

# Rock Characterization for Subsurface Energy Applications

**Dustin Crandall**

NETL Research & Innovation Center  
Geological & Environmental Systems Directorate



*Driving Innovation and Delivering Solutions*

Western Michigan University  
Seminar Series

**Monday December 2<sup>nd</sup>**

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U.S. DEPARTMENT OF  
**ENERGY**



# Agenda



- Introduction
- Brief review of NETL, RIC, GES, and how the core analysis lab fits in here
  - The government breeds acronyms ... National Energy Technology Laboratory, Research & Innovation Center, & Geological and Environmental Systems Directorate
- Computed Tomography and Multi-Sensor scanners overview
  - Technical Reports on Core Characterization
- Multi-Sensor Core Logger scanning for characterization
  - Case study of critical mineral identification
- Computed Tomography scanning under subsurface conditions
  - Case study of fracture alteration due to geochemical interactions
- Partnering with us
- Thank you and questions!

# Disclaimer



This projects described were funded by the United States Department of Energy, National Energy Technology Laboratory, in part, through site support contracts. Neither the United States Government nor any agency thereof, nor any of their employees, nor the support contractors, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

# Introduction

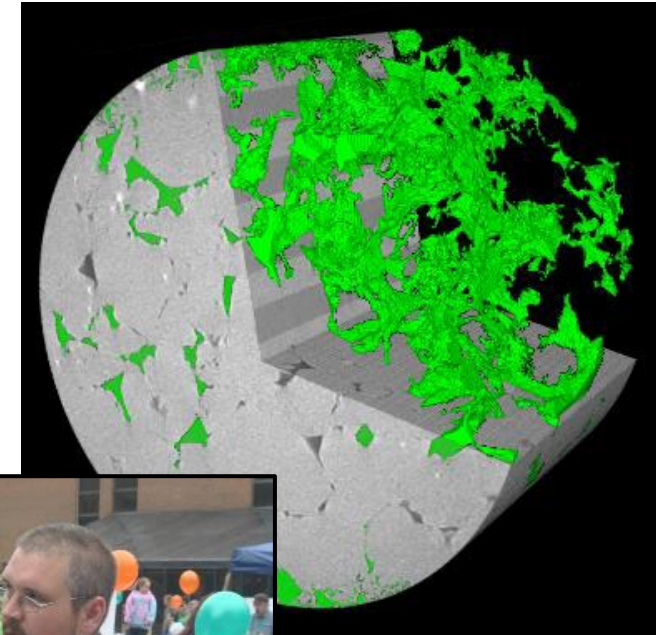
## Dustin Crandall

Mechanical Engineering PhD, 2007

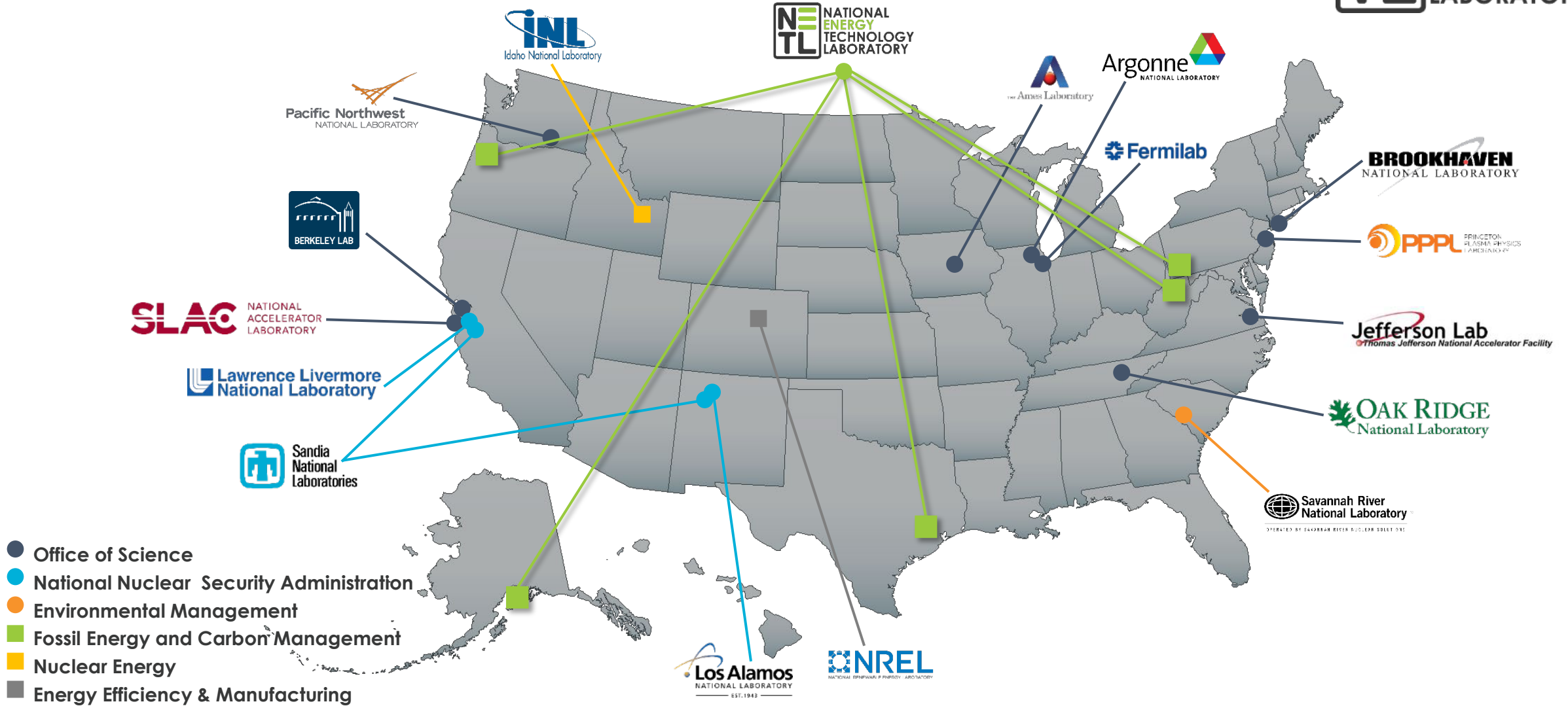
- Computational fluid flow in rocks and fractures.
- Clarkson University

At NETL in Morgantown WV since then

- CT scanning of rocks to look at fluid flow for energy applications and upscaling of physical properties.



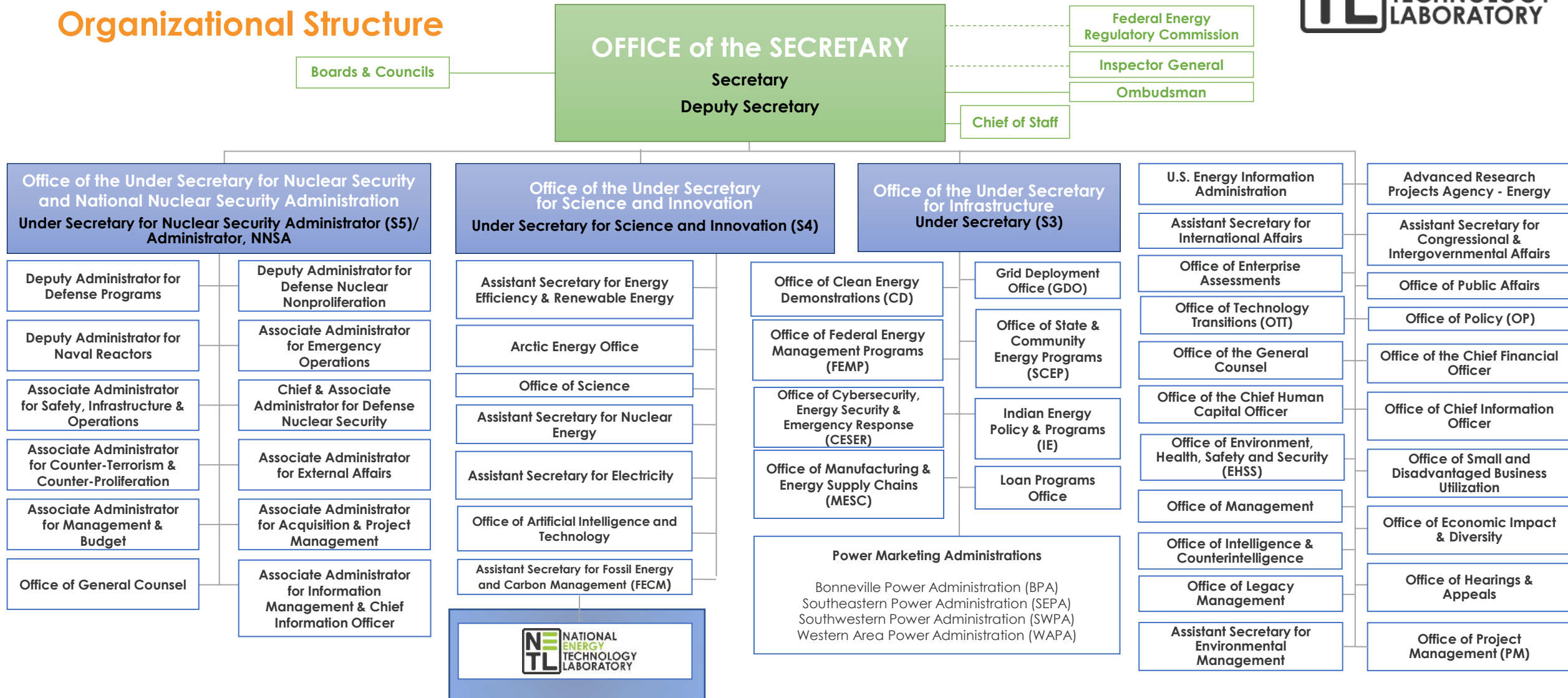
# The National Laboratory System



# Department of Energy



## Organizational Structure



# Achieving a Carbon-free Power Sector by 2035



01

NETL lends its expertise toward achieving a carbon-free power sector by 2035 and a net-zero economy by 2050.

02

NETL research catalyzes economic revitalization, creating good-paying jobs and supporting workers in energy communities, especially hard-hit coal, oil and gas, and power plant communities, across the country.

03

One of the most rewarding aspects of NETL's research is that our innovations & technologies have the potential to improve people's lives in meaningful ways.

# MISSION

Driving innovation and delivering solutions for an environmentally sustainable and prosperous energy future:

- Ensuring affordable, abundant and reliable energy that drives a robust economy and national security, while
- Developing technologies to manage carbon across the full life cycle, and
- Enabling environmental sustainability for all Americans

# VISION

To be the nation's premier energy technology laboratory, delivering integrated solutions to enable transformation to a sustainable energy future.



U.S. DEPARTMENT OF  
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# National Energy Technology Laboratory



One of 17 U.S. Department of Energy (DOE) national laboratories; producing technological solutions to America's energy challenges.

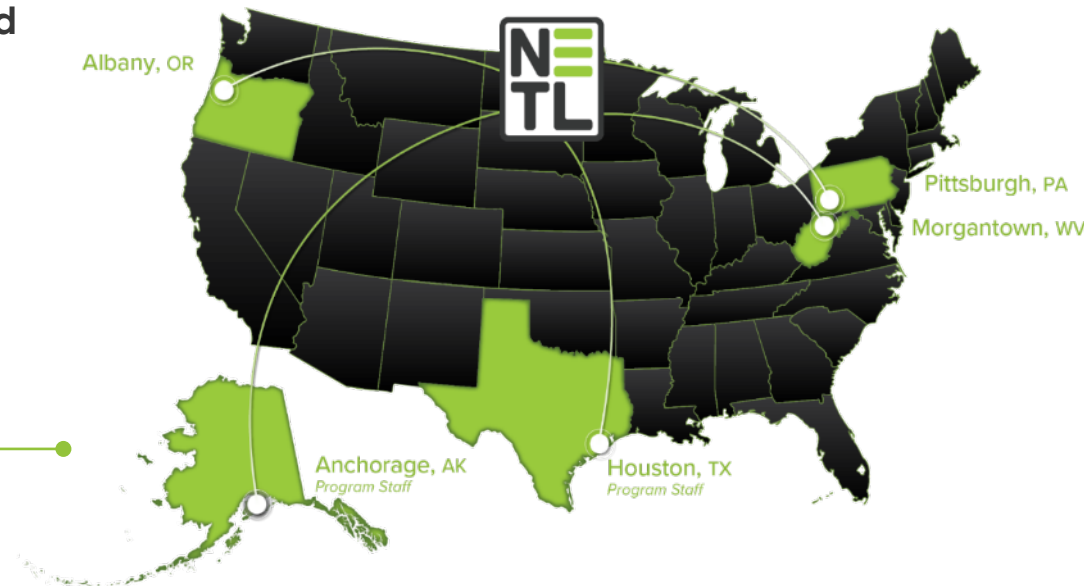
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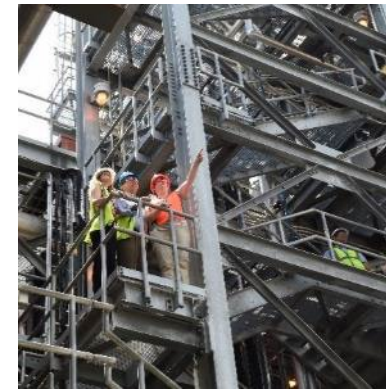
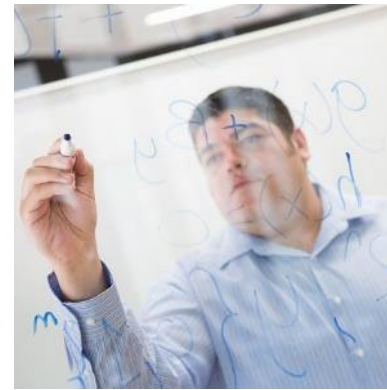
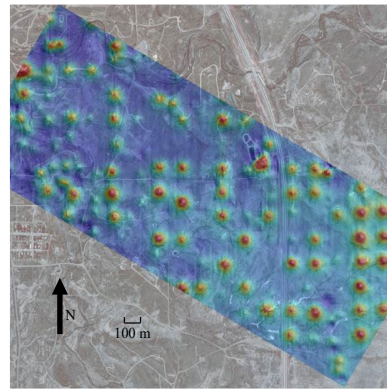
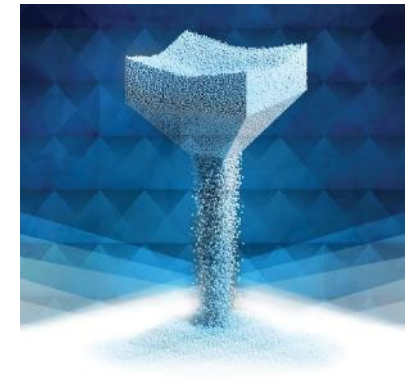


- NETL has **three** research laboratories
- **Two** strategic office locations
- **One of three** applied research national labs
- Government owned & operated
- Leader in cutting-edge research in conversion to higher value products
- Only National Lab dedicated to carbon management research

# NETL Core Competencies



**EFFECTIVE RESOURCE DEVELOPMENT • EFFICIENT ENERGY CONVERSION • ENVIRONMENTAL SUSTAINABILITY**



**COMPUTATIONAL SCIENCE & ENGINEERING**

**MATERIALS ENGINEERING & MANUFACTURING**

**GEOLOGICAL & ENVIRONMENTAL SYSTEMS**

**ENERGY CONVERSION ENGINEERING**

**STRATEGIC SYSTEMS ANALYSIS & ENGINEERING**

**PROGRAM EXECUTION & INTEGRATION**

High Performance Computing  
Multi-Scale Modeling Atomistic to Device  
Artificial Intelligence & Machine Learning

Structural & Functional Materials  
Design, Synthesis, & Performance  
Characterization

Geo-Analysis & Monitoring  
**Reservoir Engineering**  
Geochemistry

Reaction Engineering  
Design & Validation  
Thermal Sciences  
Advanced System Engineering

Energy Process & System Engineering  
Multi-scale Modeling, Simulations & Optimization  
Energy Markets Analysis

Technical Project Management

# Geological & Environmental Systems



## Key Facilities

### Center for Processes Evaluation in Rock under In-Situ Energy Conditions

Multi-scale CT scanners with controlled flow through capabilities to evaluate changes to physical structure from **millimeter to micron scale**

Surface characterization to quantify dynamic geochemical alterations to matrix materials

Core characterization and logging of geologic materials

### Quantitative Field Monitoring and Analysis Facilities

Mobile atmospheric field laboratory for remote, unattended ambient air monitoring

Drone-based platforms to locate and quantify leaks in pipelines and abandoned wells

Geochemical and Geomicrobiological characterization of complex field samples to track subsurface fluid migration and mixing

### Center for Geo-Analysis & Visualization

An online data library, laboratory, and scientific computing ecosystem. More than **2 million** data downloads **EDX**.

High-powered computing hardware and software, visualization, and collaboration resources

Novel, geo-data science tools that support big data computing, ML, spatio-temporal approaches (e.g., [Offshore Risk Modeling](#) suite)

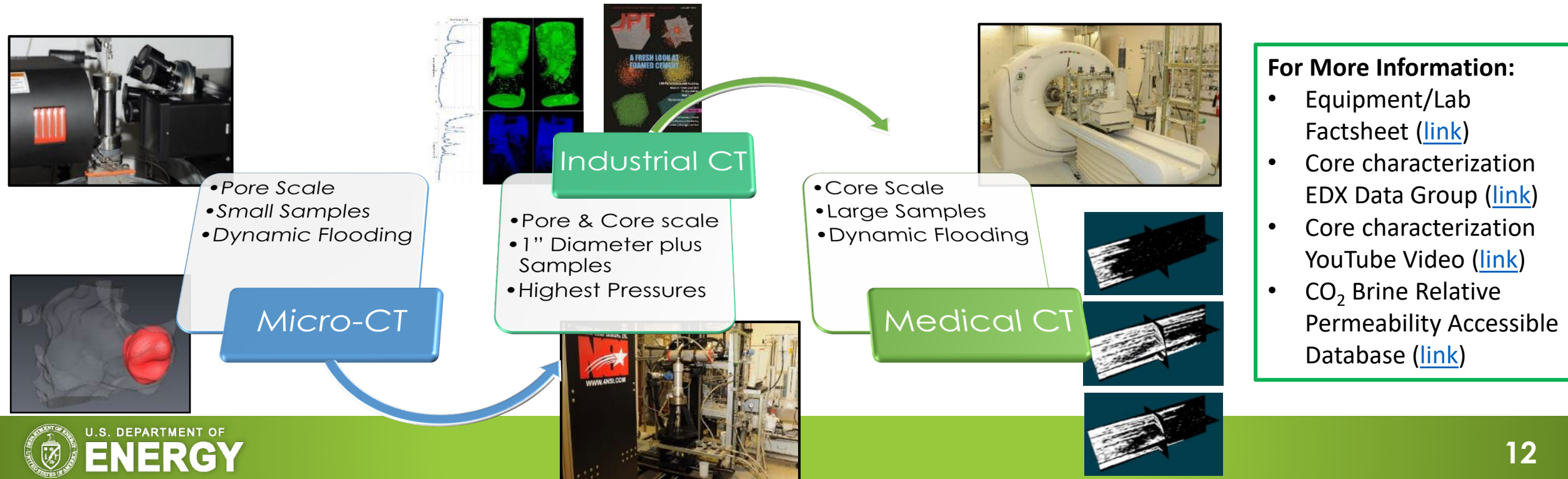


# Multi-Scale CT and Core Flow Facility

POC: [Dustin.Crandall@netl.doe.gov](mailto:Dustin.Crandall@netl.doe.gov)

**Unique Capabilities:** Four computed tomography scanners with 3D resolution from microns to millimeters, all with ancillary core flow capabilities. Able to performed controlled multiphase flow in cores from 0.25" to 2" in diameter at conditions up to 8,000 psi and 150 °C. Full time technical staff to assist with rock preparation, experimentation design, setup, execution, and analysis. Plus, controlled flow systems for long term tests, and GeoTek multi-sensor core logger.

**Opportunities:** Direct examination of rocks from carbon storage sites under *in-situ* conditions with supercritical CO<sub>2</sub>. Stressing of samples to understand mechanical behaviors. Examination of relationships between rock properties, geochemical alteration, and permeability (or structural properties). Scanning to complement other experiments, or to digitally and non-destructively preserve core from relevant locations.



# Computed Tomography at NETL Historical

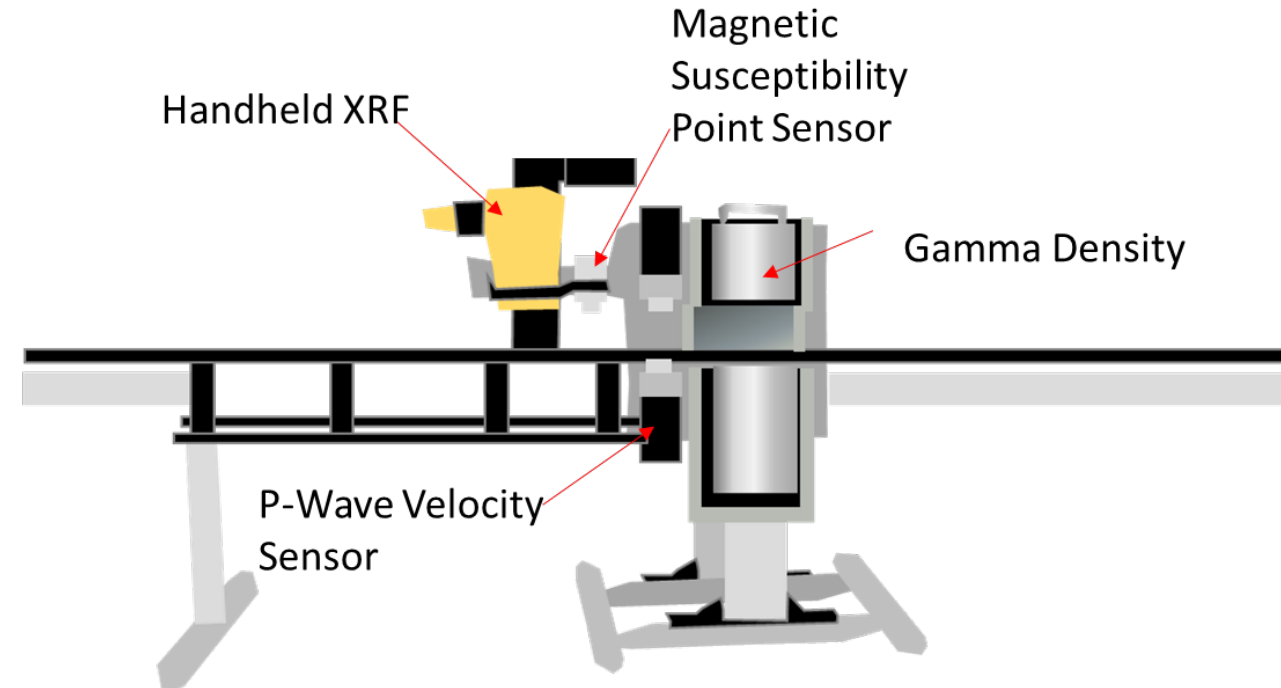
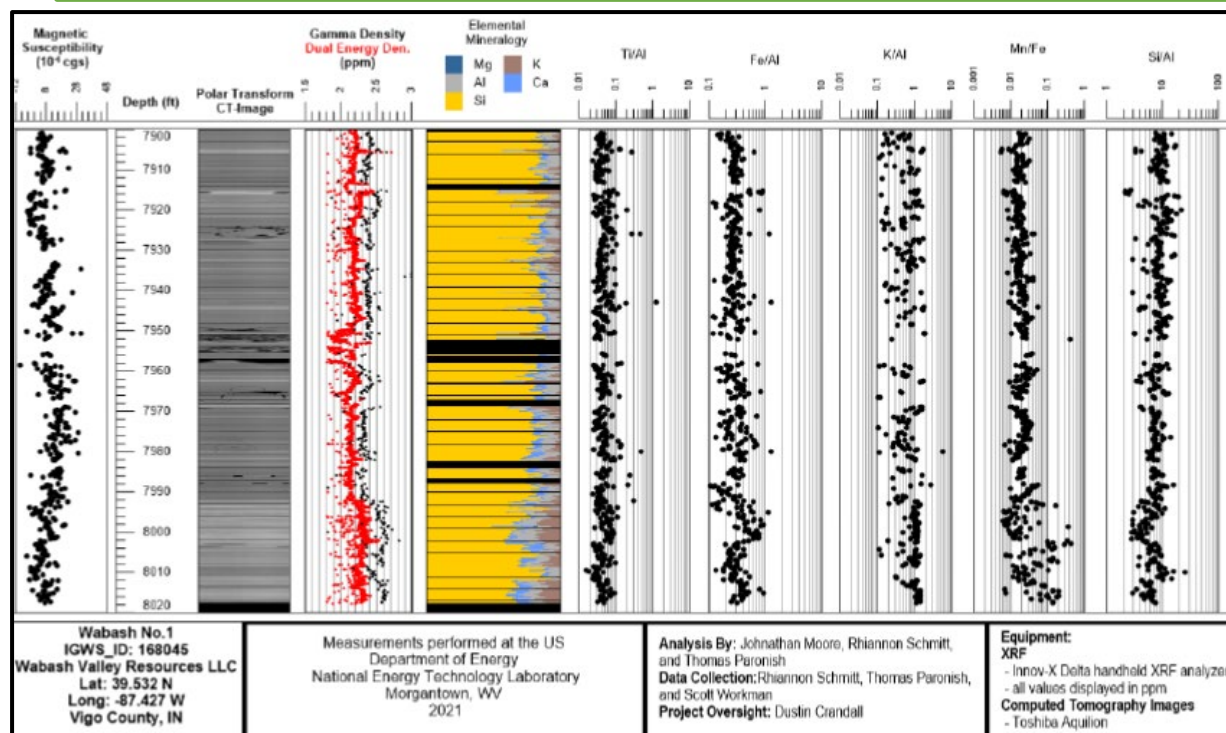
- First CT scanner at NETL operational, 2007
  - Micro-CT, 2009
  - Industrial CT, 2012
  - Dynamic CT, 2021
- 
- Over the past decade+ the infrastructure and expertise around these scanners has been incrementally built up to examine a variety of subsurface objects and phenomena.
  - Continuity of this project has been focused not about one specific problem but on understanding fundamental physical phenomena of real rocks at real conditions.
  - Numerous opportunities for collaboration, including student internships.



# GeoTek Core Logger

POC: [Thomas.Paronish@netl.doe.gov](mailto:Thomas.Paronish@netl.doe.gov)

The GeoTek Multi-Sensor Core Logger at NETL obtains high-resolution p-wave velocity, gamma density, natural gamma, resistivity, magnetic susceptibility, and handheld X-ray fluorescence spectrophotometry on whole-round and split-core samples. Analyses including XRF have been performed on more than 2 miles of core and available on EDX ([link](#)) and [www.rokbase.org](http://www.rokbase.org).



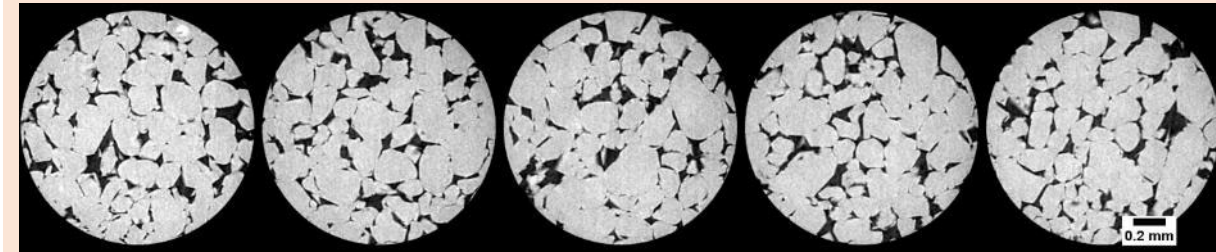
# Olympus Vanta XRF

- Built into the Multi-Sensor CoreLogger
- Automated, allowing for high spatial resolution with minimal effort from the technician
- Olympus Vanta handheld XRF: GeoChem mode
  - Includes a 3-beam investigation (40 KeV, 10 KeV, 50 KeV)
- This 3-beam investigation allows for...
  - Lower detection limits compared to the Delta (resolves Mg, K and P at about 0.5%)
  - The ability to capture light rare earth elements (La, Ce, Pr, Nd) and U and Th



# Data Formats on EDX – Lively Grove Examples

- Raw and processed CT data available on EDX at multiple resolutions
- Raw (csv) format data from the GeoTek Multi-Sensor Core logger, in addition to generated logs

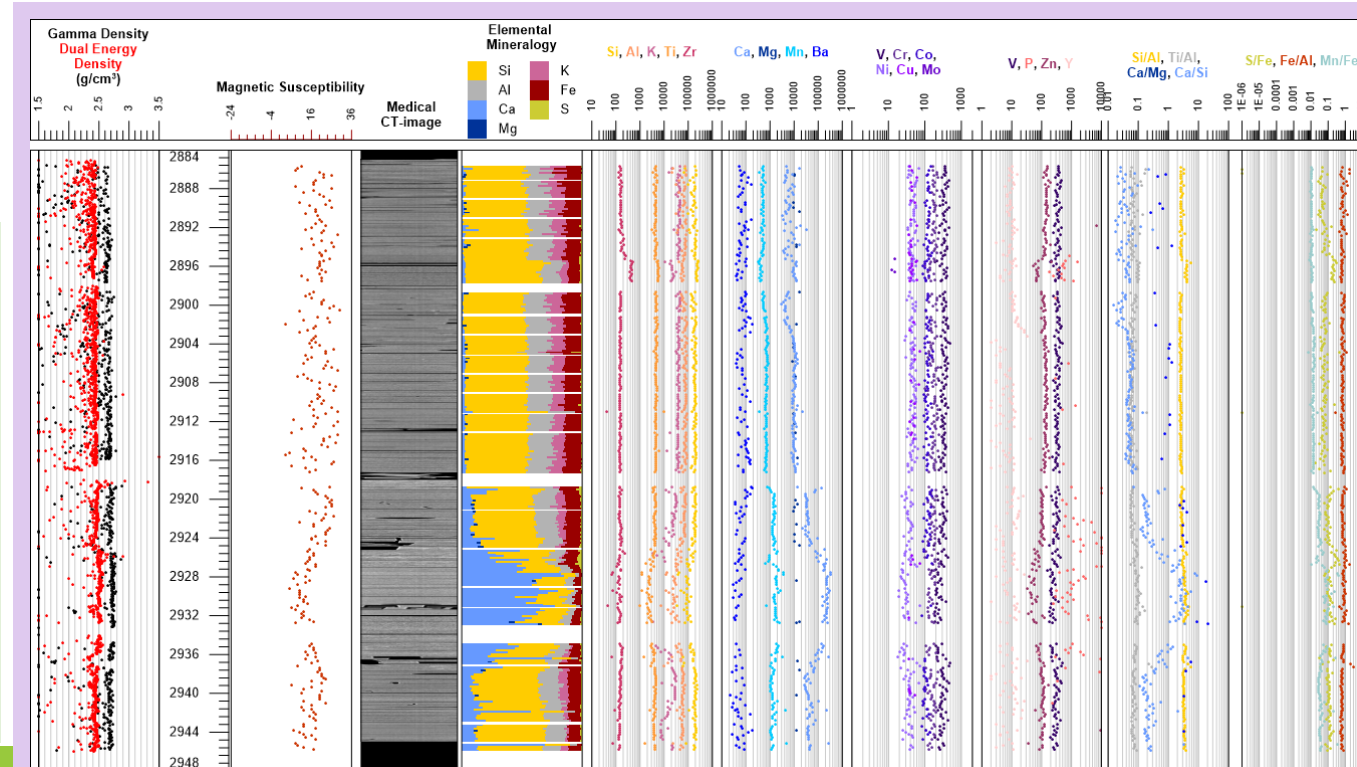
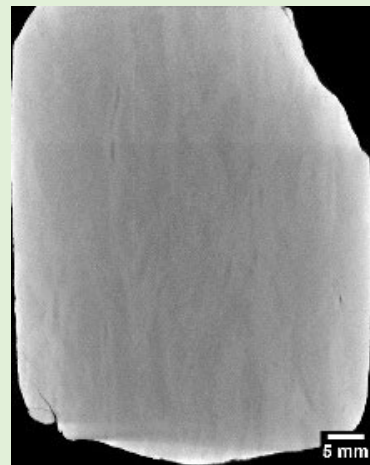


Micro-CT images from the LG #1 core, depth of 3,660 ft.  
1 voxel = 1.5 microns

Medical-CT scan from the LG #1 core,  
depth of 3,666 ft.  
1 voxel = 430 microns



Industrial-CT image from the LG #1 core,  
depth of 3,594 ft.  
1 voxel = 57.4 microns

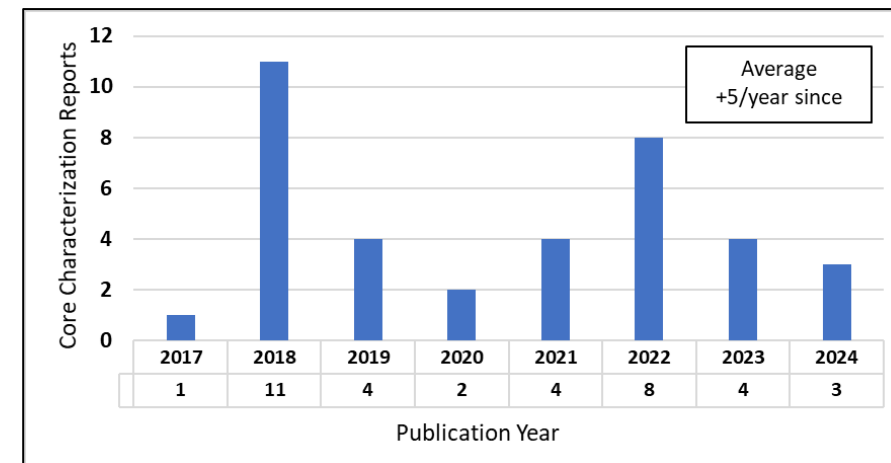
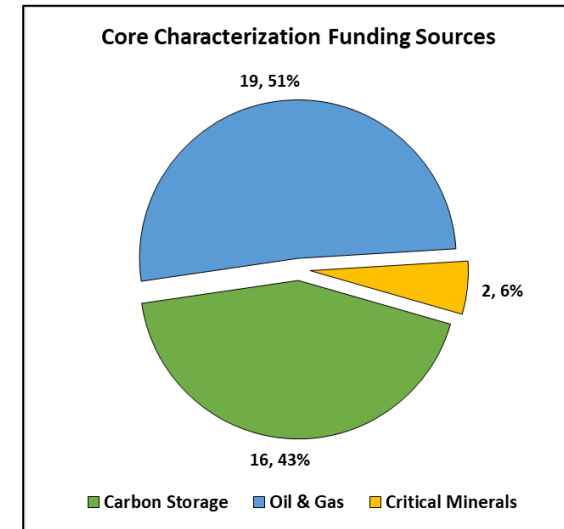


Compiled log of the MSCL data from the LG #1 core 2,885-2,945.8 ft

# Core Characterization Reports

## Carbon Storage, consistent but less than 1/2 of overall effort

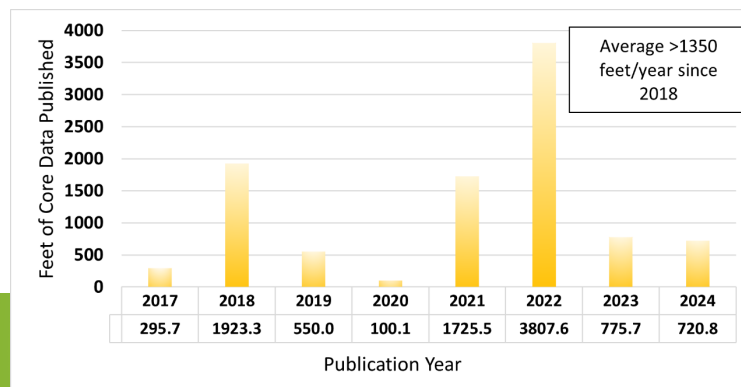
- Since ~2017 we've been fortunate to maintain a small amount of support each year for core characterization activities.
  - Basic yearly goal is to obtain core from relevant field locations, non-destructively characterize, write results in a TRS, and make all the raw and processed data publicly available.
  - Always coupled with a Go/No-Go that if unable to obtain core to halt the effort.
- Early efforts were medical computed tomography (CT) scans and measurements with our GeoTek Multi-Sensor Core Logger (MSCL).
  - Expansion of measurements over the years, when appropriate.



# Since 2017...

- **~2 miles** of core data have been published
  - Averaging more than 1350' a year since 2018
- Data from **90 wells** has been published, spanning **37 TRSs**
- Across different funding lines
  - Carbon Storage
  - Unconventional Oil & Gas/Resource Sustainability
  - Critical Minerals

- Partnered with **19 external organizations**
- State Geological Surveys
  - Illinois, Ohio, West Virginia, Pennsylvania, Kansas, and Oklahoma
- Universities
  - WVU, Pitt, U. Utah, U. Illinois, Indiana U., Oklahoma State, and South Dakota School of Mines and Technology
- Industrial Partners
  - Southwestern Energy, Greylock Energy, Eclipse Resources, and Triana Energy
- National Labs
  - Sandia and LBNL



# Group Effort!

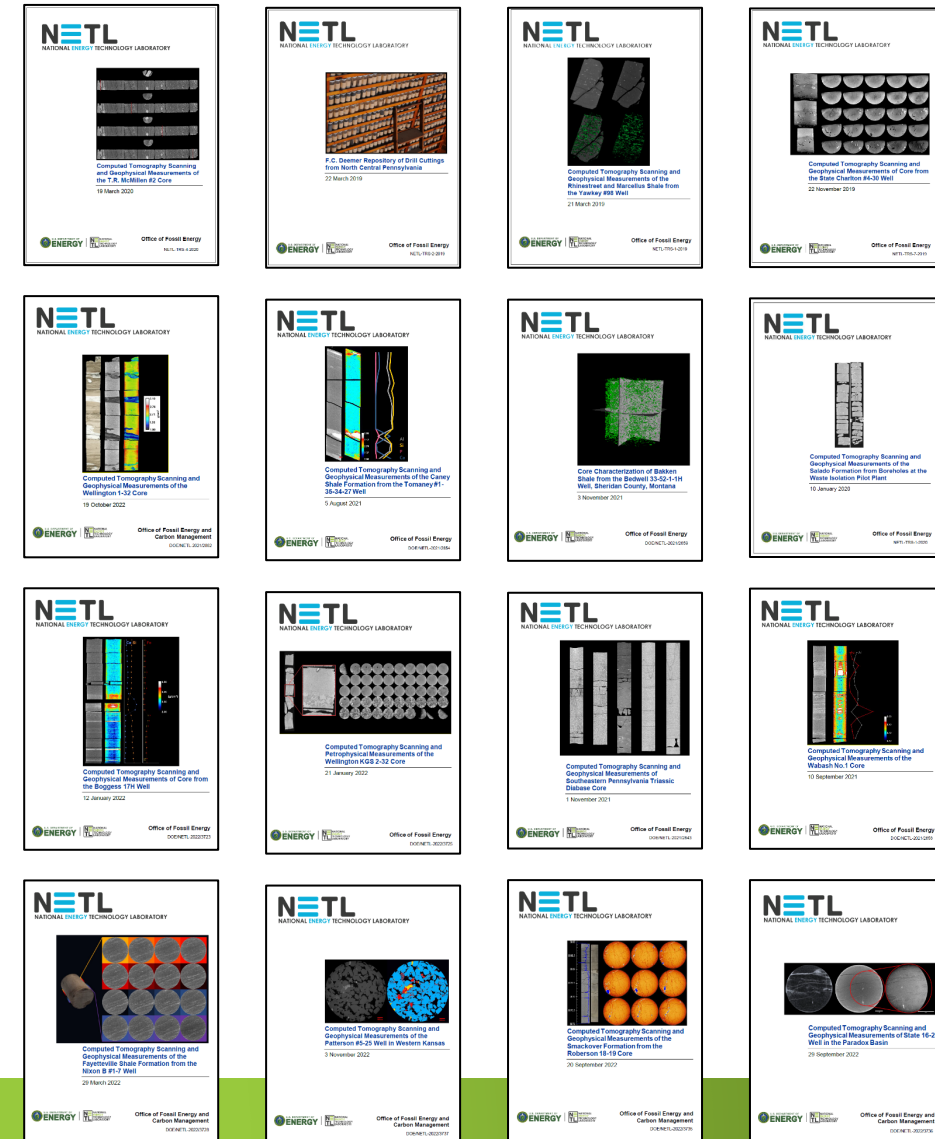


NETL co-Authors: across contracts, teams, and centers

- Dustin Crandall, Thomas Paronish, Sarah Brown, Johnathan Moore, Scott Workman, Karl Jarvis, Magdalena Gill, Jessica Dorsche, Natalie Mitchell, Mathias Pohl, Terry McKisic, Maneesh Sharma, Joseph Renk, Daniel Soeder, Dustin McIntyre, Lianbo Hu, Richard Spaulding, Igor Haljasmaa

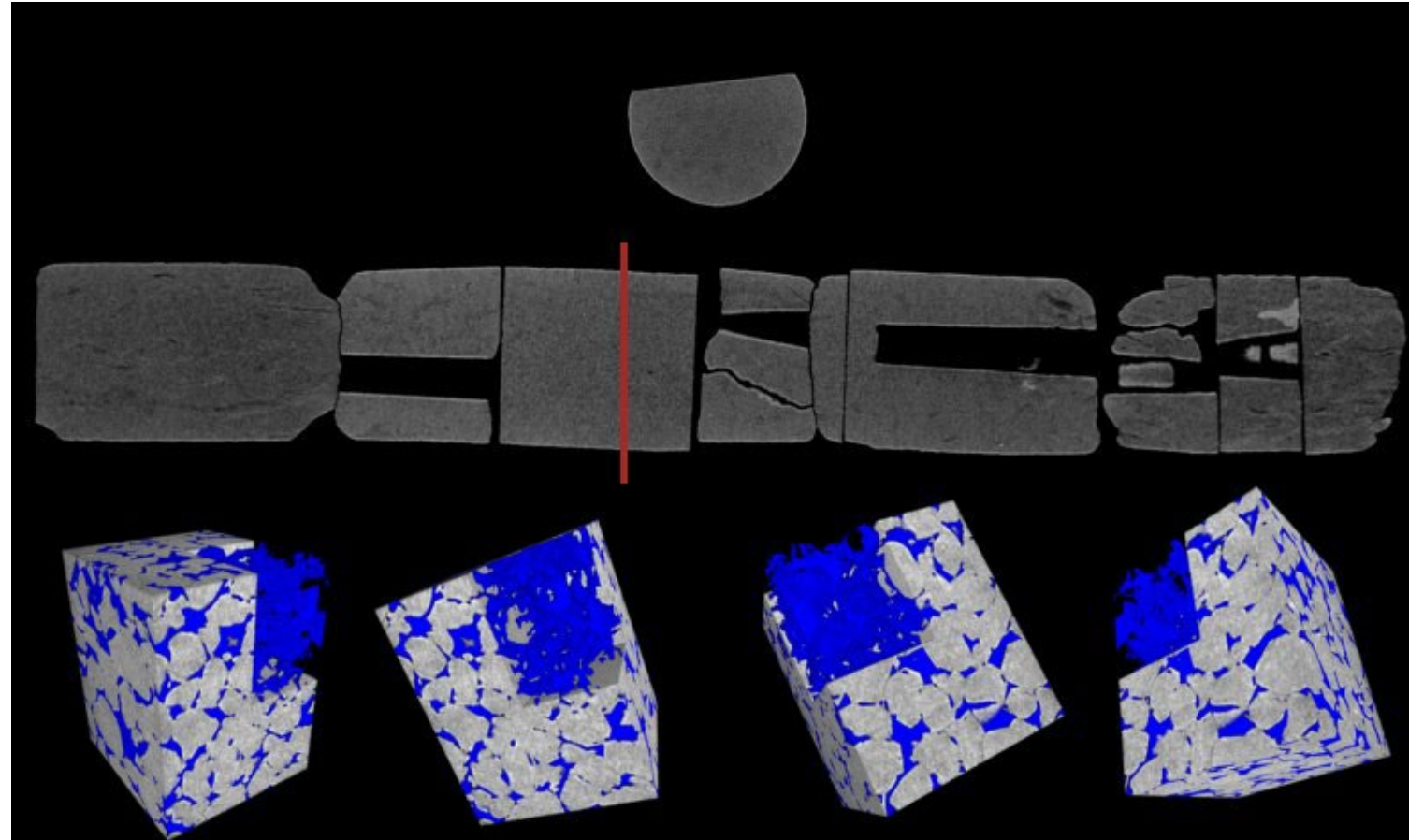
Student engagement: MLEF, ORISE and others

- Keithan Martin, Charity Betters, Jamie Vornlocher, Daniella Cimadomo, Rhiannon Schmitt, Paige E. Mackey, Alexis Parker, Devanshi Patel, Sydney Zerbe, Stephen Pyle, Chris Howard, Amy Haldeman, Andrew Holleran, Thomas J. Paronish



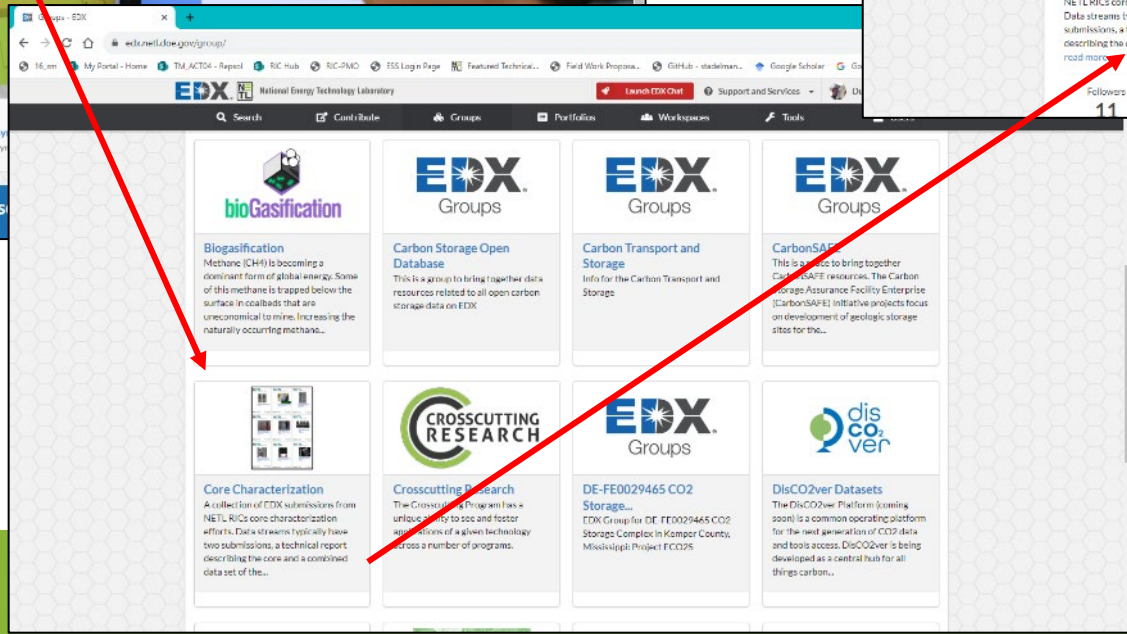
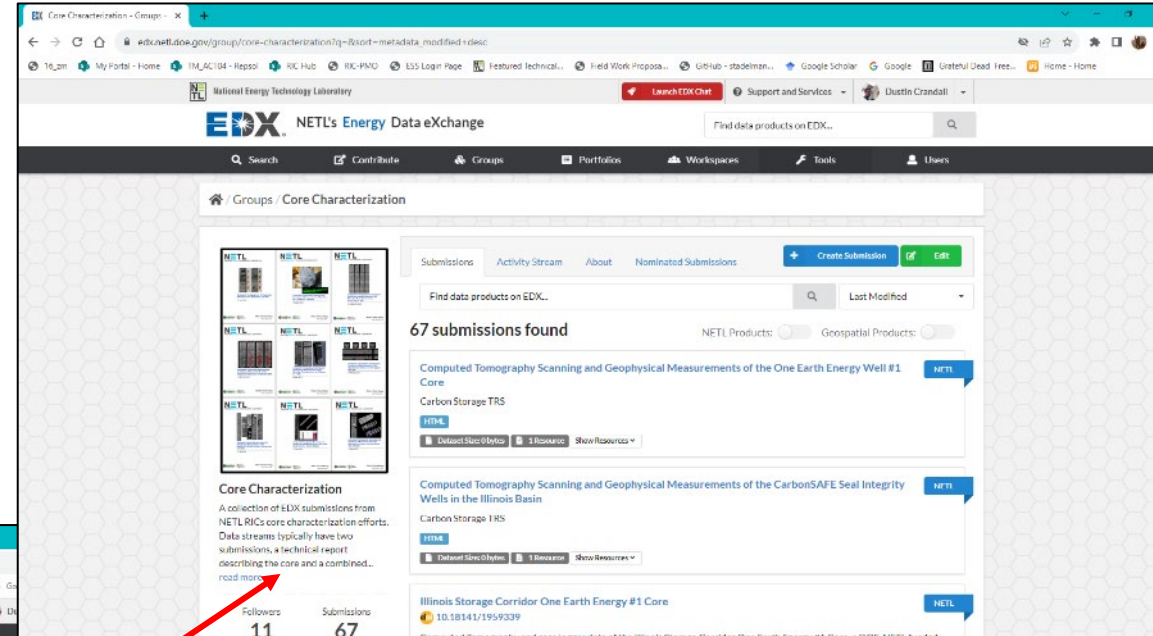
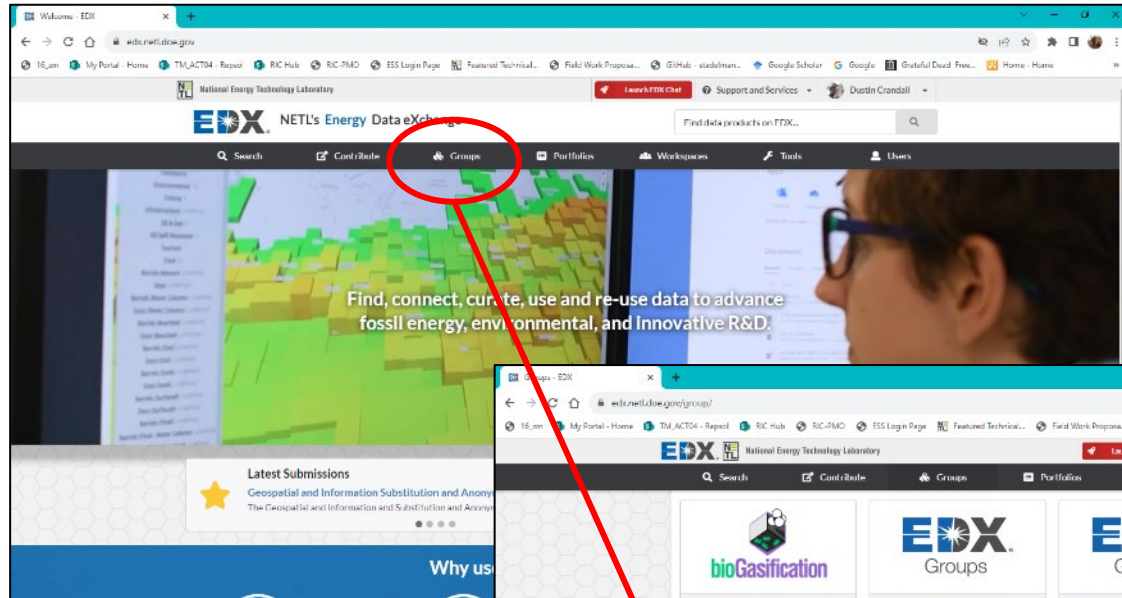
# We (*typically*) do Minimal Processing

- But do dive in when unique or important features found
  - Or, if there is a feature of importance to the project, can interrogate...
- For example, the cover image of the Lively Grove report
  - Top, cross-sectional image of medical CT scan of section from Lively Grove core, depths of 3,665 to 3,667 feet. Bottom, four representations of isolated pore space (blue) from micro-CT scan of core from a depth of 3,666 feet.



# Data Publicly Available on EDX

- Start in the “Groups” at <https://edx.netl.doe.gov/>

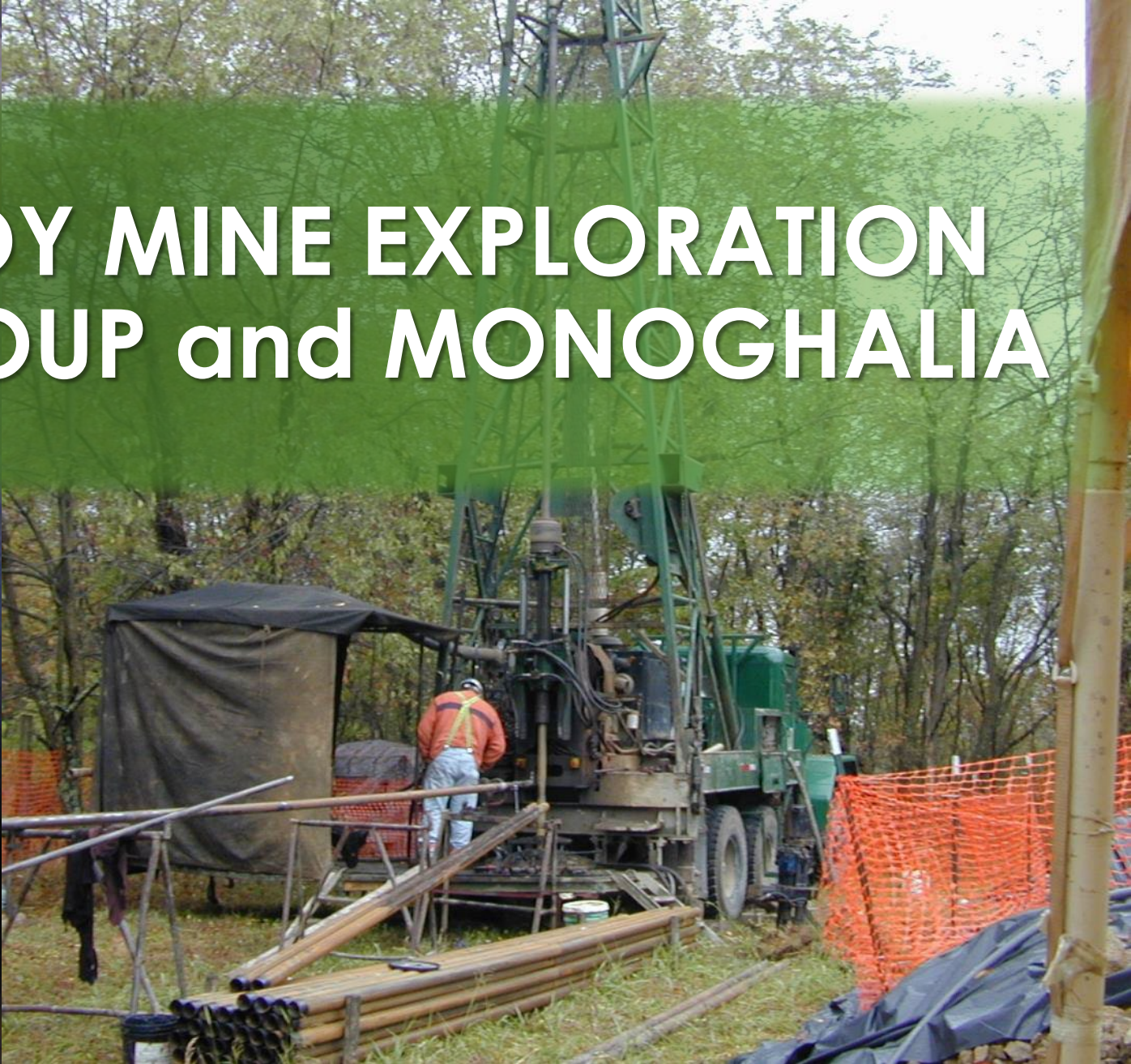
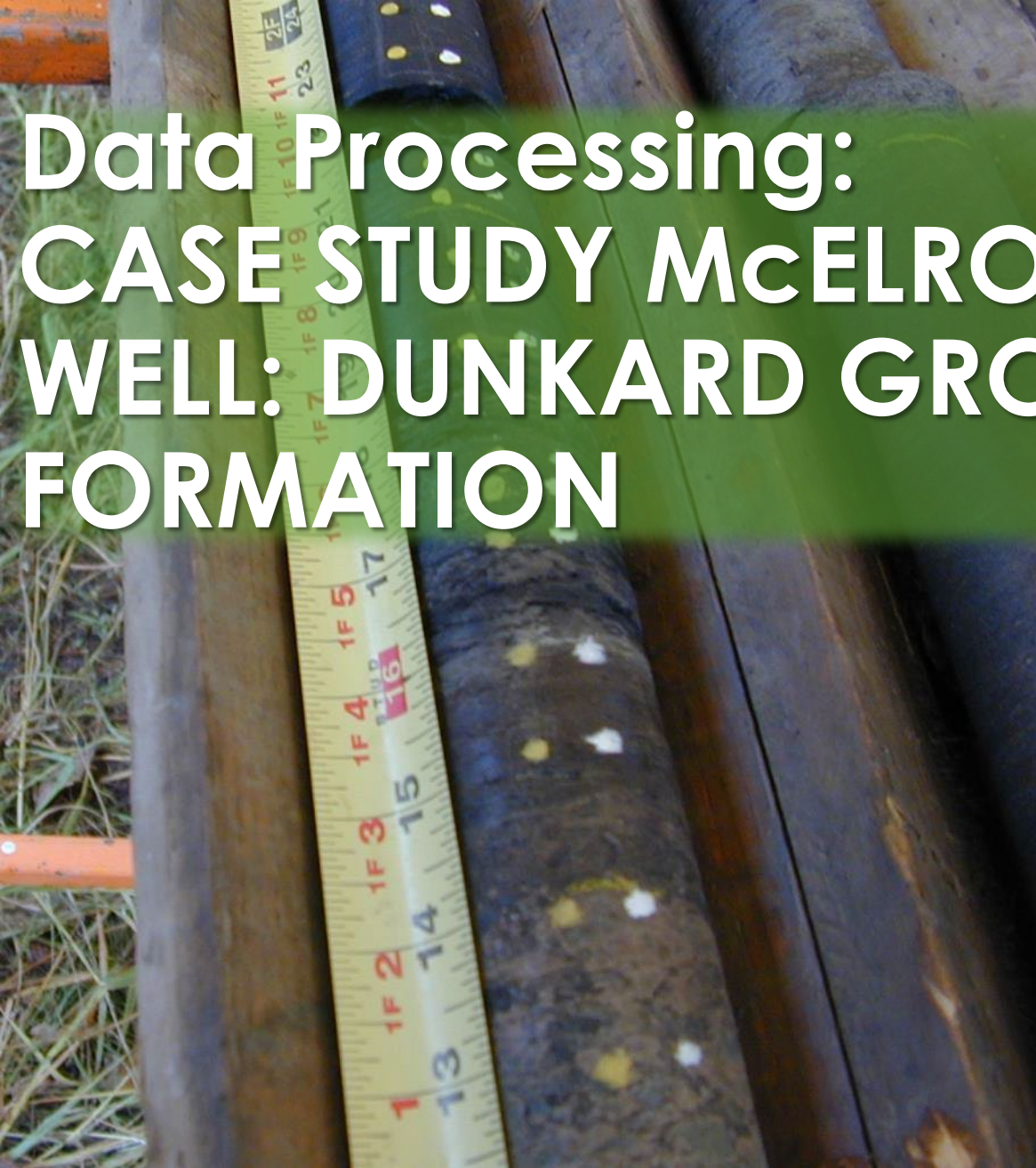


Links to reports, the raw data, and any processed data are here

Scroll down to the “Core Characterization” group



# Data Processing: CASE STUDY McELROY MINE EXPLORATION WELL: DUNKARD GROUP and MONOGHALIA FORMATION



- Drilled in 2010 targeting exploration of the Sewickley Coal Seam.
- Located in Marshall County, WV.
- Includes core from the surface bedrock (30ft) to 963 ft.
- This includes strata from the Dunkard Group and Monongahela Group (to about the Pittsburgh Coal seam)



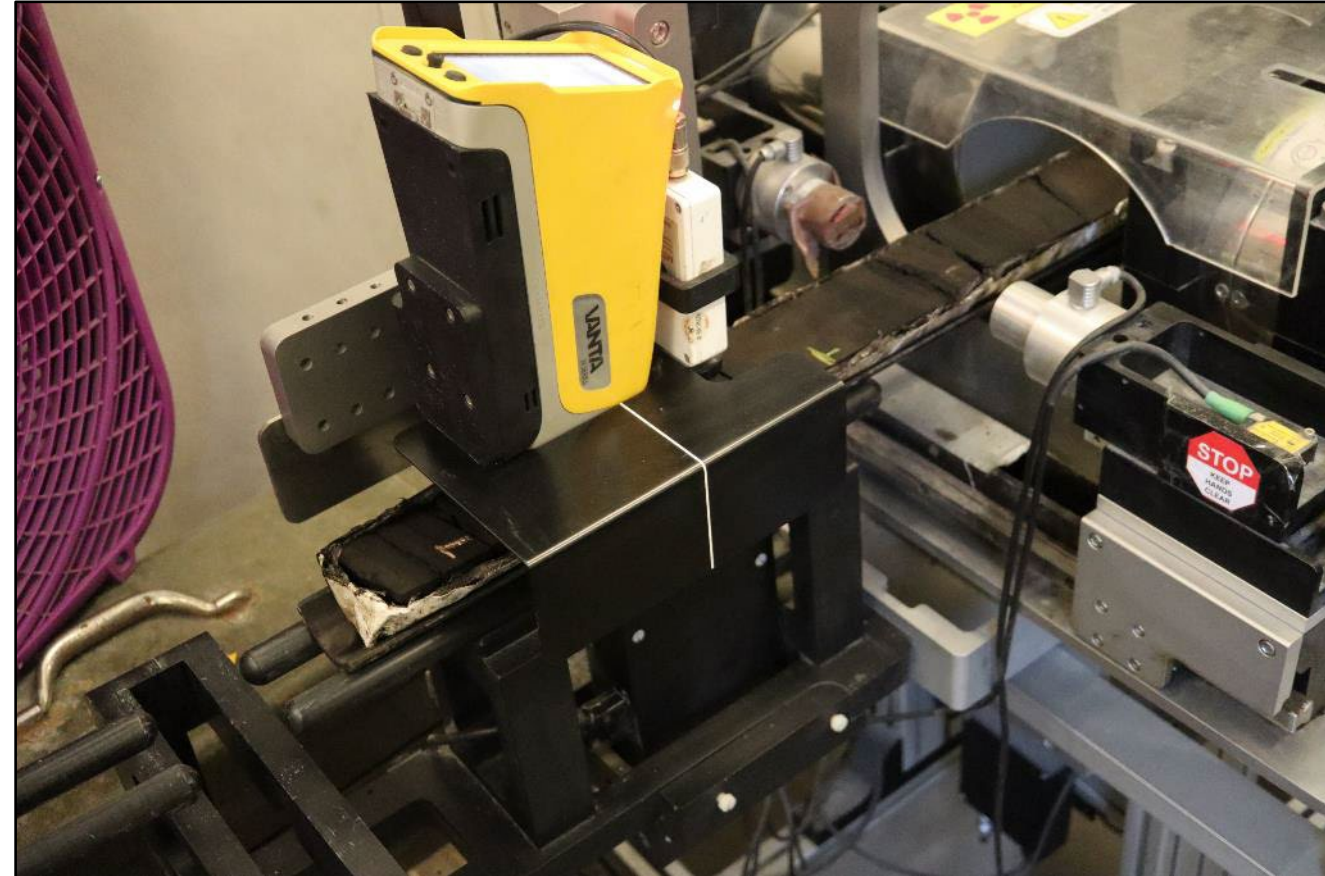
# Data Acquisition

## MC-10-09:

**Goal:** REE prospecting/exploration in Coal strata.

### Data acquired:

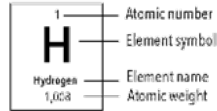
- Medical CT images
- MSCL: 6 cm sampling resolution
- XRF: Vanta GeoChem
  - 40 sec exposure time per beam (120 sec. total)
- P-Wave Velocity
- Gamma Density



# What is a Critical Mineral?

## PERIODIC TABLE OF THE ELEMENTS

1 H Hydrogen 1.008																	2 He Helium 4.003
3 Li Lithium 6.941	4 Be Beryllium 9.012											5 B Boron 10.811	6 C Carbon 12.011	7 N Nitrogen 14.007	8 O Oxygen 15.999	9 F Fluorine 18.998	10 Ne Neon 20.180
11 Na Sodium 22.990	12 Mg Magnesium 24.305											13 Al Aluminum 26.982	14 Si Silicon 28.086	15 P Phosphorus 30.974	16 S Sulfur 32.065	17 Cl Chlorine 35.453	18 Ar Argon 39.948
19 K Potassium 39.098	20 Ca Calcium 40.078	21 Sc Scandium 44.956	22 Ti Titanium 47.867	23 V Vanadium 50.942	24 Cr Chromium 51.996	25 Mn Manganese 54.938	26 Fe Iron 55.845	27 Co Cobalt 58.933	28 Ni Nickel 58.693	29 Cu Copper 63.546	30 Zn Zinc 65.390	31 Ga Gallium 69.723	32 Ge Germanium 72.640	33 As Arsenic 74.922	34 Se Selenium 78.960	35 Br Bromine 79.904	36 Kr Krypton 83.800
37 Rb Rubidium 85.468	38 Sr Strontium 87.620	39 Y Yttrium 88.906	40 Zr Zirconium 91.224	41 Nb Niobium 92.906	42 Mo Molybdenum 95.938	43 Tc Technetium 98.000	44 Ru Ruthenium 101.070	45 Rh Rhodium 102.905	46 Pd Palladium 106.420	47 Ag Silver 107.868	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.600	53 I Iodine 126.905	54 Xe Xenon 131.293
55 Cs Cesium 132.905	56 Ba Barium 137.327	57-71 Lanthanides	72 Hf Hafnium 178.490	73 Ta Tantalum 180.948	74 W Tungsten 183.848	75 Re Rhenium 186.207	76 Os Osmium 190.230	77 Ir Iridium 192.222	78 Pt Platinum 195.084	79 Au Gold 196.967	80 Hg Mercury 200.590	81 Tl Thallium 204.383	82 Pb Lead 207.200	83 Bi Bismuth 208.980	84 Po Polonium 209.000	85 At Astatine 210.000	86 Rn Radon 222.000
87 Fr Francium 223.000	88 Ra Radium 226.000	89-103 Actinides	104 Rf Rutherfordium 261.000	105 Db Dubnium 262.000	106 Sg Seaborgium 266.000	107 Bh Bohrium 264.000	108 Hs Hassium 277.000	109 Mt Meitnerium 278.000	110 Ds Darmstadtium 281.000	111 Rg Roentgenium 282.000	112 Cn Copernicium 285.000	113 Nh Nihonium 286.000	114 Fl Flerovium 289.000	115 Mc Moscovium 290.000	116 Lv Livermorium 293.000	117 Ts Tennessine 291.000	118 Og Oganesson 294.000
			57 La Lanthanum 138.905	58 Ce Cerium 140.116	59 Pr Praseodymium 140.908	60 Nd Neodymium 144.242	61 Pm Promethium 145.000	62 Sm Samarium 150.358	63 Eu Europium 151.964	64 Gd Gadolinium 157.250	65 Tb Terbium 158.925	66 Dy Dysprosium 162.500	67 Ho Holmium 164.930	68 Er Erbium 167.255	69 Tm Thulium 168.934	70 Yb Ytterbium 173.054	71 Lu Lutetium 174.967
			89 Ac Actinium 227.000	90 Th Thorium 232.038	91 Pa Protactinium 231.036	92 U Uranium 238.029	93 Np Neptunium 237.000	94 Pu Plutonium 244.000	95 Am Americium 243.000	96 Cm Curium 247.000	97 Bk Berkelium 247.000	98 Cf Californium 251.000	99 Es Einsteinium 252.000	100 Fm Fermium 257.000	101 Md Mendelevium 258.000	102 No Nobelium 259.000	103 Lr Lawrencium 262.000

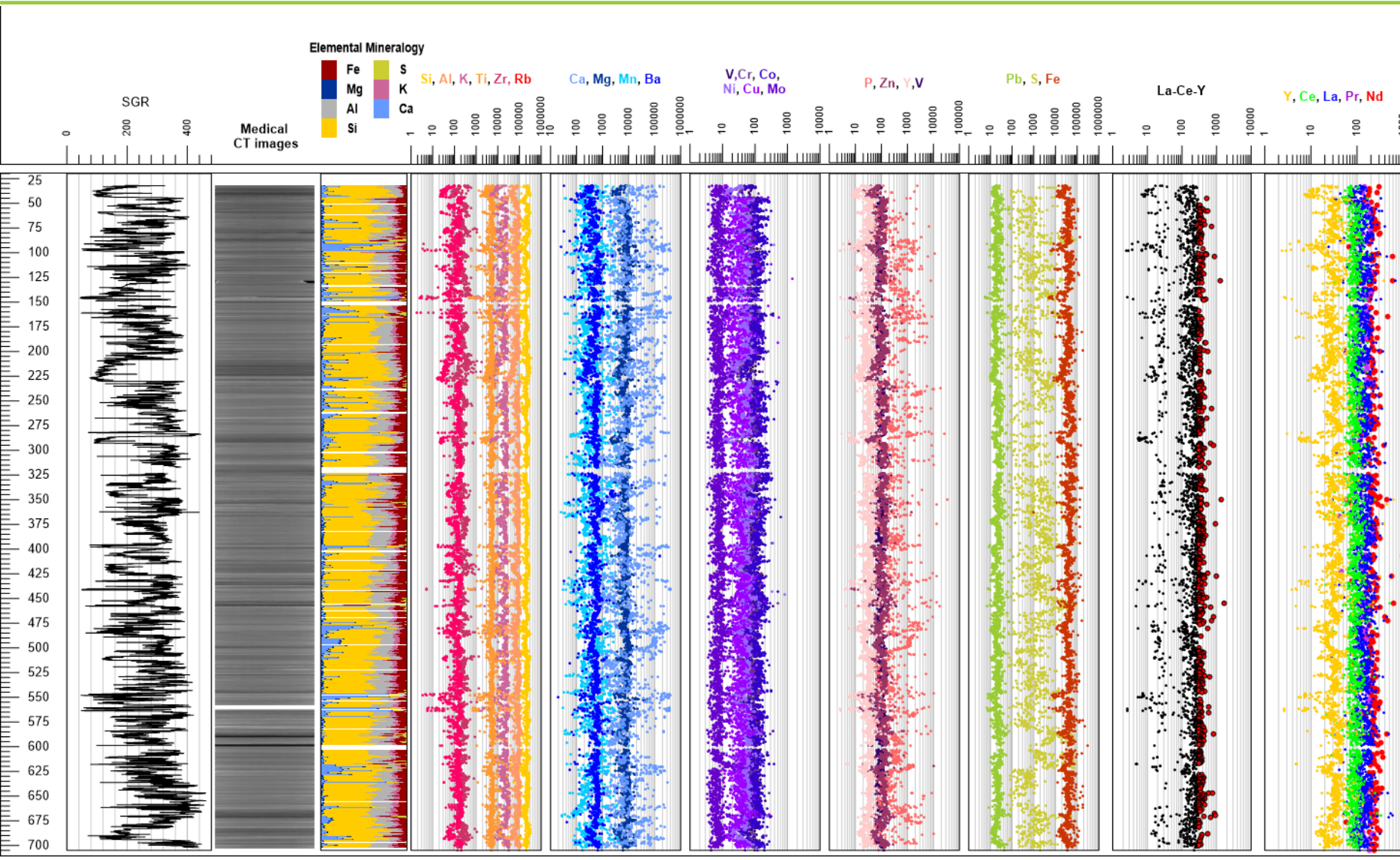


Critical Minerals –  
USGS

Critical Minerals –  
Resolved using  
hhXRF

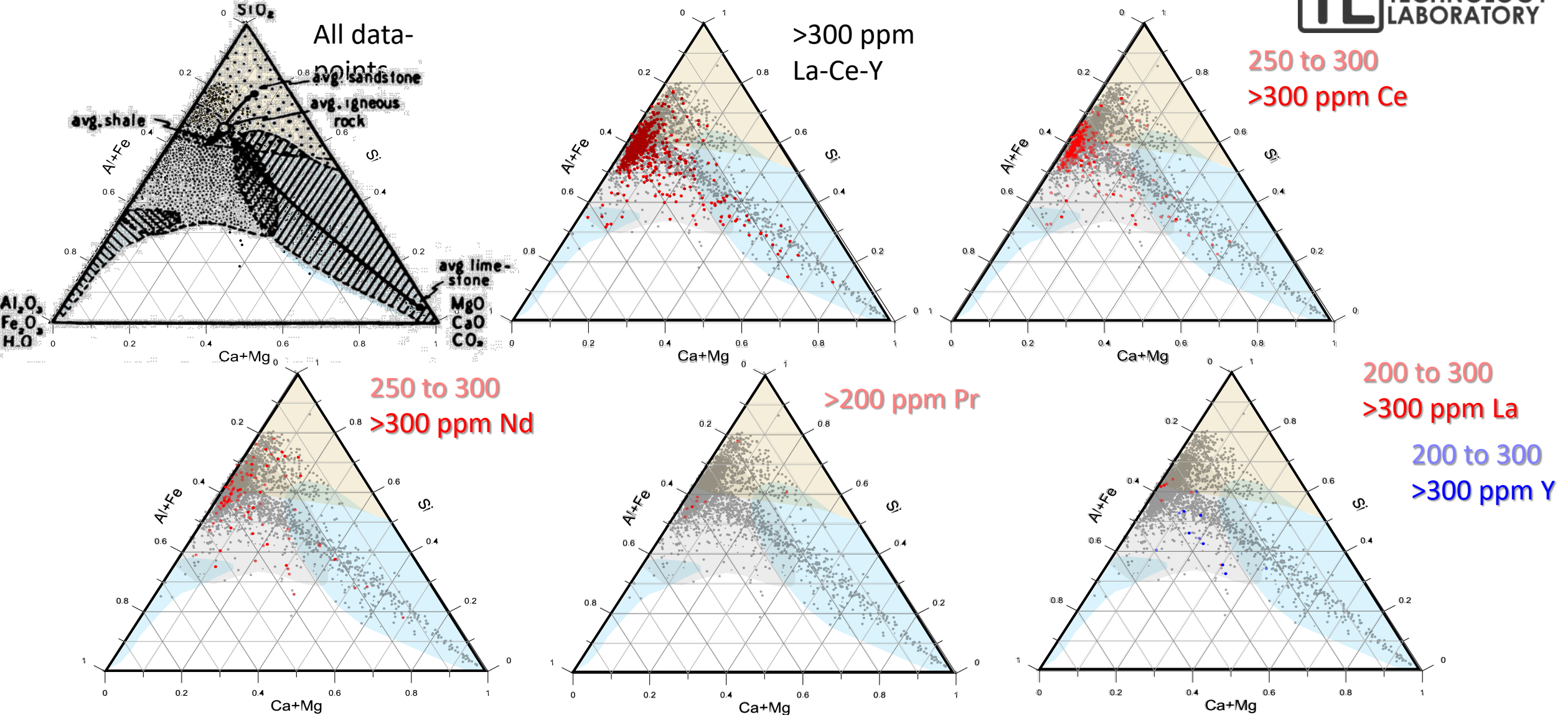
DOE – Energy  
Critical Minerals

# Results: Corelog



- Mostly claystone and shale, with zones of carbonate (brighter bands in the medical CT and Ca increases) and sand/siltstone intervals (darker CT bands, separation between clay minerals (Al, Ti, K, Rb, Zr) and Si)
- REE enrichment throughout the well mostly contributed through Nd and Ce, Summation of La, Ce, Y shows **>300 ppm** enrichment clay-rich zones
- There are multi high-P zones in the well; areas with P values of > 5000 ppm the increases in Y and highest total REEs
- Most other critical minerals are below 1000 ppm (redox proxy elements) apart from Mn

# REE element enrichments

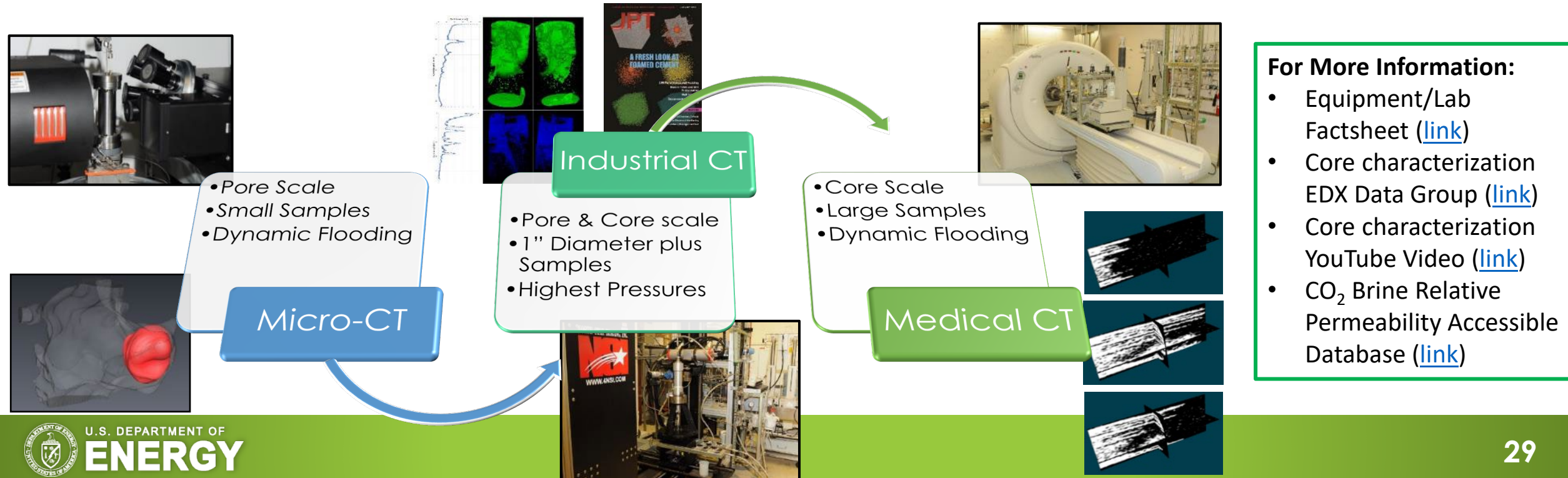


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**Opportunities:** Direct examination of rocks from carbon storage sites under *in-situ* conditions with supercritical CO<sub>2</sub>. Stressing of samples to understand mechanical behaviors. Examination of relationships between rock properties, geochemical alteration, and permeability (or structural properties). Scanning to complement other experiments, or to digitally and non-destructively preserve core from relevant locations.

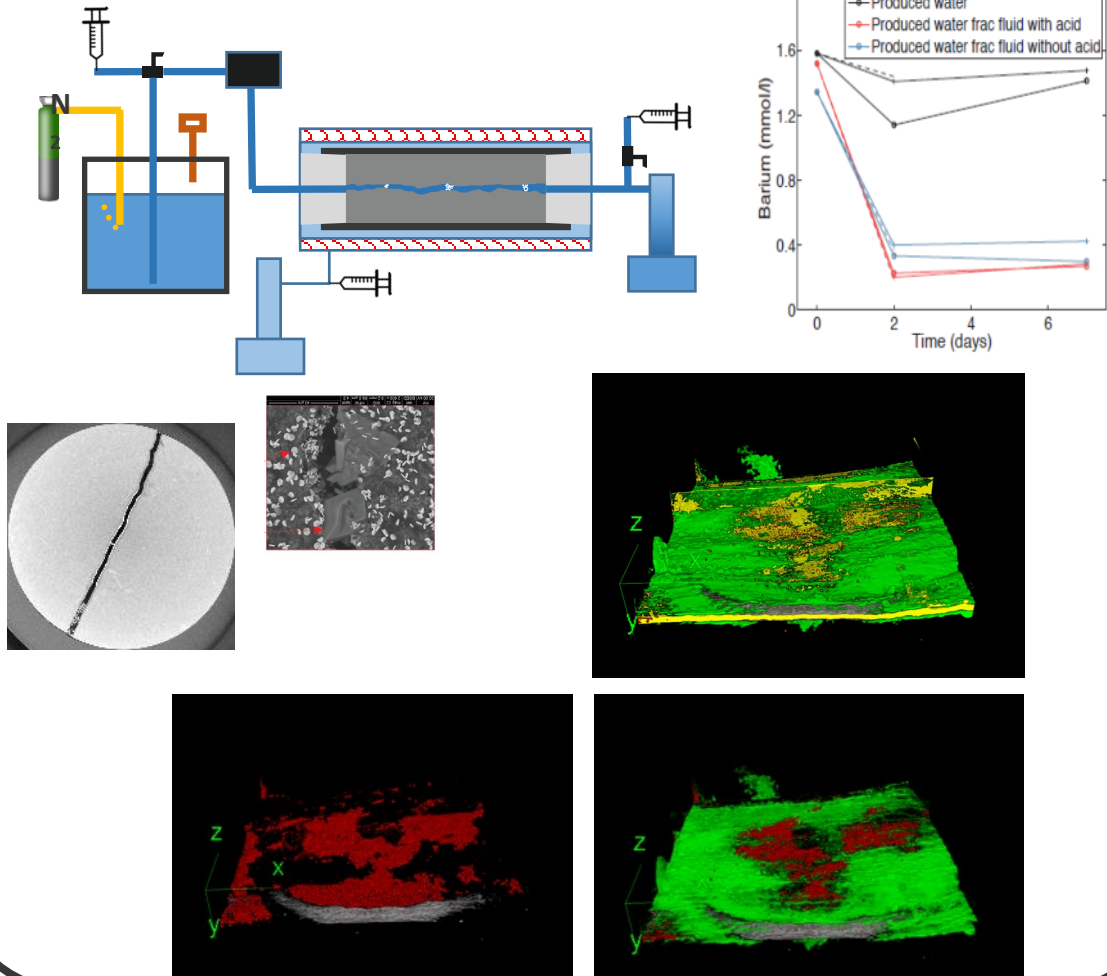


## For More Information:

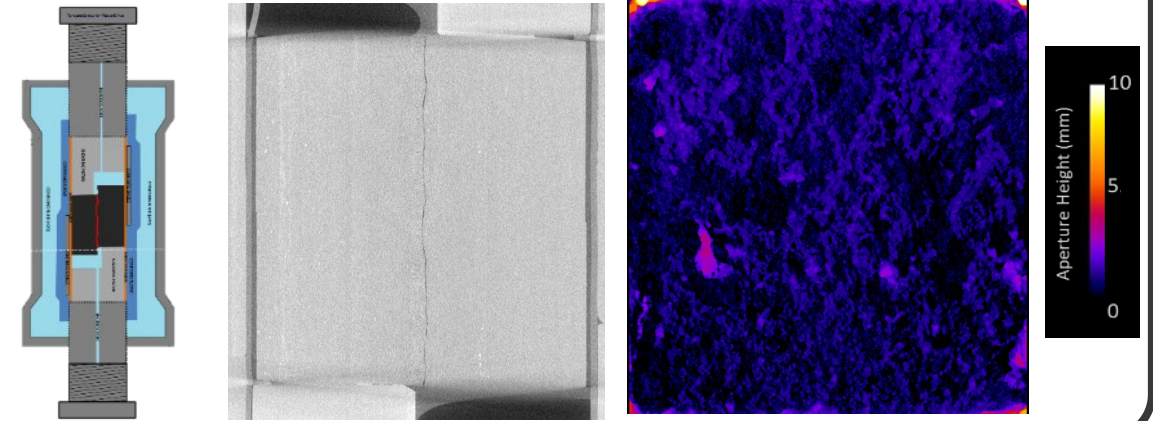
- Equipment/Lab Factsheet ([link](#))
- Core characterization EDX Data Group ([link](#))
- Core characterization YouTube Video ([link](#))
- CO<sub>2</sub> Brine Relative Permeability Accessible Database ([link](#))

# Industrial CT Scanner

## Fracture Alteration



## Mechanical Deformation

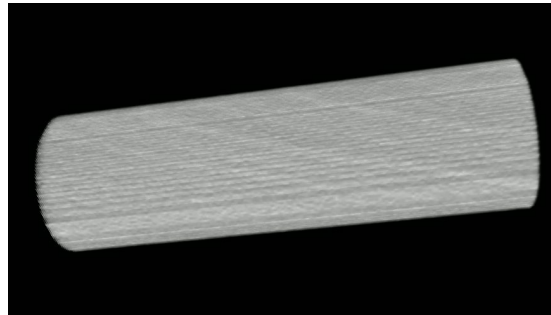
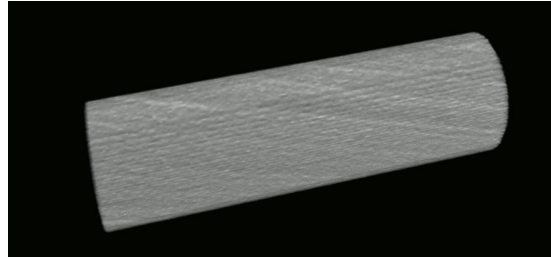
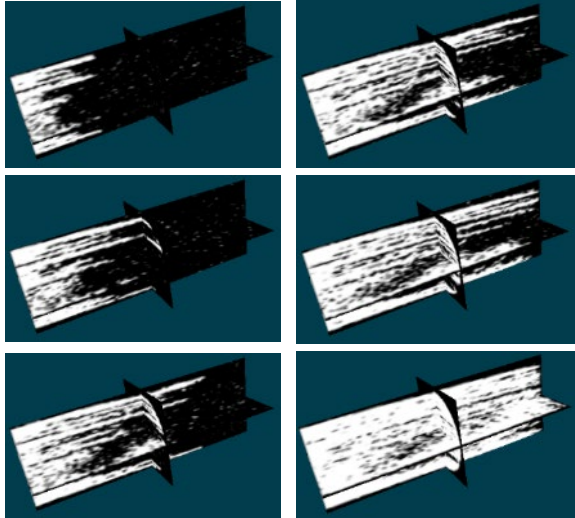


## Wellbore Integrity/Material Characterization

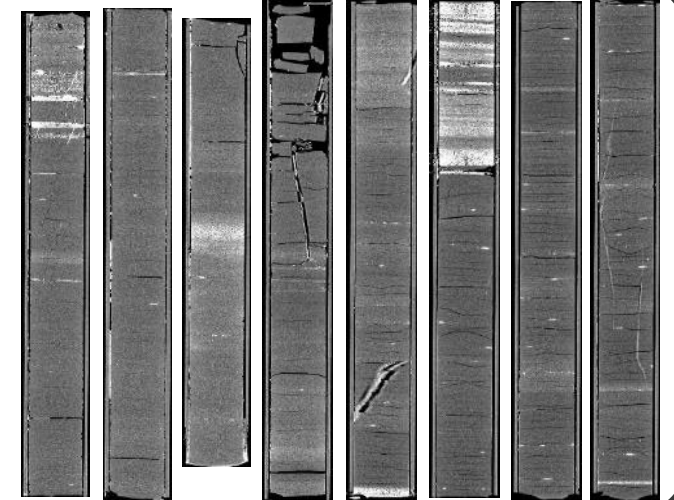


# Medical CT Scanner

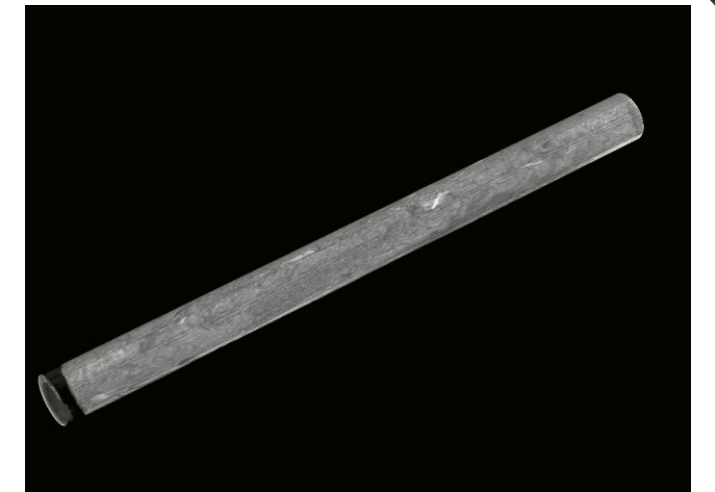
## Multiphase Transport/Relative Permeability



## Core Characterization

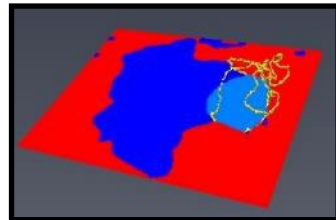
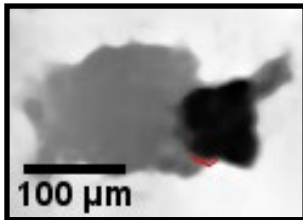
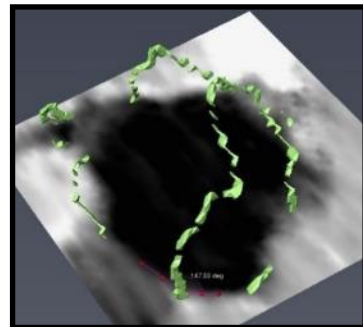
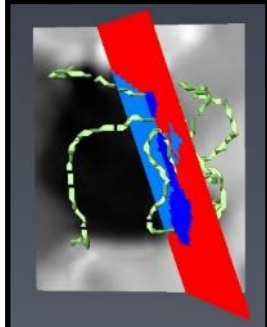
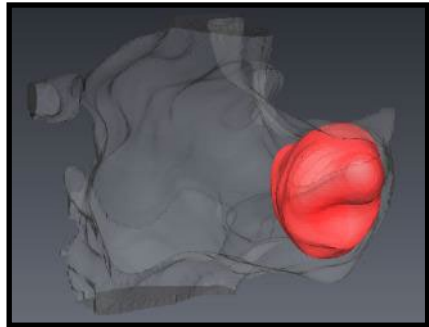
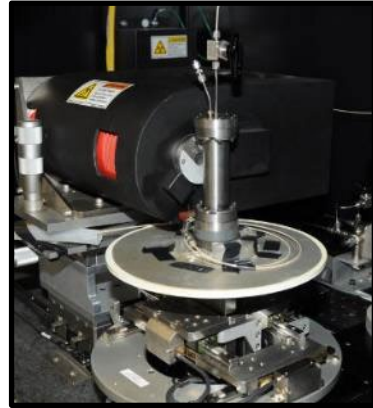
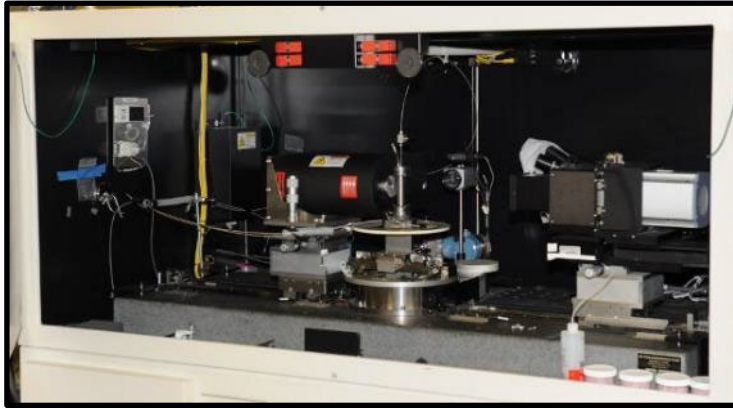


## Wellbore Integrity

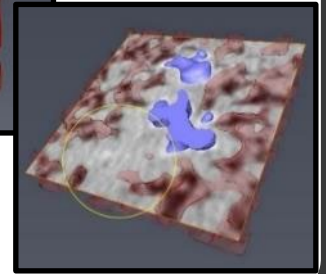
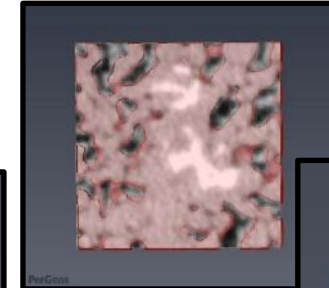
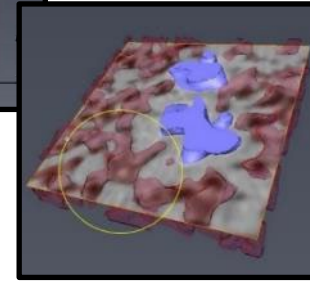
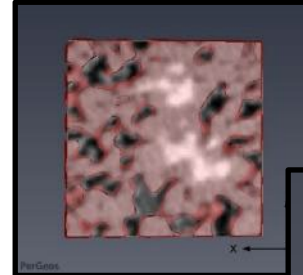


# Micro CT Scanner

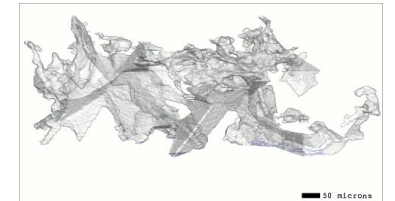
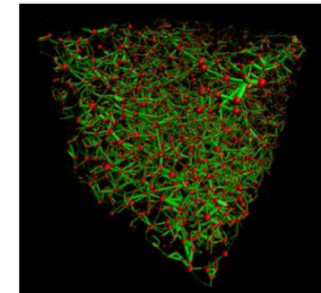
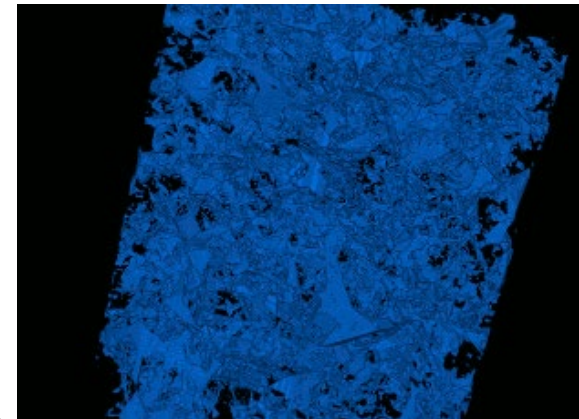
## Rock-Fluid Measurements



## Geochemical Alteration



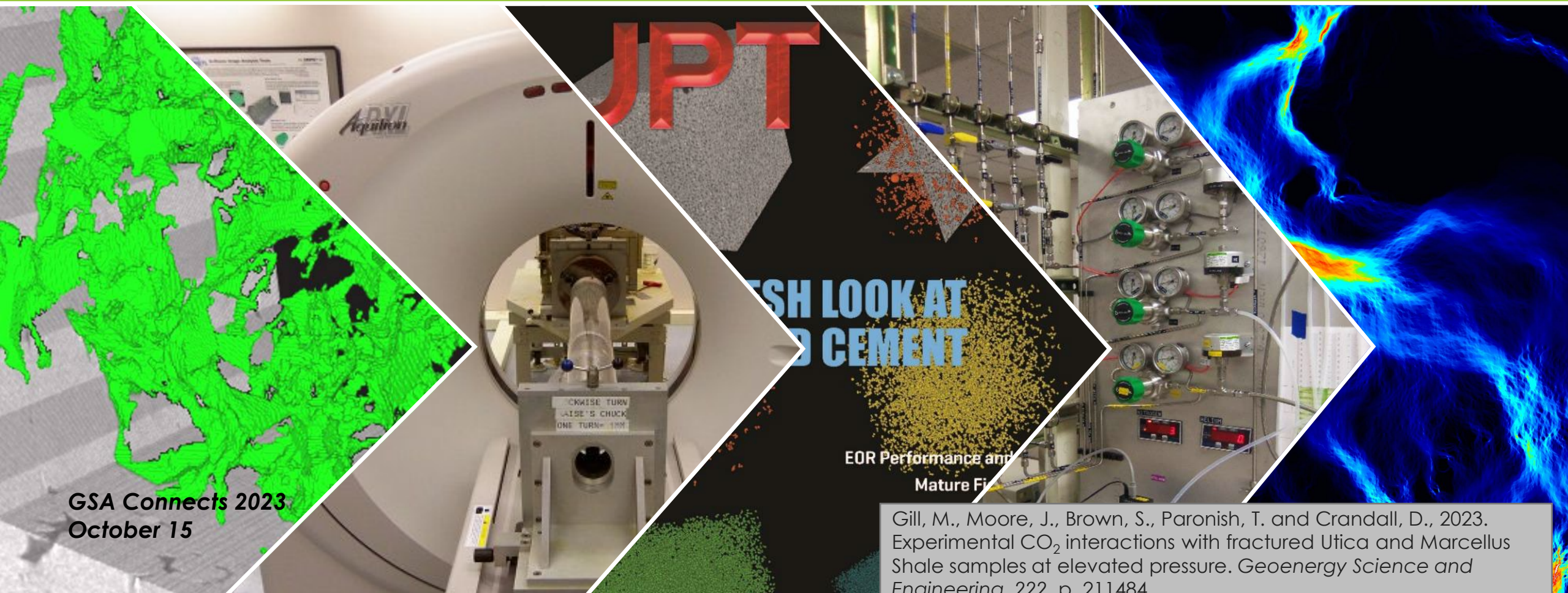
## Pore Characterization



# Experimental CO<sub>2</sub> Interactions with Fractured Calcite-Rich Shale Samples at Elevated Pressure



**Magdalena Gill**  
NETL Research Geologist



GSA Connects 2023  
October 15

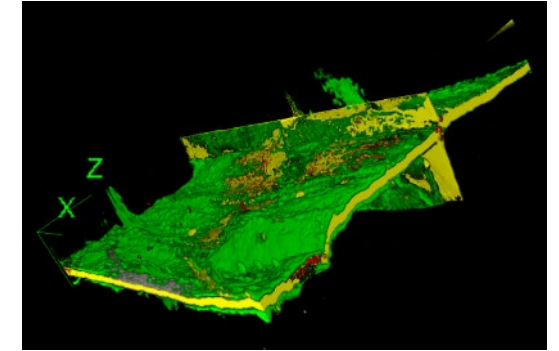
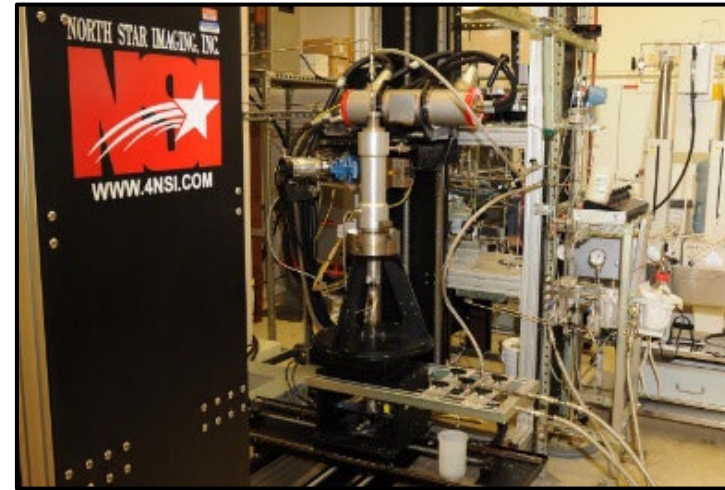
EOR Performance and  
Mature Fi

Gill, M., Moore, J., Brown, S., Paronish, T. and Crandall, D., 2023. Experimental CO<sub>2</sub> interactions with fractured Utica and Marcellus Shale samples at elevated pressure. *Geoenergy Science and Engineering* 222, p. 211484.

# CT Scanning at NETL's Geocharacterization Lab

## North Star Industrial CT Scanner:

- Workhorse CT
- Pore to core scale resolution range
- Scans at elevated temperature and pressure



## TESCAN DynaTOM CT Scanner:

- Installed in 2021
- First of its kind in U.S.
- High-speed, high-resolution scanning
- Resolution ~10 microns

# A Tale of Two Shales

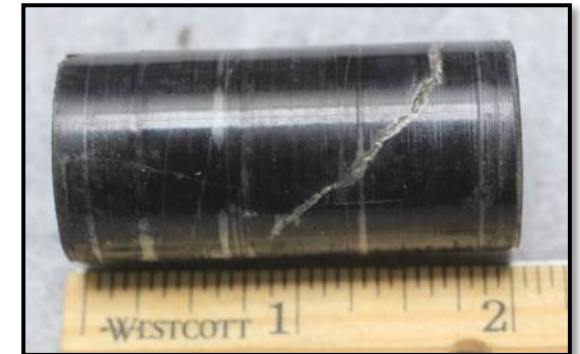
## Utica Shale

- Herrick 3H Well
- Monroe, OH (39.6572°N, 80.9847°W)
- Depth: 10,577.6 ft
- Point Pleasant Member
- Fossiliferous, gray, calcareous shale
- Higher Ca content – more calcareous
- Lower Si content – less silty

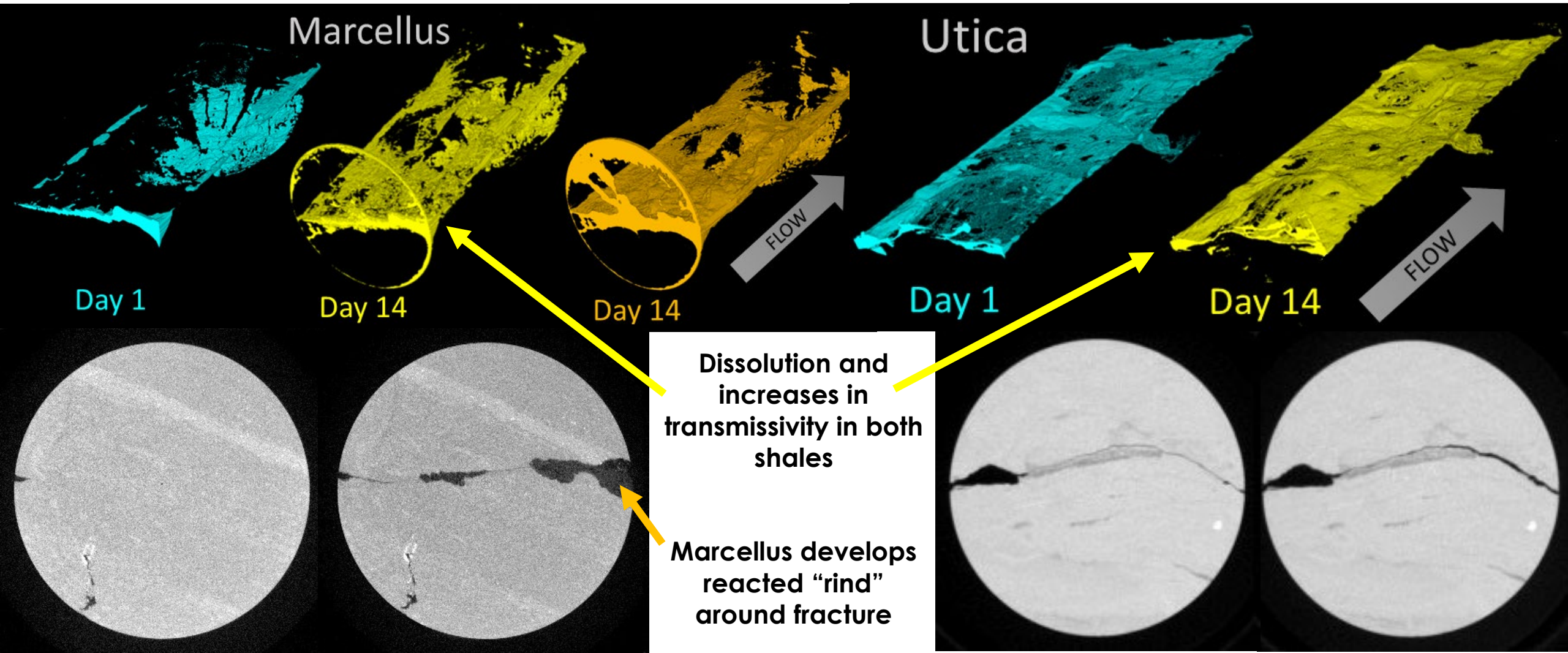


## Marcellus Shale

- Outcrop exposure (unweathered rock)
- Bedford County, PA (40.1382°N, 78.5837°W)
- Union Springs Member
- Organic-rich, black, calcareous shale
- Lower Ca content – less calcareous
- Higher Si content – more silty

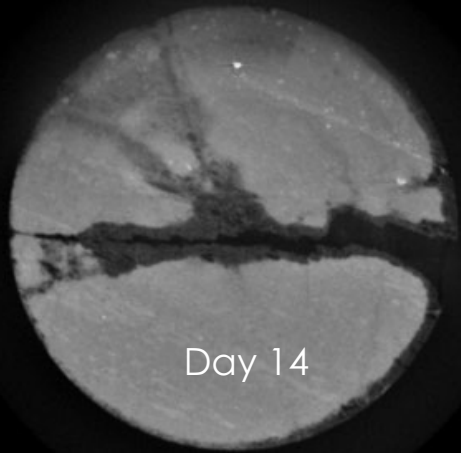
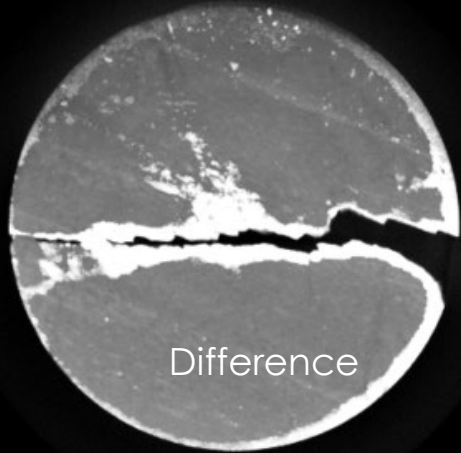
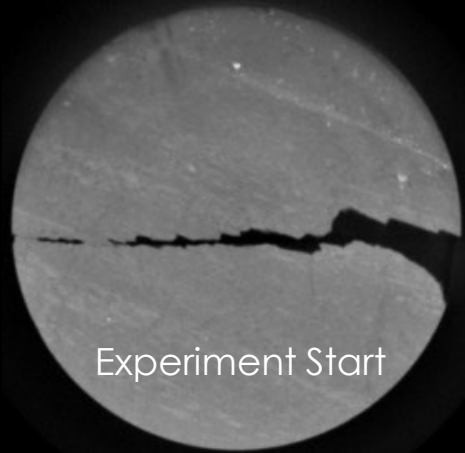


# Findings: Different Dissolution Styles

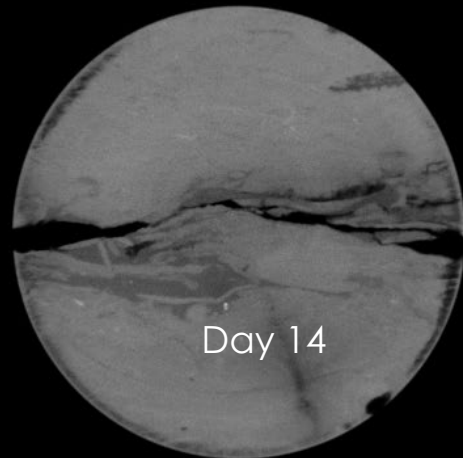
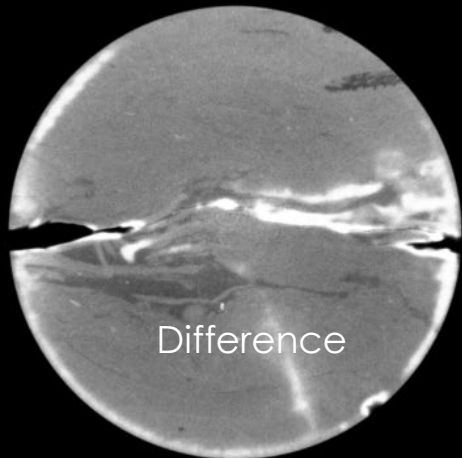


# Matrix Dissolution – Change Highlighted in White

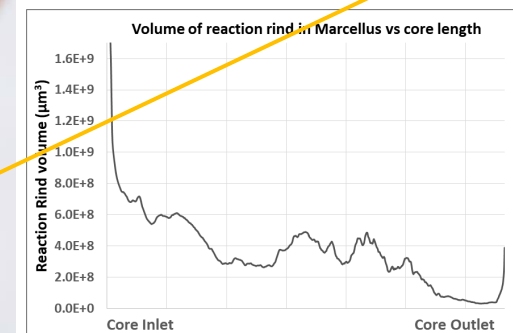
## Marcellus

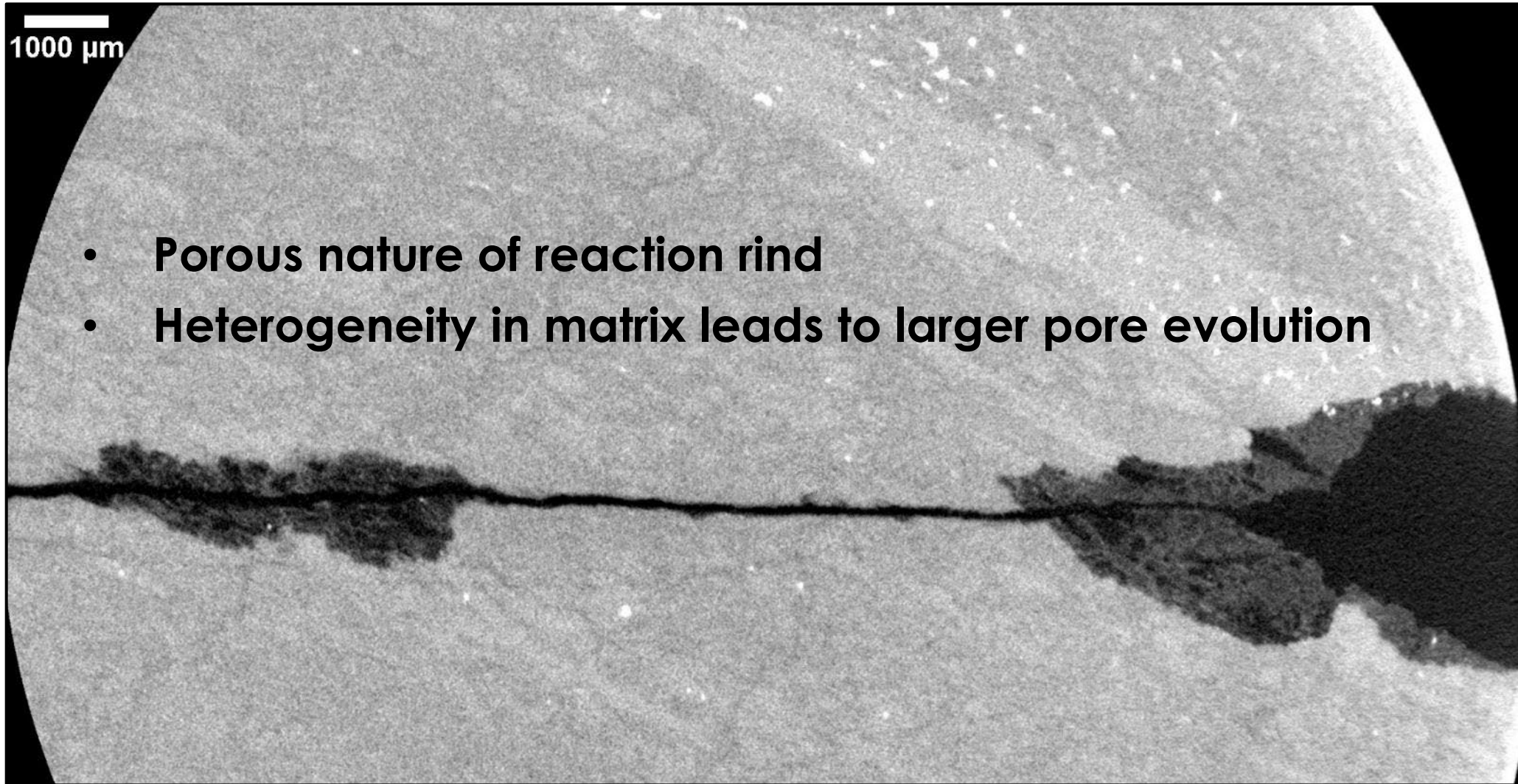


## Utica



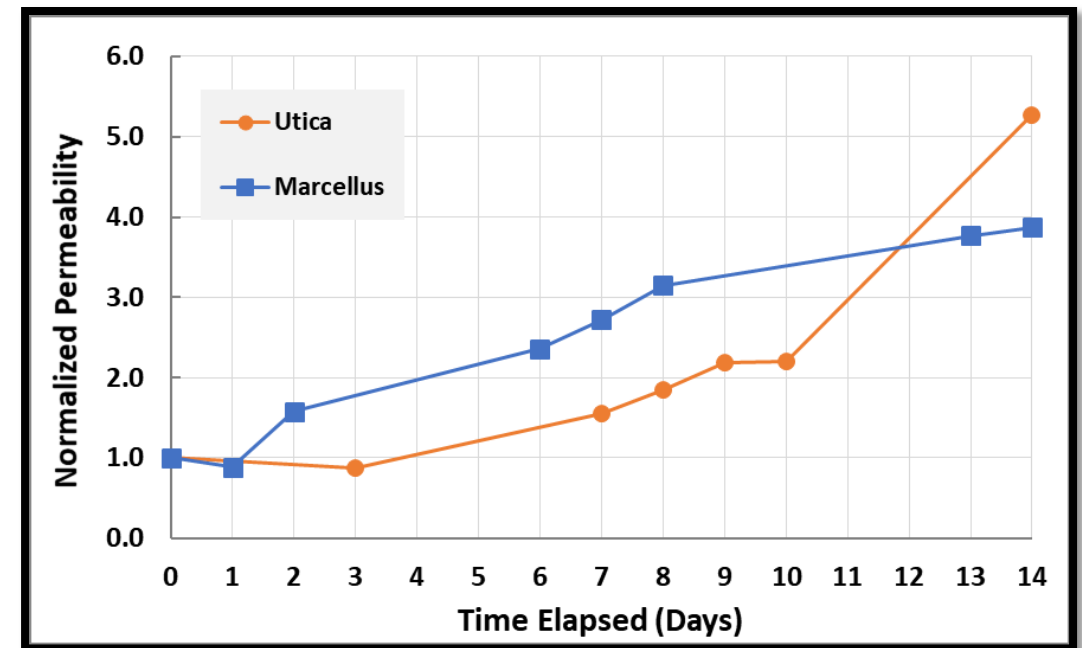
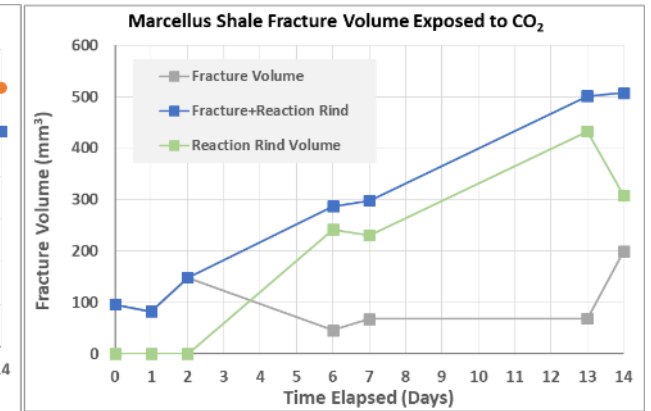
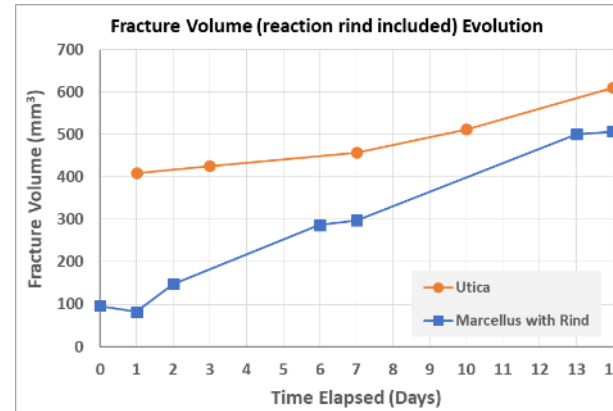
- **Utica:** homogenous dissolution
- **Marcellus:** porous reaction rind





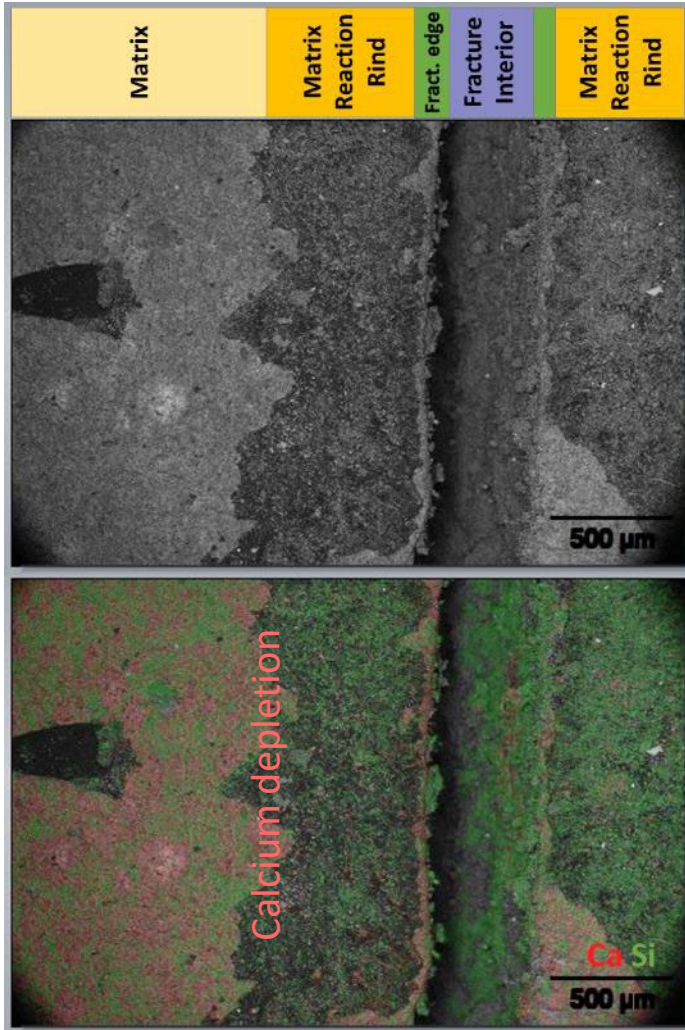
# Permeability and Dissolution Style

- Permeability  $k$  calculated from differential pressure across core
- Inclusion of reacted zone in Marcellus correlates well with rise in  $k$
- $k_{normalized} = k_{time}/k_0$

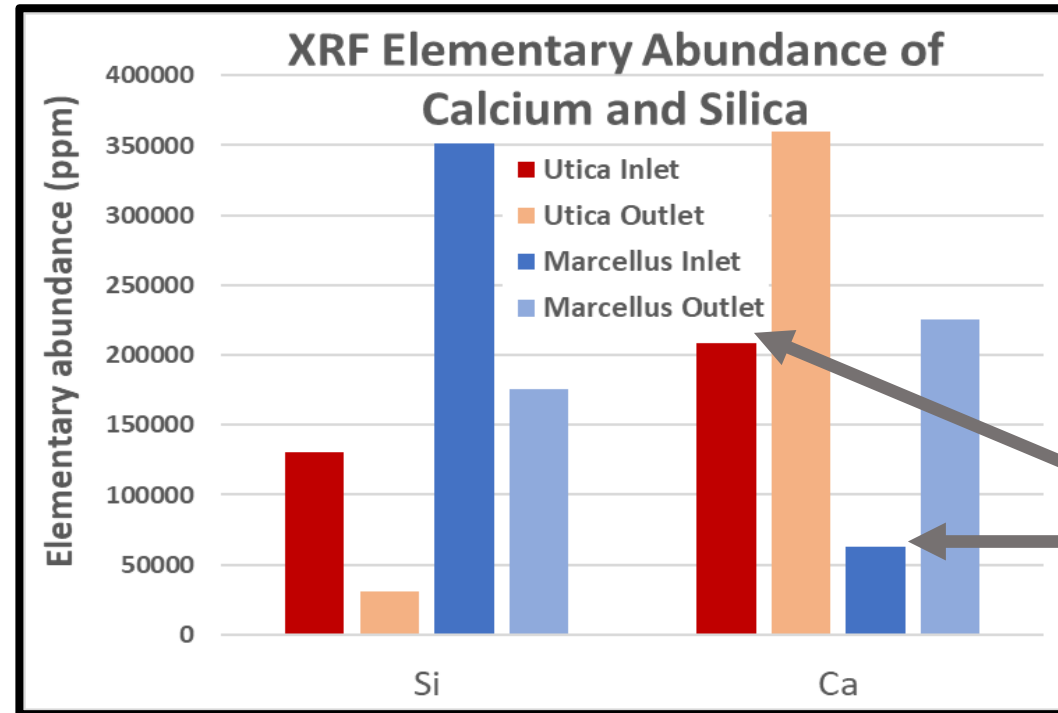


# SEM, Elemental Mapping, and XRF

## SEM and EDS of Marcellus Shale



- **Utica:** more calcium-rich (higher carbonate content; limey)
- **Marcellus:** more silica-rich (higher siliciclastic content; silty)
- **Ca depletion in reacted areas of both shales**
- **Si exposed wherever Ca dissolved away**



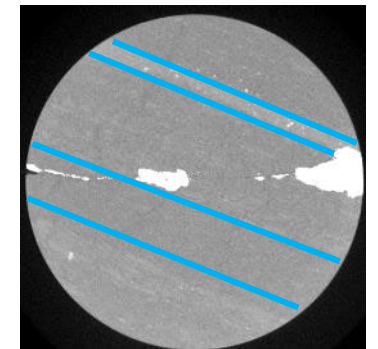
# Conclusions

- Comparison of reactivity of:
  - Marcellus:** Low Ca / High Si
  - Utica:** High Ca / Low Si
- Despite differences in dissolution, both show similar increases in fracture permeability
- A framework of silicious clastic grains facilitates creation of porous and permeable zones upon calcite dissolution
- Less calcareous shales may experience substantial Ca dissolution – leading to increases in permeability comparable to those found in more Ca-rich rocks
- Calcite distribution in shale matrix influences local dissolution rates
- Porous zone has lower mechanical strength: potential for future geomechanical work?



Find more information about this study in:

Gill, M., Moore, J., Brown, S., Paronish, T. and Crandall, D., 2023. Experimental CO<sub>2</sub> interactions with fractured Utica and Marcellus Shale samples at elevated pressure. *Geoenergy Science and Engineering*, 222, p. 211484.



# Thank You!

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U.S. DEPARTMENT OF  
**ENERGY**