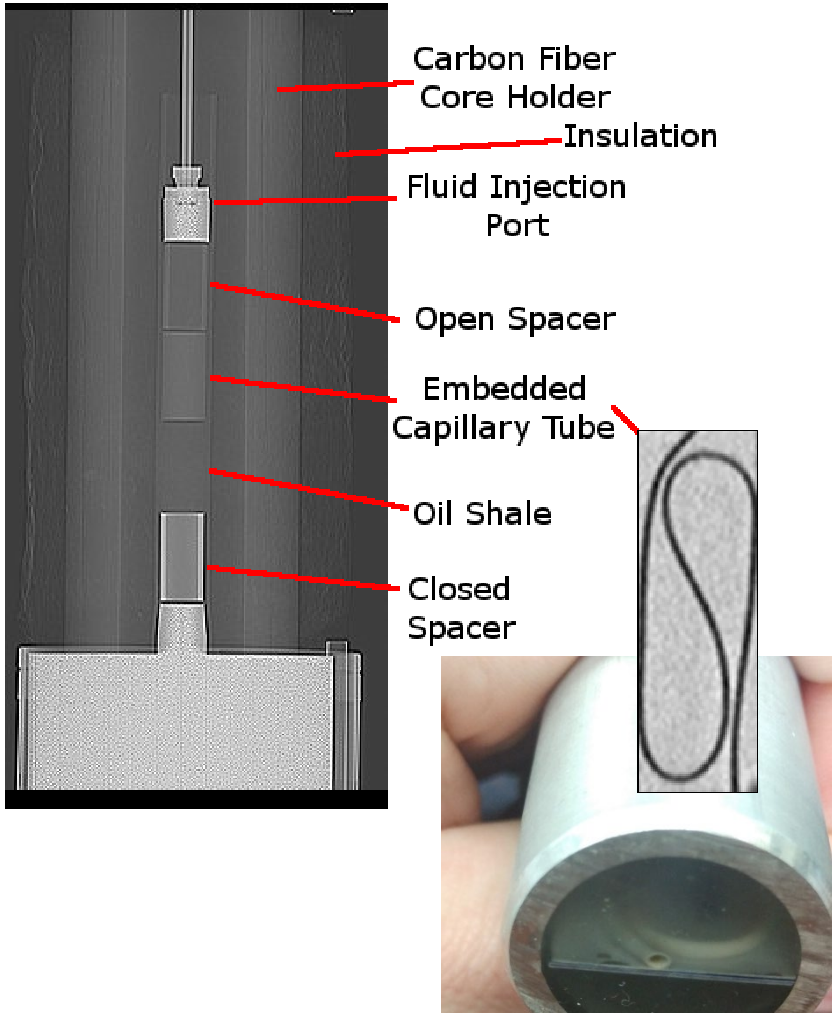


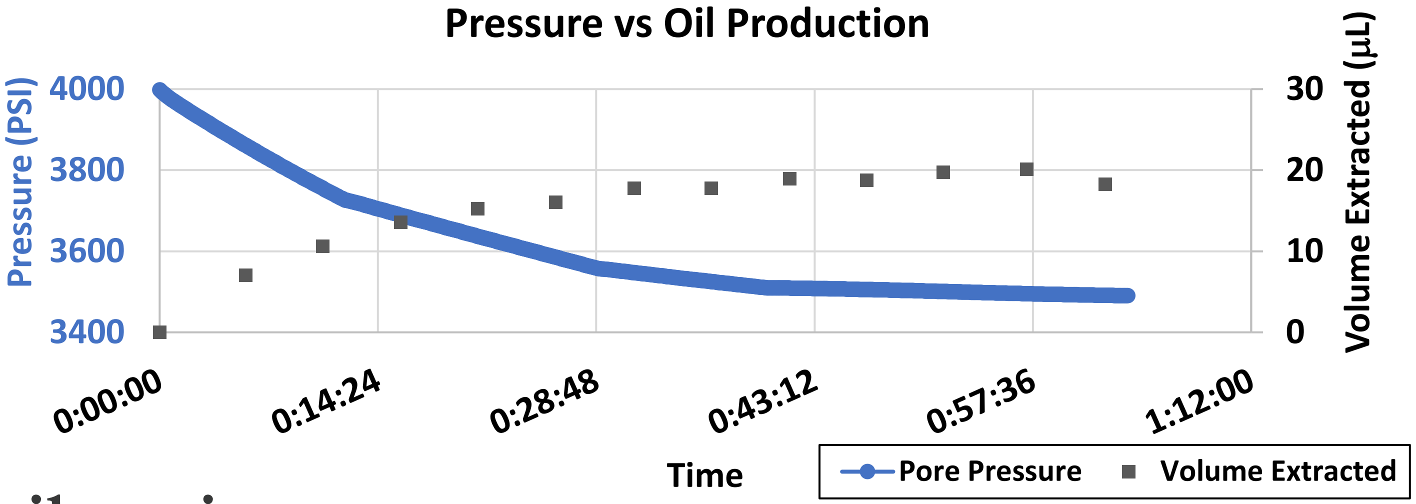



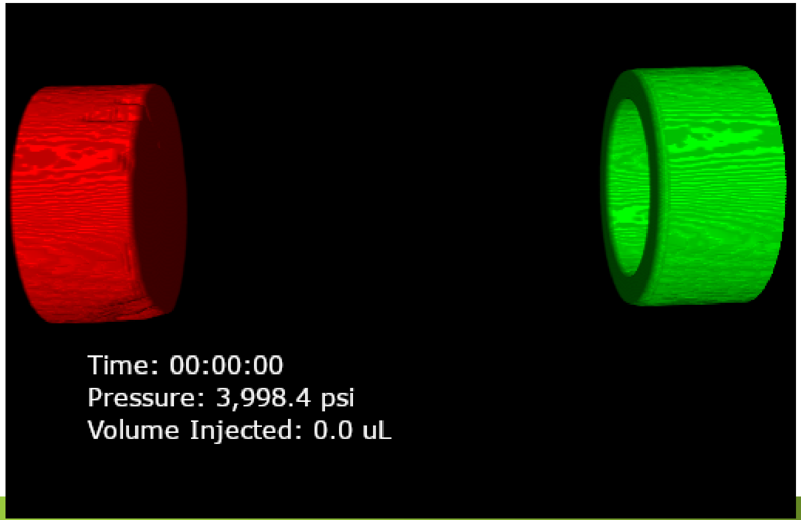
# Huff and Puff with Live Oil

## Live oil measurements without depressurization




- Live oil testing on Permian shale sample
- While maintaining T&P, reduce injection pressure and measure volume of oil produced




**2020 URTeC: A New Methodology to Evaluate Huff and Puff Effectiveness at in-Situ Conditions**
**Johnathan Moore, Dustin Crandall and Scott Workman**

# Matrix Permeability Next to Fractures

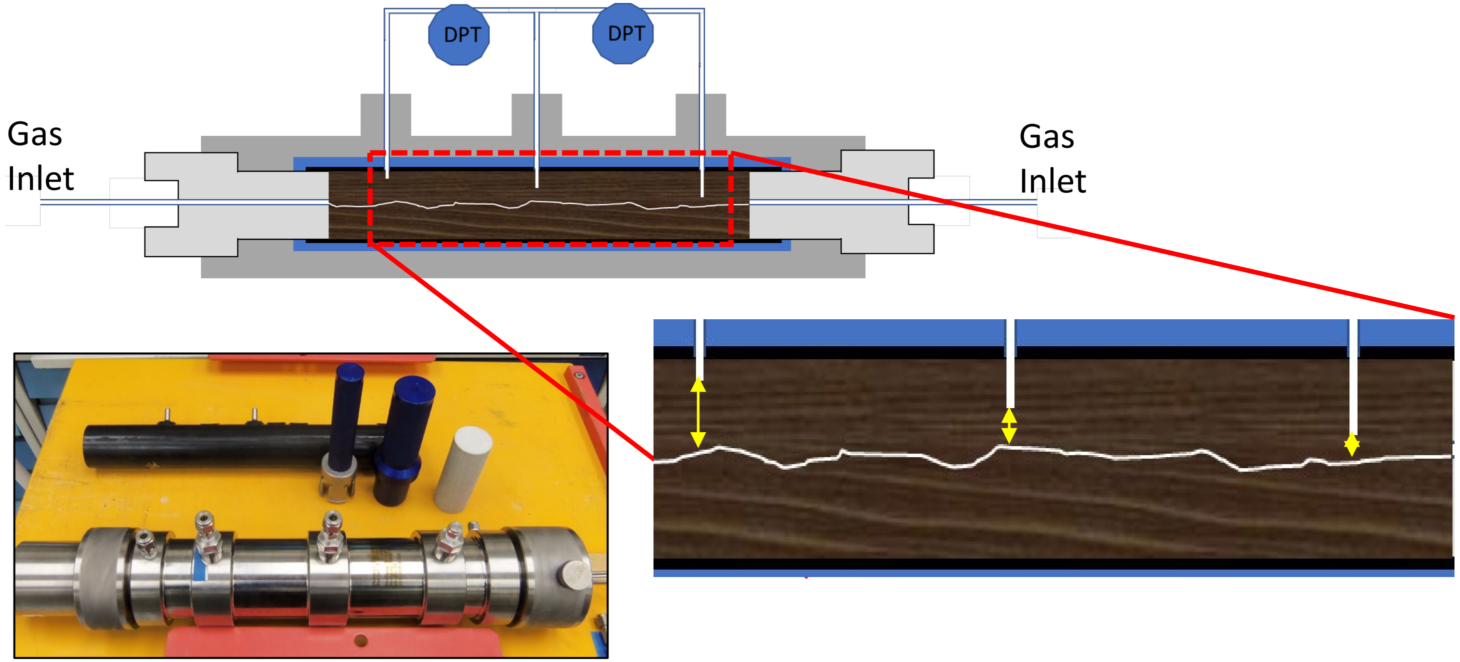
## Need became apparent from discussions with model developers

As work in Task 3 shows, geochemical alteration in fractured shale can be significant

- We can measure changes in the fracture permeability

But what does this dissolution or precipitation mean for flow in the matrix perpendicular to the fracture?

Is this critical for stopping or enhancing flow to the fractures?



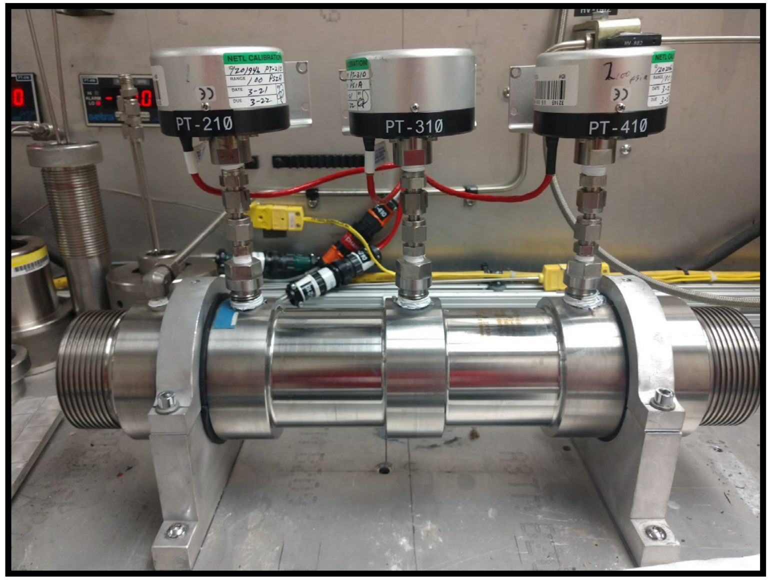

**Concept**

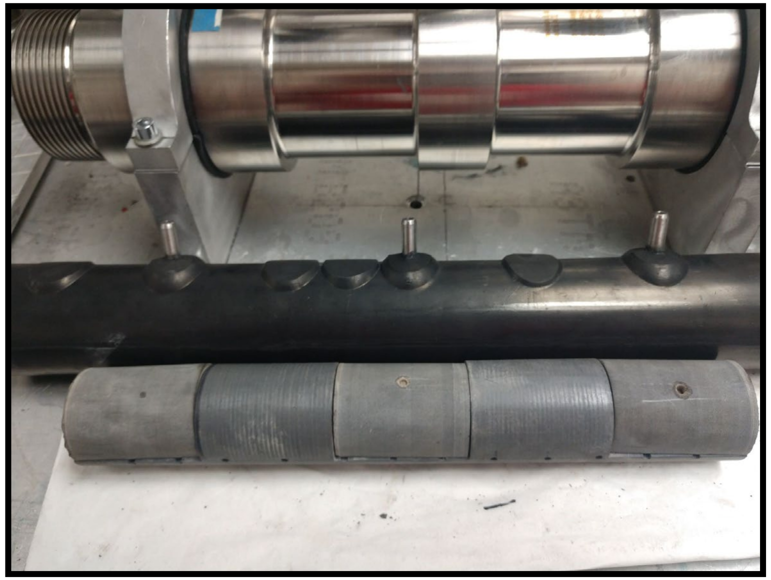
- Holes drilled perpendicular to the fracture, to different depths.
- Pore pressure applied to fracture, while system under pressure.
- Different lengths between holes and fracture will enable measurements of bulk permeability, potentially revealing information about the depth of alteration in the matrix.

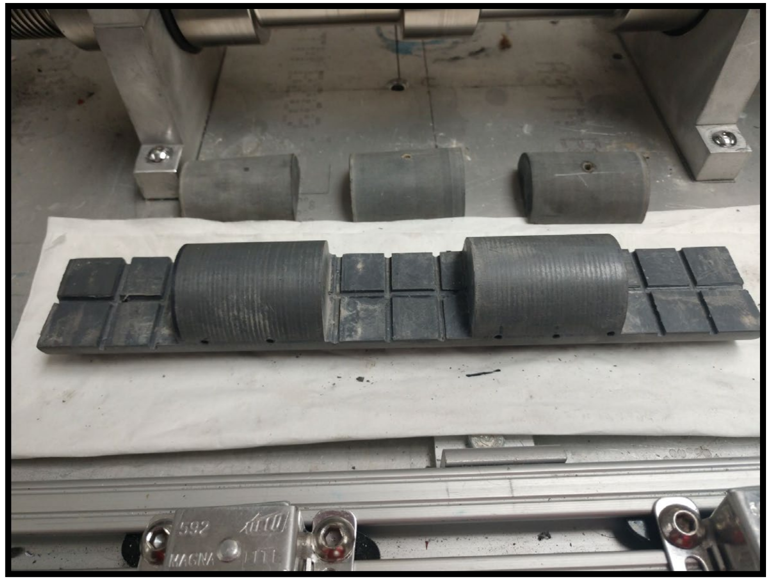
# Initial Shakedown

## Slightly different from the concept, but not much

- Changed from two differential transducers to single point measurements.
- Tested with small subcores to save on preparation complexities.



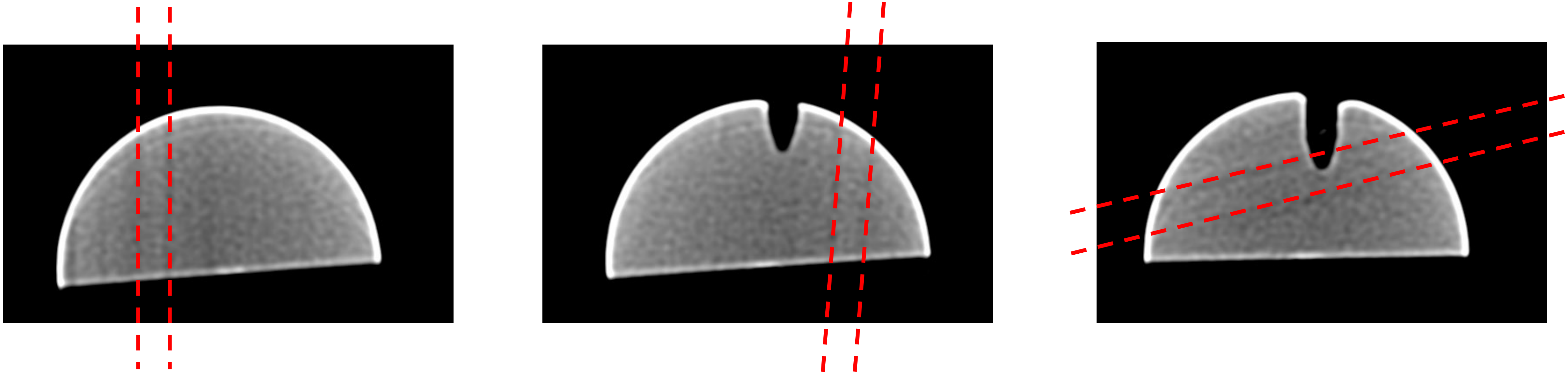





# CT Scanning for Bedding and Volume

NATIONAL ENERGY TECHNOLOGY LABORATORY

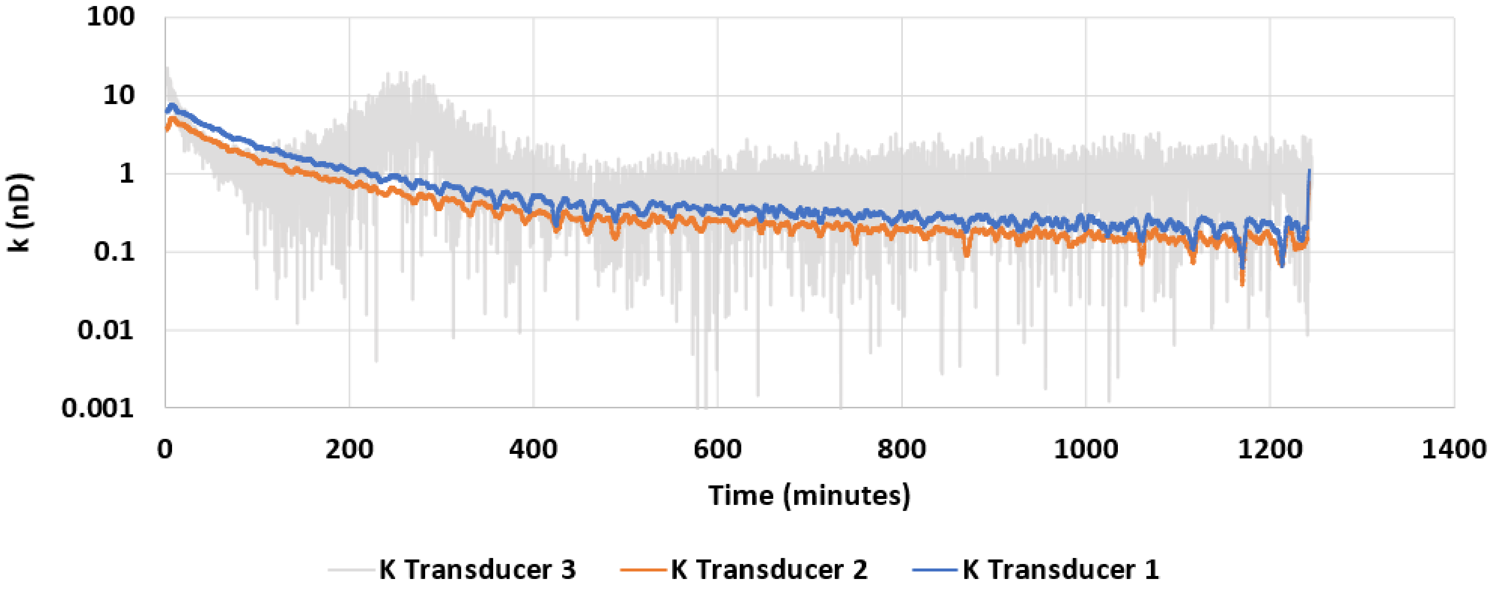
- We need an accurate volume of the port holes to get the permeability from this deadheaded system; but we get that quickly with CT scanning
- Bedding orientation was quickly observed to have a significant impact
    - Not surprising, but again CT scanning helped to illustrate the internal differences.



# Initial Results from the System

## Using PV=nRT to determine increase in mols in set volumes

- Appears to be communication between transducers 1 & 2.
  - New sleeve has been ordered.
- Mixing fluid for reactive flow this month, will be testing initial changes in permeability to build on SLAC HFTS observations.




| Seconds Elapsed | Minutes | Transducer 1 Setra | Transduce | Transduce | Box Temperature | Moles of N2 Transducer 1 | Moles of N2 Transducer 2 | Moles of N2 Transducer 3 | DP (pa) Q Transducer 1 | DP (pa) Q Transducer 2 | DP (pa) Q Transducer 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 14.37573 | 14.48136 | 14.37699 | 73.5701 | 1.34147E-06 | 1.35133E-06 | 1.34159E-06 | 535201 | 534472 | 535192 |
| 1 | 0.016666667 | 14.478561 | 14.48136 | 14.37699 | 73.552555 | 1.35111E-06 | 1.35137E-06 | 1.34163E-06 | 534492 | 534472 | 535192 |
| 3 | 0.05 | 14.272899 | 14.68709 | 14.27417 | 73.566688 | 1.33189E-06 | 1.37054E-06 | 1.332E-06 | 535910 | 533054 | 535901 |
| 5 | 0.083333333 | 14.37573 | 14.48136 | 14.27417 | 73.593288 | 1.34141E-06 | 1.35127E-06 | 1.33194E-06 | 535201 | 534472 | 535901 |
| 7 | 0.116666667 | 14.272899 | 14.48136 | 14.27417 | 73.548482 | 1.33193E-06 | 1.35138E-06 | 1.33205E-06 | 535910 | 534472 | 535901 |
| 9 | 0.15 | 14.37573 | 14.58423 | 14.27417 | 73.58741 | 1.34143E-06 | 1.36088E-06 | 1.33195E-06 | 535201 | 533763 | 535901 |
| 11 | 0.183333333 | 14.272899 | 14.48136 | 14.58265 | 73.498269 | 1.33206E-06 | 1.35151E-06 | 1.36096E-06 | 535910 | 534472 | 533774 |
| 139 | 2.316666667 | 14.37573 | 14.48136 | 14.89113 | 73.804738 | 1.34088E-06 | 1.35074E-06 | 1.38896E-06 | 535201 | 534472 | 531647 |
| 141 | 2.35 | 14.478561 | 14.58423 | 14.89113 | 73.789986 | 1.35051E-06 | 1.36037E-06 | 1.38899E-06 | 534492 | 533763 | 531647 |
| 143 | 2.383333333 | 14.478561 | 14.48136 | 14.89113 | 73.794595 | 1.3505E-06 | 1.35076E-06 | 1.38898E-06 | 534492 | 534472 | 531647 |
| 145 | 2.416666667 | 14.478561 | 14.3785 | 15.09678 | 73.770895 | 1.35056E-06 | 1.34123E-06 | 1.40823E-06 | 534492 | 535182 | 530229 |
| 147 | 2.45 | 14.478561 | 14.58423 | 14.99396 | 73.774897 | 1.35055E-06 | 1.36041E-06 | 1.39863E-06 | 534492 | 533763 | 530938 |
| 149 | 2.483333333 | 14.37573 | 14.48136 | 15.19961 | 73.671878 | 1.34122E-06 | 1.35107E-06 | 1.41808E-06 | 535201 | 534472 | 529520 |
| 151 | 2.516666667 | 14.478561 | 14.48136 | 15.19961 | 73.768389 | 1.35057E-06 | 1.35083E-06 | 1.41783E-06 | 534492 | 534472 | 529520 |
| 153 | 2.55 | 14.478561 | 14.48136 | 15.09678 | 73.728157 | 1.35067E-06 | 1.35093E-06 | 1.40834E-06 | 534492 | 534472 | 530229 |
| 155 | 2.583333333 | 14.581392 | 14.48136 | 15.19961 | 73.754497 | 1.36019E-06 | 1.35086E-06 | 1.41786E-06 | 533783 | 534472 | 529520 |

| Seconds Elapsed | Cumulative Mole K Transducer 1 | Cumulative Mole K Transducer 2 | Cumulative Mole K Transducer 3 | Cumulative N2 Vol (ml) K Transducer 1 | Cumulative N2 Vol (ml) K Transducer 2 | Cumulative N2 Vol (ml) K Transducer 3 | Rate (m3/s) K Transducer 1 | Rate (m3/s) K Transducer 2 | Rate (m3/s) K Transducer 3 | K (nD) K Transducer 1 | K (nD) K Transducer 2 | K (nD) K Transducer 3 | K (nD) avg 4 minutes K Transdu | K (nD) avg 4 minutes K Transdu | K (nD) avg 4 minutes K Transducer 3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0.00001 | 0.00001 | 0.00001 | | | | | | | | | |
| 1 | 9.64014E-09 | 4.44638E-11 | 4.41433E-11 | 0.008490606 | 3.91541E-05 | 3.91541E-05 | | | | | | | | | |
| 3 | -9.58716E-09 | 1.92063E-08 | -9.58679E-09 | 0.00001 | 0.016676316 | 0.00001 | | | | | | | | | |
| 5 | -5.83315E-11 | -5.87602E-11 | -9.65323E-09 | 0.00001 | 0.00001 | 0.00001 | | | | | | | | | |
| 7 | -9.54169E-09 | 5.47863E-11 | -9.54131E-09 | 0.00001 | 4.82436E-05 | 0.00001 | | | | | | | | | |
| 9 | -4.35454E-11 | 9.55459E-09 | -9.63855E-09 | 0.00001 | 0.00835483 | 0.00001 | | | | | | | | | |
| 11 | -9.41625E-09 | 1.82058E-10 | 1.9374E-08 | 0.00001 | 0.000160301 | 0.016940278 | | | | | | | | | |
| 139 | -5.90019E-10 | -5.94355E-10 | 4.73656E-08 | 0.00001 | 0.00001 | 0.040580861 | 1.92878E-12 | 1.43788E-12 | 1.03101E-11 | 5.369529296 | 2.672259498 | 9.618640896 | 6.098281 | 3.616635 | 9.748006181 |
| 141 | 9.03879E-09 | 9.03781E-09 | 4.7404E-08 | 0.007964509 | 0.007905942 | 0.040612646 | 9.41578E-13 | 1.43097E-12 | 9.90288E-12 | 2.621261816 | 2.655885895 | 9.618640896 | 6.107122 | 3.616459 | 9.749495002 |
| 143 | 9.02712E-09 | -5.68673E-10 | 4.7392E-08 | 0.007954296 | 0.00001 | 0.040602715 | 1.44439E-12 | 4.49285E-13 | 1.02749E-11 | 4.021052966 | 0.832769414 | 9.644363118 | 6.115821 | 3.640066 | 9.751127745 |
| 145 | 9.08712E-09 | -1.01039E-08 | 6.66372E-08 | 0.00800681 | 0.00001 | 0.056310676 | 1.45039E-12 | 1.44028E-12 | 1.06444E-11 | 4.037733594 | 2.676724618 | 9.631484771 | 6.124039 | 3.662949 | 9.752899074 |
| 147 | 9.07699E-09 | 9.07628E-09 | 5.70349E-08 | 0.007997943 | 0.007939378 | 0.048527313 | 1.92597E-12 | 9.52074E-13 | 9.90825E-12 | 5.354611454 | 1.767053113 | 9.657275825 | 6.132238 | 3.662057 | 9.754263103 |
| 149 | -2.55994E-10 | -2.57875E-10 | 7.64921E-08 | 0.00001 | 0.00001 | 0.064189218 | 1.92743E-12 | 9.45124E-13 | 1.10027E-11 | 5.365786527 | 1.754153776 | 9.657275825 | 6.157811 | 3.695432 | 9.756124956 |
| 151 | 9.09347E-09 | -5.02315E-10 | 7.62355E-08 | 0.008012363 | 0.00001 | 0.063985496 | 2.40791E-12 | 1.91341E-12 | 9.64922E-12 | 6.703386799 | 3.551295293 | 9.644363118 | 6.181967 | 3.716717 | 9.757762373 |
| 153 | 9.19534E-09 | -4.00427E-10 | 6.675E-08 | 0.008101509 | 0.00001 | 0.056401505 | 1.42564E-12 | 1.43522E-12 | 1.064E-11 | 3.974112725 | 2.663765228 | 9.657275825 | 6.205457 | 3.74846 | 9.759357805 |
| 155 | 1.8721E-08 | -4.67135E-10 | 7.62725E-08 | 0.01637855 | 0.00001 | 0.06401482 | 2.39436E-12 | 1.43194E-12 | 1.00052E-11 | 6.665682148 | 2.657682145 | 9.657275825 | 6.194976 | 3.768694 | 9.761084465 |

# Core Characterization Workflow

## Not "one size fits all", but what we strive for at a minimum

SESAR
SYSTEM FOR EARTH SAMPLE REGISTRATION

EDX Energy Data eXchange — NETL's Energy Data eXchange

https://edx.netl.doe.gov/group/core-characterization

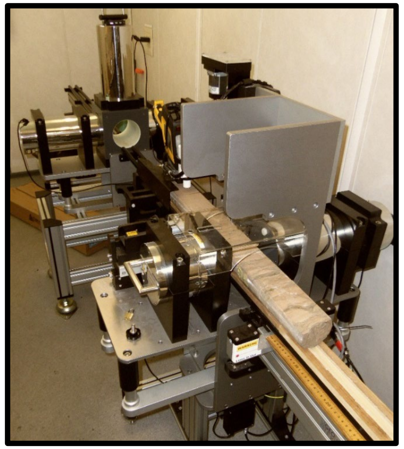
New cores arrives

Joining our repository → Entered into System for Earth Sample Registration (SESAR)

**IGSN:** XXXXXXXXX
**Name:** My Sample Name
**Type:** My Sample Type
**Depth Min:** My Sample Other Names

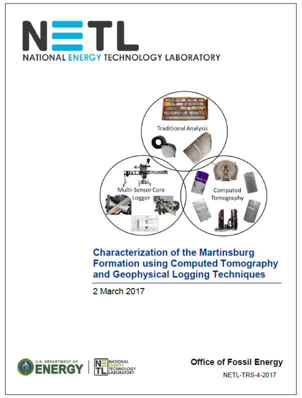
On loan → Scanned in Medical CT

Scanned in Multi-Sensor Core Logger (MSCL)

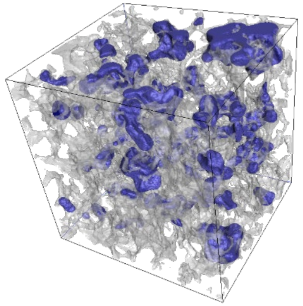


Upload → Energy Data eXchange (EDX) online

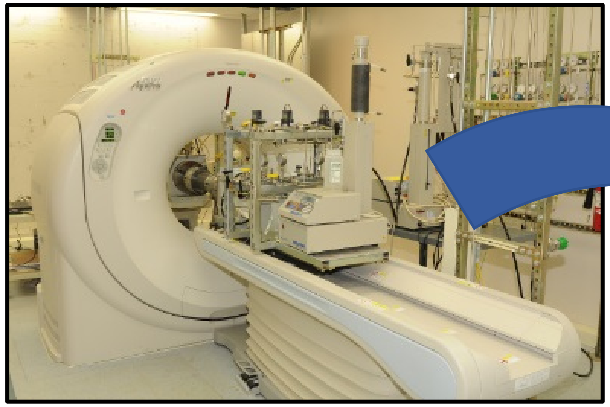
Publish → NETL's Technical Report Series

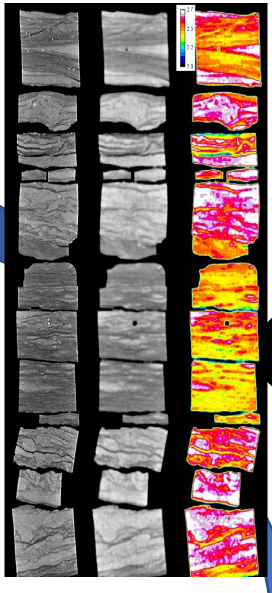


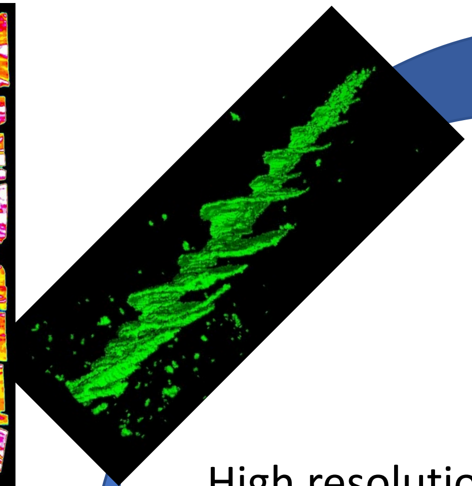

Upload → Digital Rocks Portal

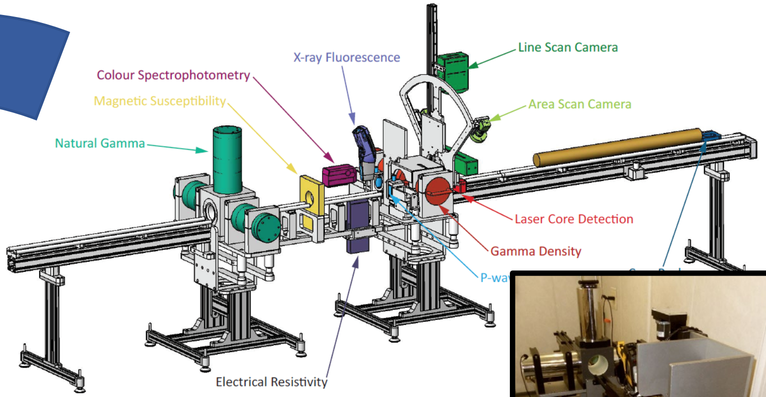


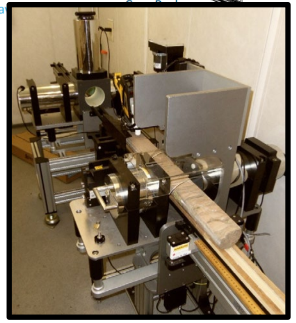
# Core Characterization Data Collection





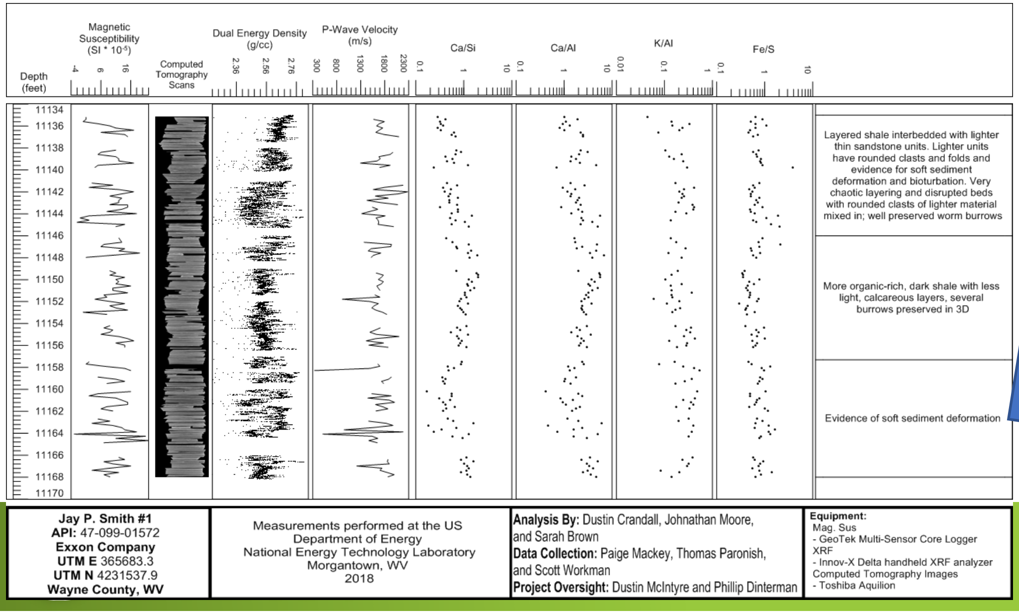


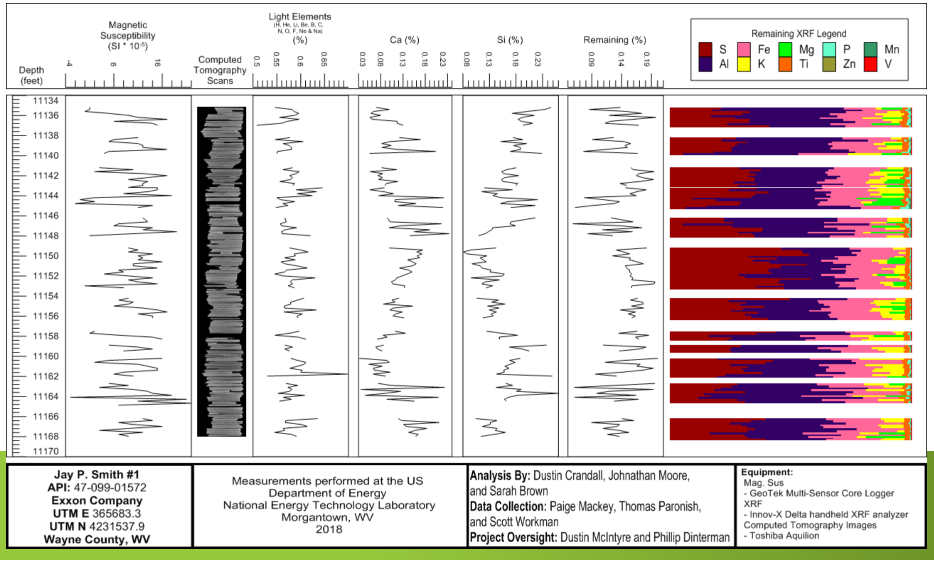


Dual energy scanning for structural features and internal density

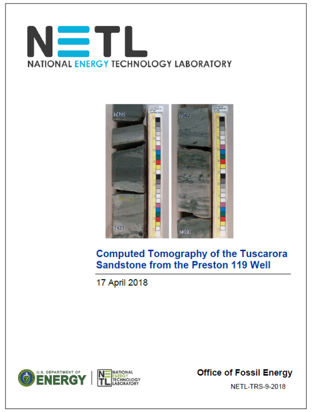
High resolution core logging for XRF, p-wave, magnetic susceptibility, and gamma density

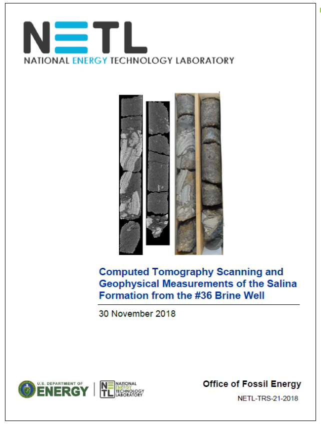


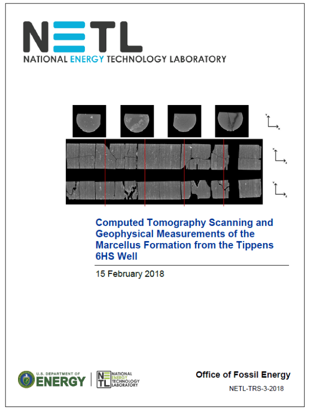



# Core Characterization Published

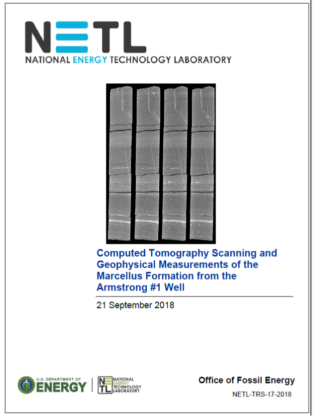
Full reports and data sets available on
https://edx.netl.doe.gov/group/core-characterization

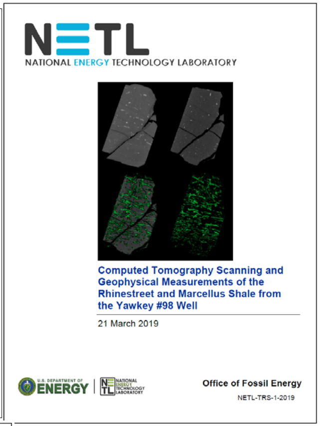

NATIONAL ENERGY TECHNOLOGY LABORATORY
Computed Tomography of the Tuscarora Sandstone from the Preston 119 Well
17 April 2018
Office of Fossil Energy
NETL-TRS-9-2018


NATIONAL ENERGY TECHNOLOGY LABORATORY
Computed Tomography Scanning and Geophysical Measurements of the Salina Formation from the #36 Brine Well
30 November 2018
Office of Fossil Energy
NETL-TRS-21-2018

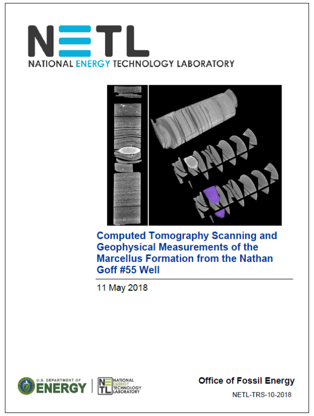

NATIONAL ENERGY TECHNOLOGY LABORATORY
Computed Tomography Scanning and Geophysical Measurements of the Marcellus Formation from the Tippens 6HS Well
15 February 2018
Office of Fossil Energy
NETL-TRS-3-2018

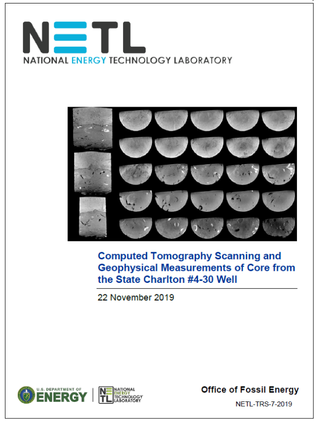

NATIONAL ENERGY TECHNOLOGY LABORATORY
Computed Tomography Scanning and Geophysical Measurements of the Marcellus Formation from the Whipkey ST 1 Well
22 May 2018
Office of Fossil Energy
NETL-TRS-12-2018

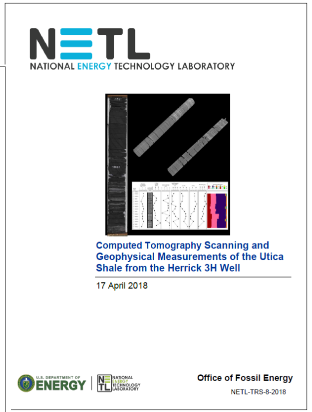

NATIONAL ENERGY TECHNOLOGY LABORATORY
Computed Tomography Scanning and Geophysical Measurements of the Marcellus Formation from the Armstrong #1 Well
21 September 2018
Office of Fossil Energy
NETL-TRS-17-2018

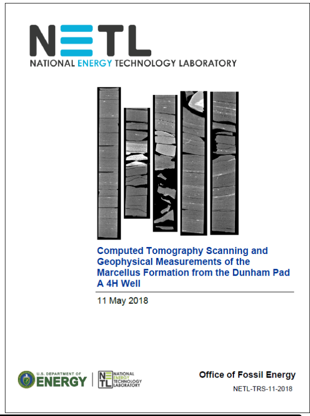

NATIONAL ENERGY TECHNOLOGY LABORATORY
Computed Tomography Scanning and Geophysical Measurements of the Rhinestreet and Marcellus Shale from the Yawkey #98 Well
21 March 2019
Office of Fossil Energy
NETL-TRS-1-2019

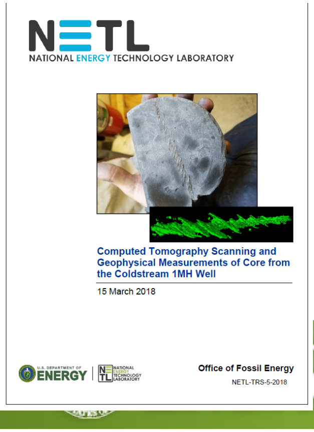

NATIONAL ENERGY TECHNOLOGY LABORATORY
Computed Tomography Scanning and Geophysical Measurements of the Rogersville Shale from the Smith #1 Well
4 September 2018
Office of Fossil Energy
NETL-TRS-16-2018

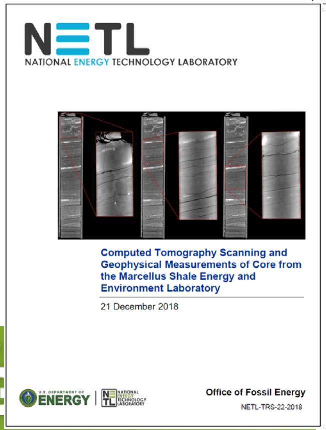

NATIONAL ENERGY TECHNOLOGY LABORATORY
Computed Tomography Scanning and Geophysical Measurements of the Marcellus Formation from the Nathan Goff #55 Well
11 May 2018
Office of Fossil Energy
NETL-TRS-10-2018

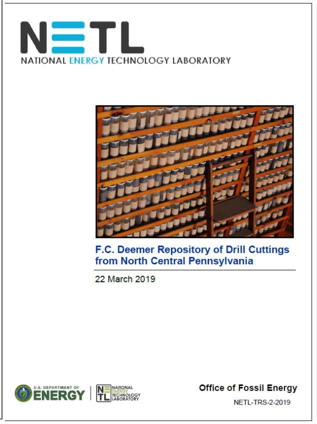

NATIONAL ENERGY TECHNOLOGY LABORATORY
Computed Tomography Scanning and Geophysical Measurements of Core from the State Charlton #4-30 Well
22 November 2019
Office of Fossil Energy
NETL-TRS-7-2019

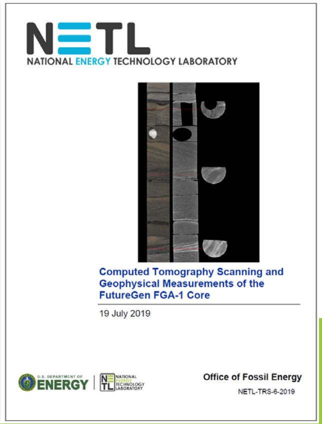

NATIONAL ENERGY TECHNOLOGY LABORATORY
Computed Tomography Scanning and Geophysical Measurements of the Utica Shale from the Herrick 3H Well
17 April 2018
Office of Fossil Energy
NETL-TRS-8-2018

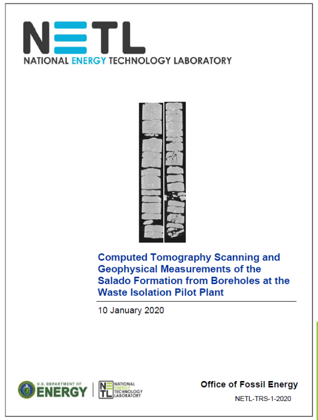

NATIONAL ENERGY TECHNOLOGY LABORATORY
Computed Tomography Scanning and Geophysical Measurements of the Marcellus Formation from the Dunham Pad A 4H Well
11 May 2018
Office of Fossil Energy
NETL-TRS-11-2018

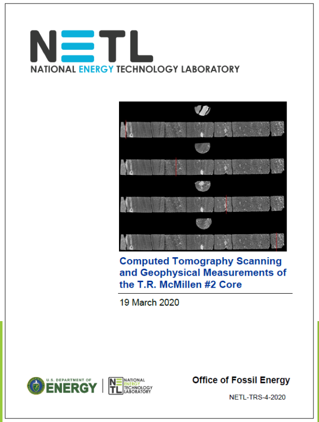

NATIONAL ENERGY TECHNOLOGY LABORATORY
Computed Tomography Scanning and Geophysical Measurements of Core from the Coldstream 1MH Well
15 March 2018
Office of Fossil Energy
NETL-TRS-5-2018

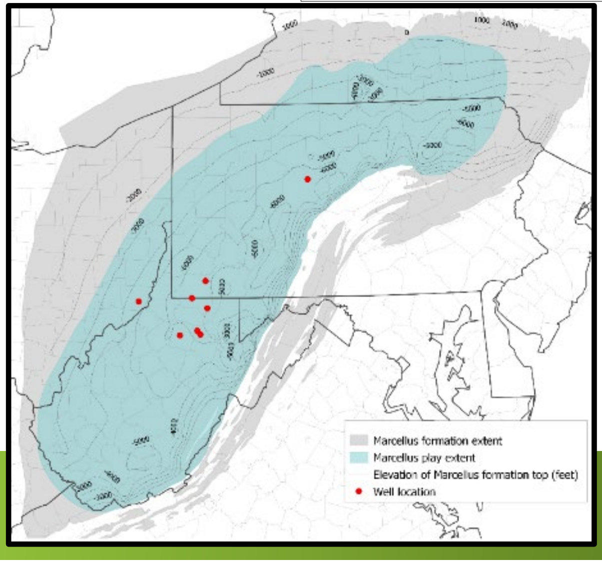

NATIONAL ENERGY TECHNOLOGY LABORATORY
Computed Tomography Scanning and Geophysical Measurements of Core from the Marcellus Shale Energy and Environment Laboratory
21 December 2018
Office of Fossil Energy
NETL-TRS-22-2018


NATIONAL ENERGY TECHNOLOGY LABORATORY
F.C. Deemer Repository of Drill Cuttings from North Central Pennsylvania
22 March 2019
Office of Fossil Energy
NETL-TRS-2-2019


NATIONAL ENERGY TECHNOLOGY LABORATORY
Computed Tomography Scanning and Geophysical Measurements of the FutureGen FGA-1 Core
19 July 2019
Office of Fossil Energy
NETL-TRS-6-2019


NATIONAL ENERGY TECHNOLOGY LABORATORY
Computed Tomography Scanning and Geophysical Measurements of the Salado Formation from Boreholes at the Waste Isolation Pilot Plant
10 January 2020
Office of Fossil Energy
NETL-TRS-1-2020


NATIONAL ENERGY TECHNOLOGY LABORATORY
Computed Tomography Scanning and Geophysical Measurements of the T.R. McMillen #2 Core
19 March 2020
Office of Fossil Energy
NETL-TRS-4-2020



# Core Characterization

## 2020-2021

### MSEEL Phase 2 Boggess well

- TRS under internal review {WVU}

### Caney Shale Field Lab

- TRS published w/ 590 GB data (link) {Oklahoma State University}

### ESUP Field Lab (Lower Huron Shale)

- Subcores scanned at NETL {Virginia Tech}

### $CO_2$/EOR in Trenton/Black River

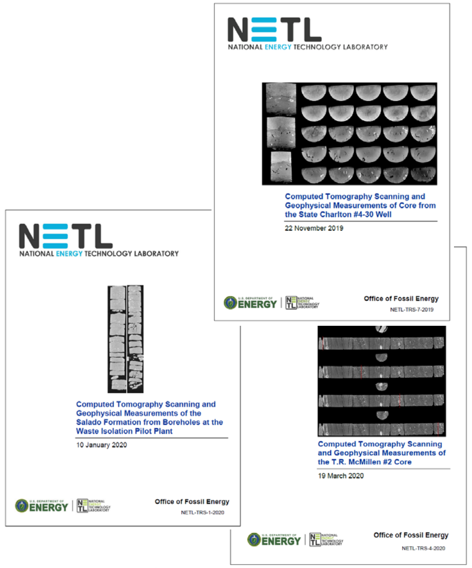
- Representative core from MSGS scanned {Battelle}

### Bakken, Fayetteville, and Brown Dense cores obtained and scanned

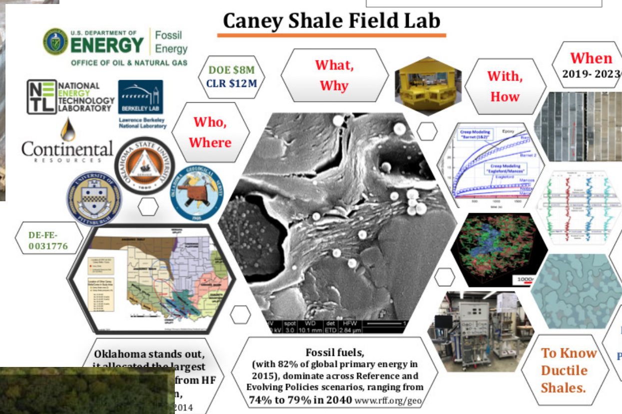
- ~1000 ft scanned in the past year

Pallet of Paradox Basin core {U of Utah} arrived at NETL yesterday (8/24/21)

NATIONAL ENERGY TECHNOLOGY LABORATORY




650 feet of Caney Shale At NETL, 5/19/2020

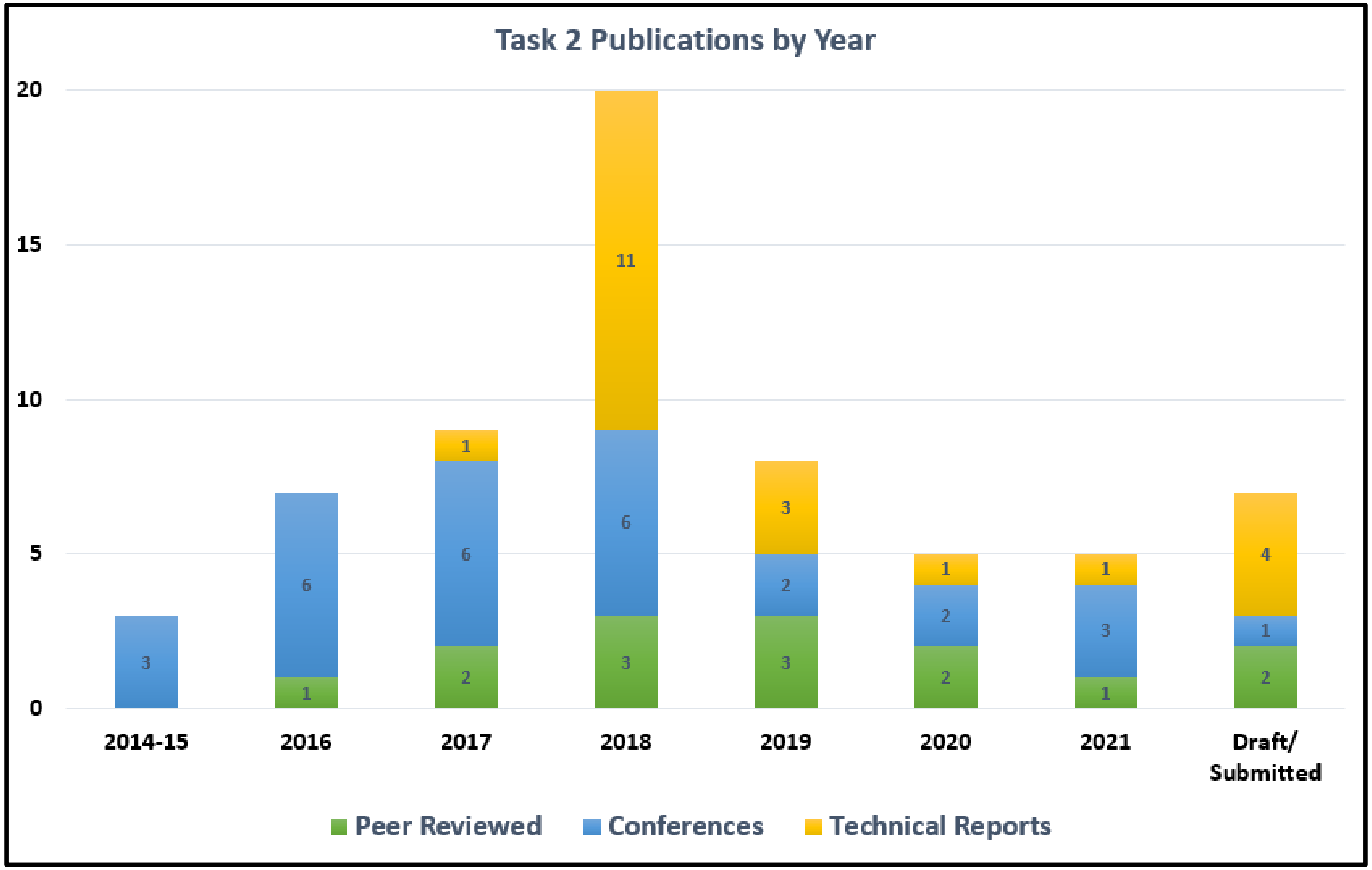



# Publications and Products

## 57 publications (and 7 drafts/submissions)

Early conference publications, as research matured to peer reviewed manuscripts.

WVU/MSEEL collaboration in 2017-2018 kicked of the core characterization work (TRS jump).



# Summary

## Even with COVID, laboratory work is going well

On track to complete milestones this year

Couple of URTeC conference papers this year, looking to Fall AGU as well

Continued /increased interest in characterization from field laboratories

- Three oil/gas focused technical reports this year will not be an issue

Matrix permeability method adjacent to fractures method

- Getting initial results, happy but need some small improvements

Fracture shearing publications rolling out/wrapping up

- NETL focused micro-heterogeneity impacts paper under review at IJRMMS

# Thank you!

Dustin.Crandall@netl.doe.gov

NATIONAL ENERGY TECHNOLOGY LABORATORY

Thank you to the team who got this work done!

- Johnathan Moore
- Thomas Paronish
- Magdalena Gill
- Scott Workman
- Rhiannon Schmitt
- Bryan Tennant
- Terry McKisic

Thank you to all the great collaborators from so many field labs

- We know we're a small part of the overall projects you are doing, but happy to have the opportunity to help

And thank you to the support from technical leadership over the years

- - Elena Melchert, Jared Ciferno, and Ale Hakala!