Core Characterization of the Cane Creek Interval in the Paradox Formation from the State 16-2 Well

Solutions for Today | Options for Tomorrow

NATIONAL ENERGY TECHNOLOGY LABORATORY

Thomas Paronish
Research Geologist
Geological & Environmental Systems

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Authors and Contact Information

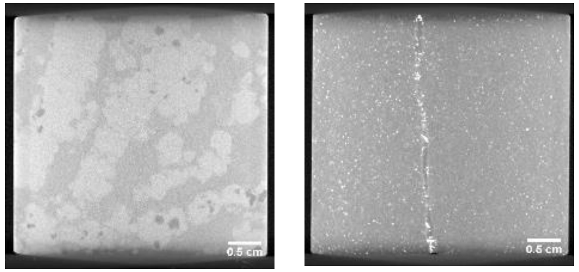
Tom Paronish[1, 2], Dustin Crandall[1], Johnathan Moore[1, 2], Terry McKisic[1], Natalie Mitchell[1, 2], Sarah Brown[1, 2], Bryan Tennant[1, 2], Scott Workman[1, 2], Eric Edelman[3], Brian McPherson[3], Rich Esser[3]

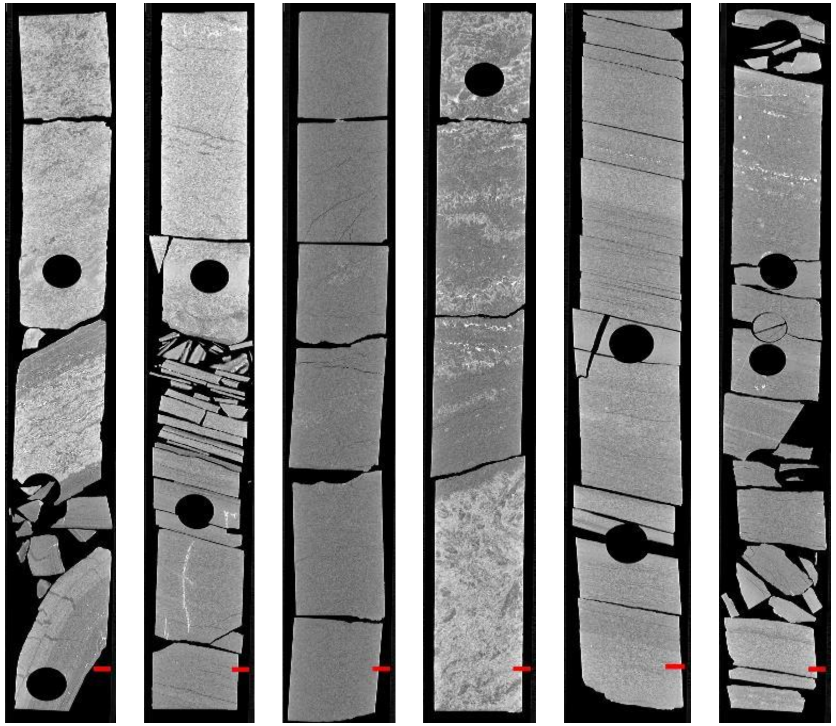
[1]National Energy Technology Laboratory
[2]NETL Support Contractor
[3] University of Utah

Outline

- **NETL Research & Innovation Center Imaging Capabilities and Methods for Core Analysis**
- **Standard Core Characterization**
  - Medical Computed Tomography (CT) Scanning
  - Multi-Sensor Core Logging
- **Sidewall Core Analysis**
  - High-Resolution CT Imaging
  - Permeability as a Function of Effective Stress
  - Xenon and CT Flow Zone Identification
  - Result Tie-In with Core Data

Geotek MSCL





Multi-Scale CT and Core Flow Facility

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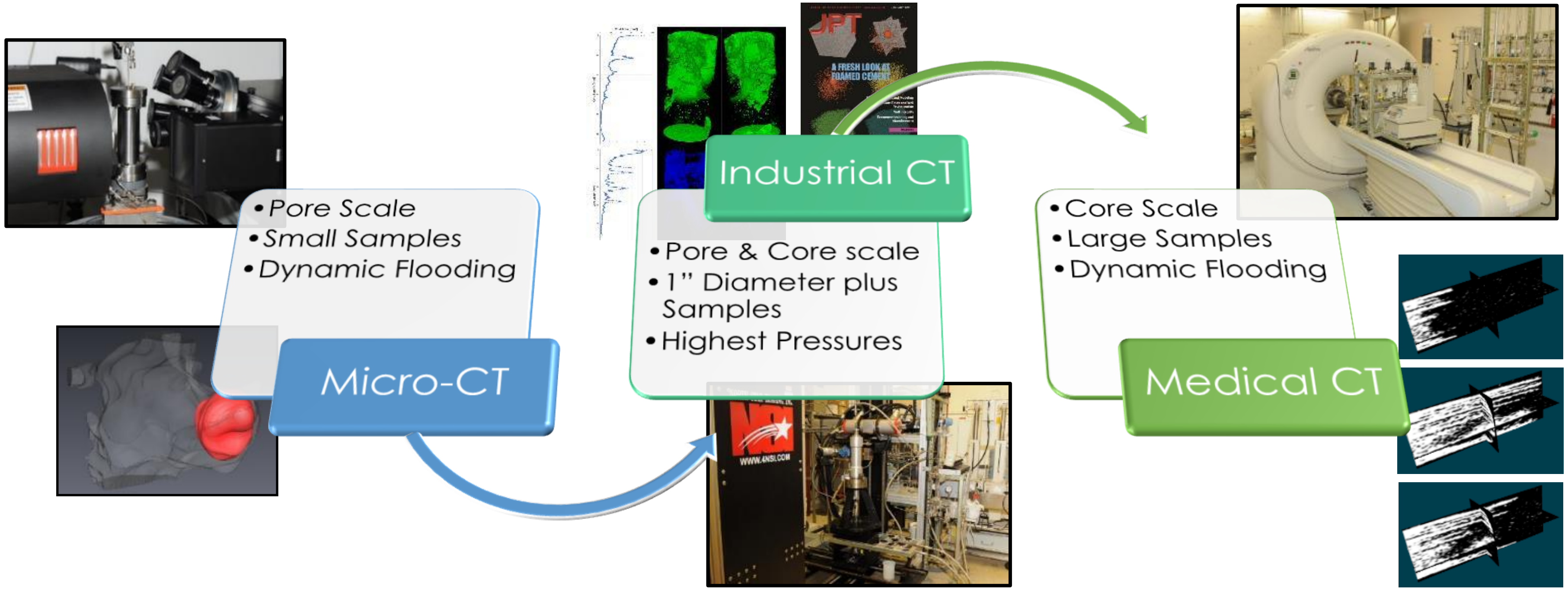
Unique Capabilities: Four CT scanners with 3D resolution from microns to millimeters, all with ancillary core flow capabilities. Able to perform controlled multiphase flow in cores from 0.25” to 2” in diameter at conditions up to 10,000 psi and 200 ˚C. Full time technical staff to assist with rock preparation, 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_2. 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.

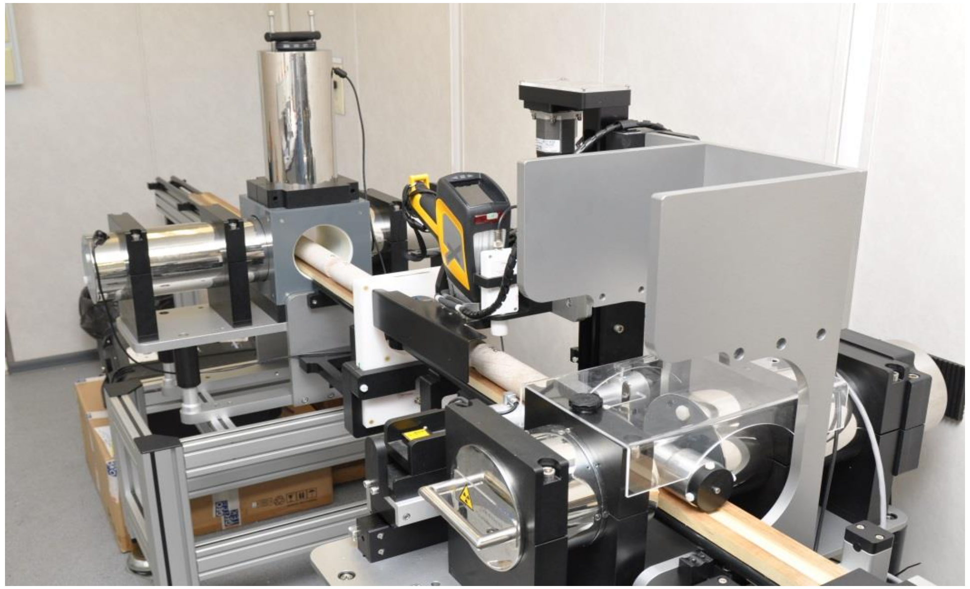


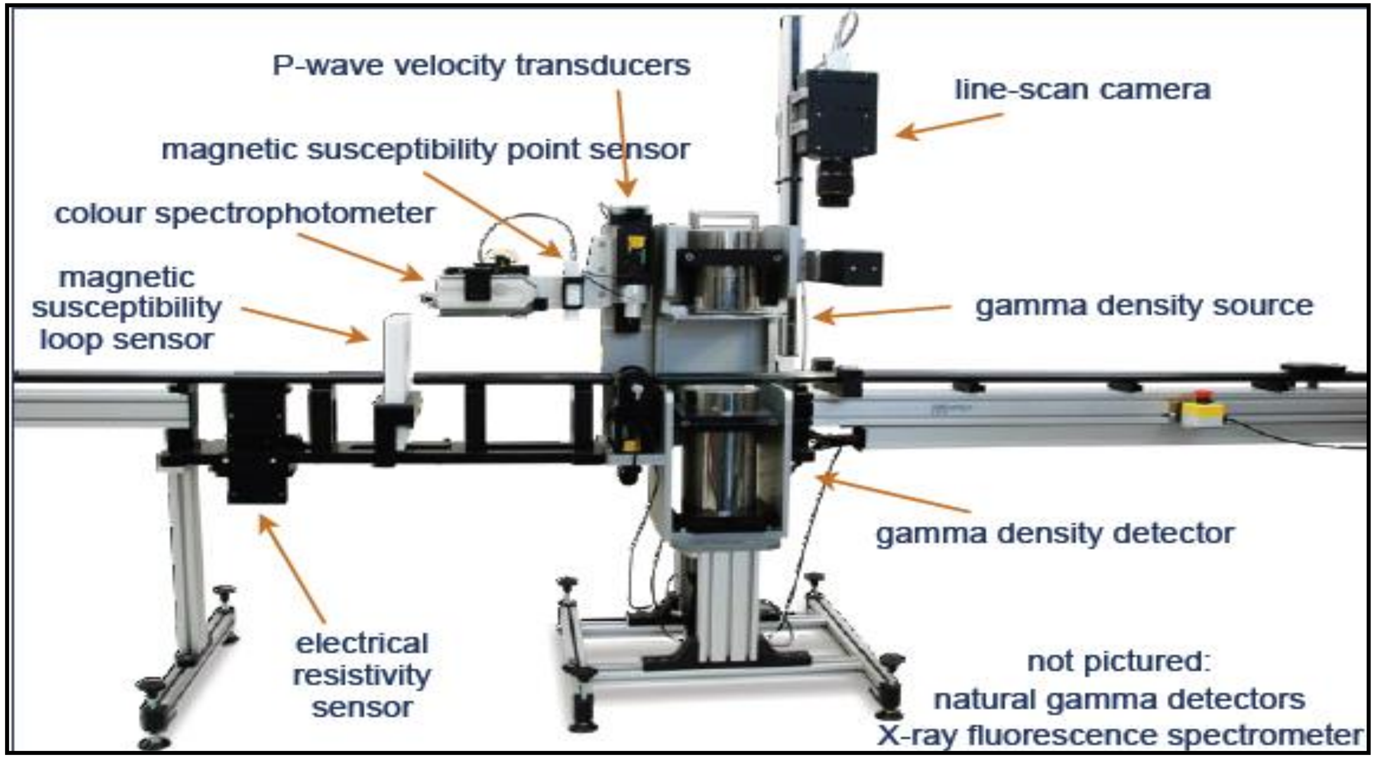
For More Information:

- Equipment/Lab Factsheet (link)
- Core characterization EDX Data Group (link)
- Core characterization YouTube Video (link)
- CO_2 Brine Relative Permeability Accessible Database (link)

Multi-Sensor Core Logger

Bulk Scans





Core Logger: Data Acquisition

State 16-2 Well:

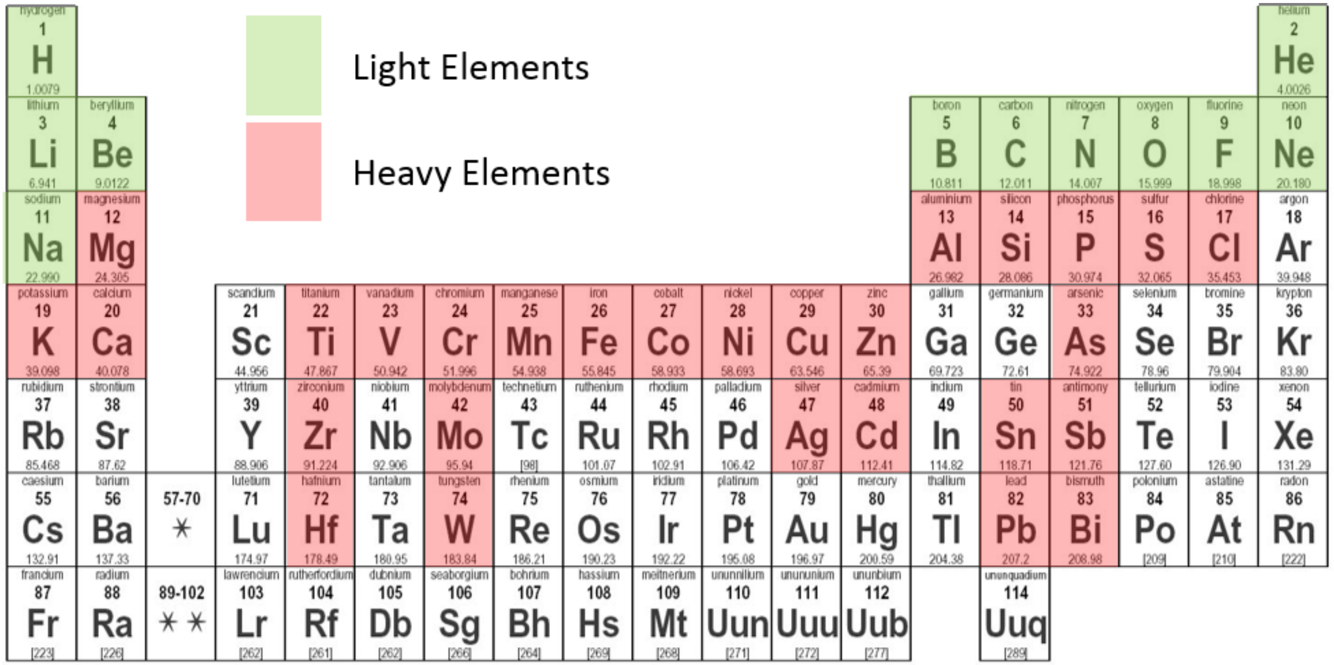
6 cm sampling resolution

Data acquired:

XRF: Mining-plus

- 60 sec exposure time per beam
- Light elements (LE) in green
- Detection limits: Mg(1%), P(2%), K(2 %), Transition metals (1-10 ppm)

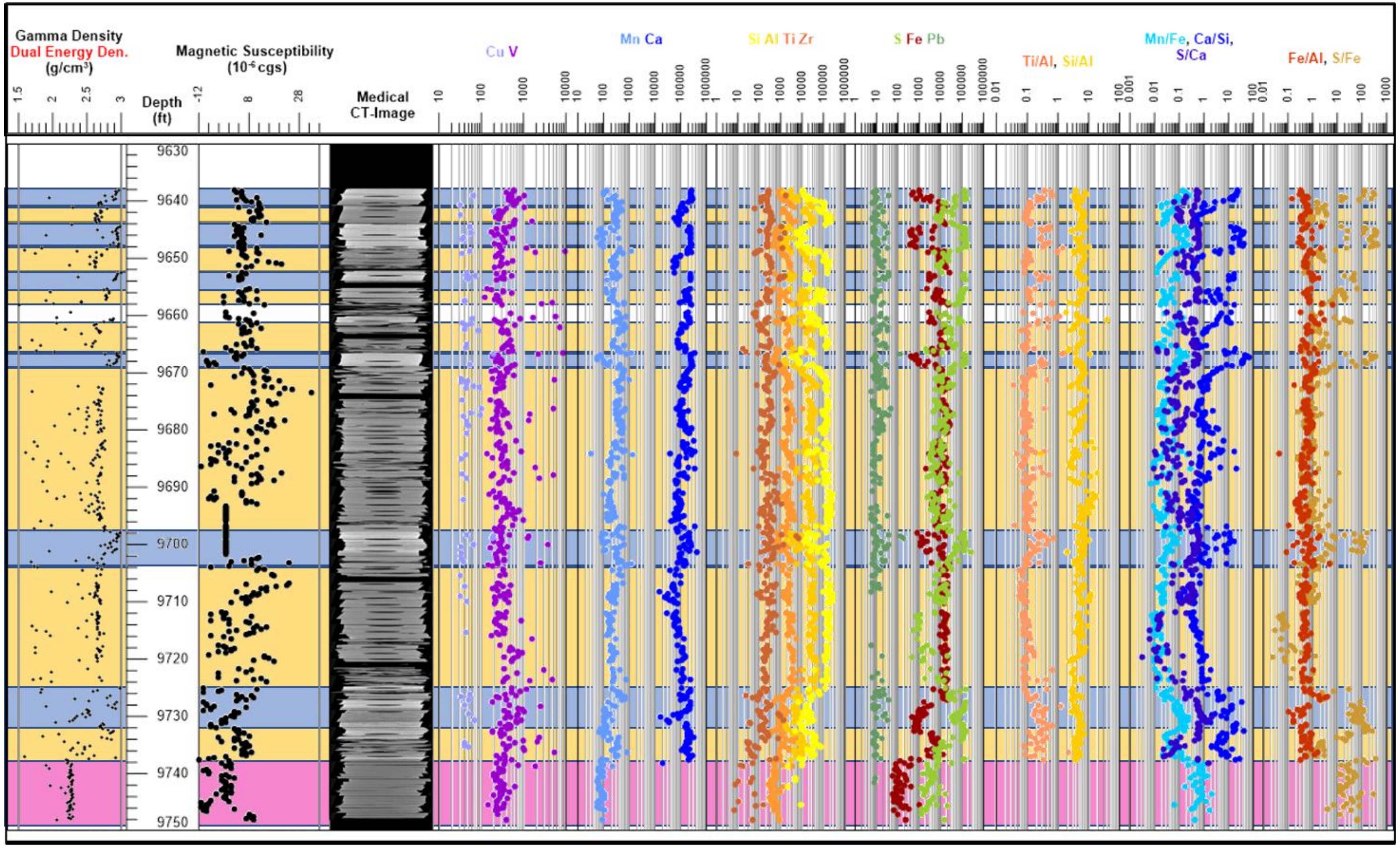
- Gamma Density
- Magnetic Susceptibility



Whole Core: CT Scanned and Logged in the MSCL

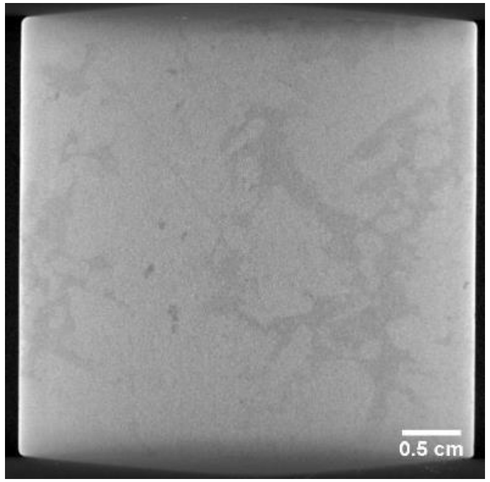
Analysis of the XRF shows 3 primary facies:

- **Anhydrite-rich zones**
  - Increases in S, Ca, and S/Ca ratio
  - Higher density up to 3 g/cm^3 and decrease in magnetic susceptibility
- **Mudstone/sandy-siltstone:**
  - Enrichment in detrital elements and depletion in S and S/Ca ratio
  - Mudstone portions of the facies occur with an increase in the Ca/Si ratio
- **Halite**
  - Enrichment in Cl and depletion in all other elements
  - Decrease in density and magnetic susceptibility

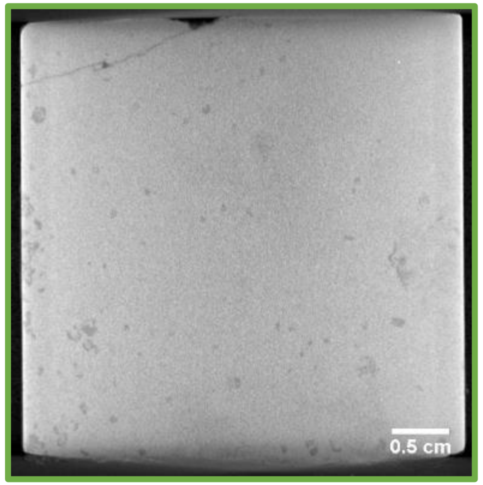


Core Plug Analysis: High Resolution CT Imaging

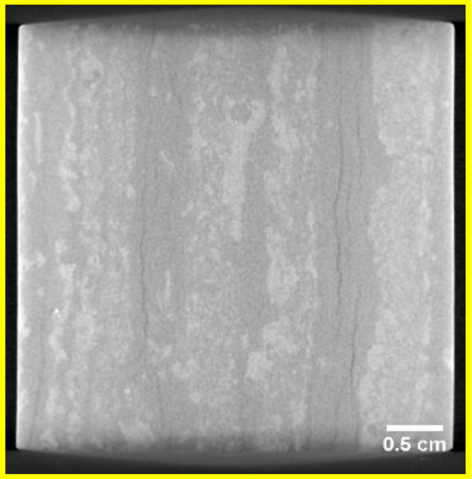
- **TESCAN DynaTOM**
  - Down to 3-micron resolution
  - Very fast scan times
- **Scans were acquired for most of the sidewall cores analyzed for steady-state permeability. Resolution varies; 0.5 cm scale bar is present on the bottom right of the image.**



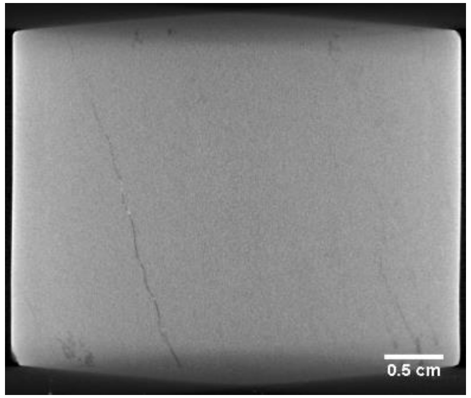
9639.3’



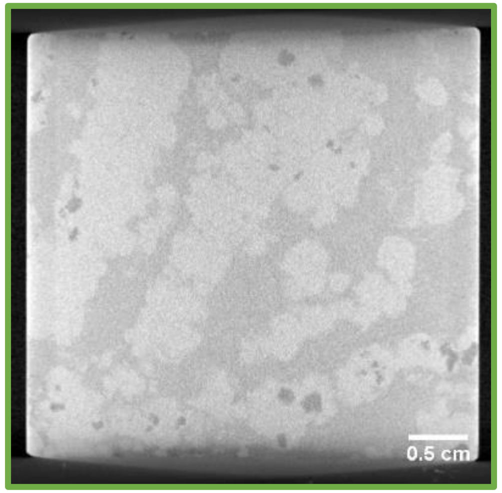
9648.15’



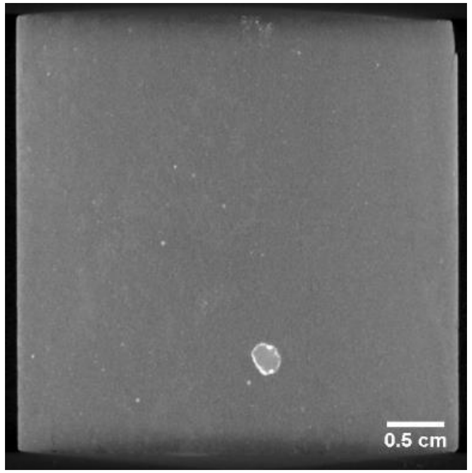
9682.1



9693.1’



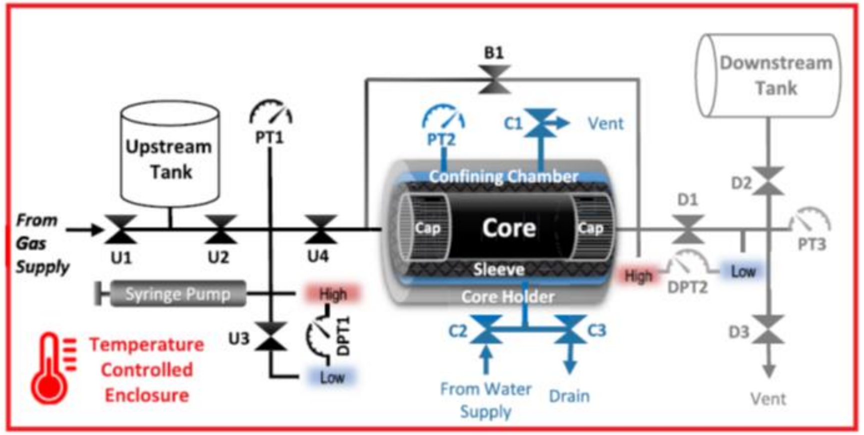
9695.9’

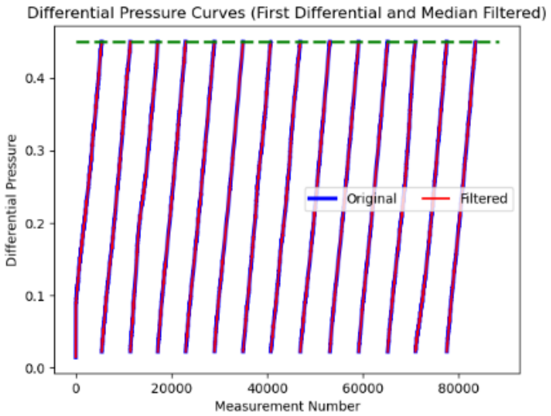


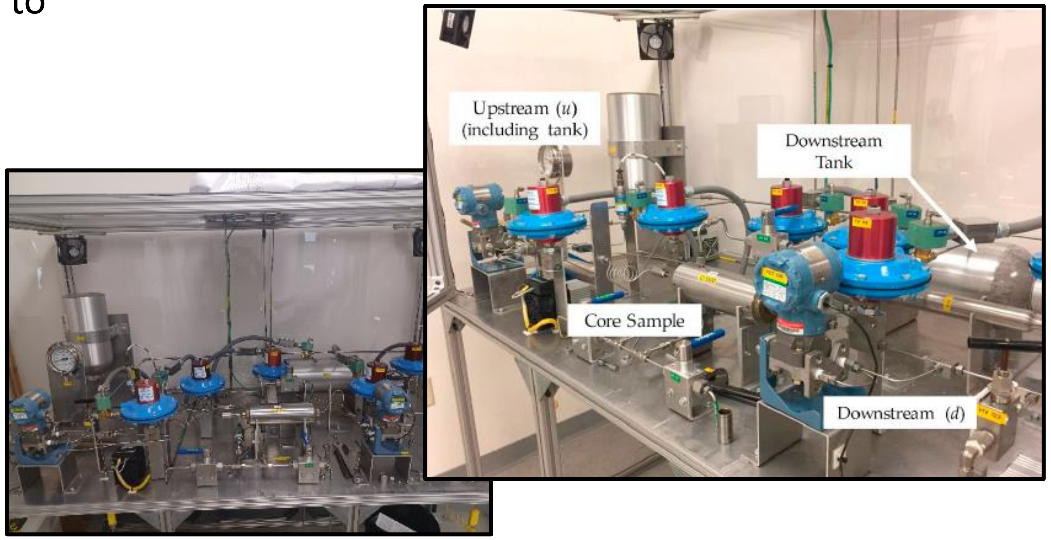
9703.9’

Core Plug Analysis: Steady-State Permeability Analysis

- Steady-state permeability measuring device for tight low permeability samples.
- Uses two larger volumes of gas, one on the inlet and one on the outlet, to maintain a constant pressure differential across the core.
- General methodology:
  1. Pressure increases in a small space downstream until it reaches 0.45 psi.
  2. Pressure is released via a valve actuating over a 10 sec period to the downstream reservoir.
  3. The downstream valve is automatically closed and the pressure increase allowed to occur again.
  4. This full process is repeated until the integration time for the pressure to reach 0.45 psi is consistent, "steady-state."
  5. Permeability is calculated by integrating the rate at which pressure climbs.







Hannon, Michael. *Experimental Data from: Quantifying the Effects of Gaseous Pore Pressure and Net Confining Stress on Low-Permeability Cores Using the "RaSSCAL" Steady-State Permeameter*. Mendeley, 23 May 2019, doi:10.17632/TK6KX5W3MC.

Permeability Measurements

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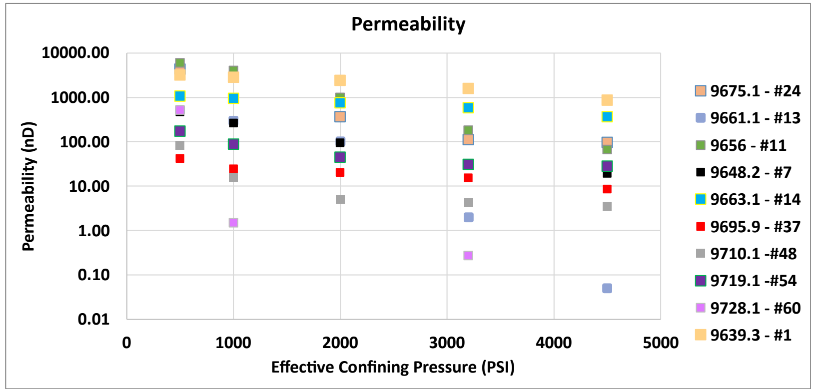
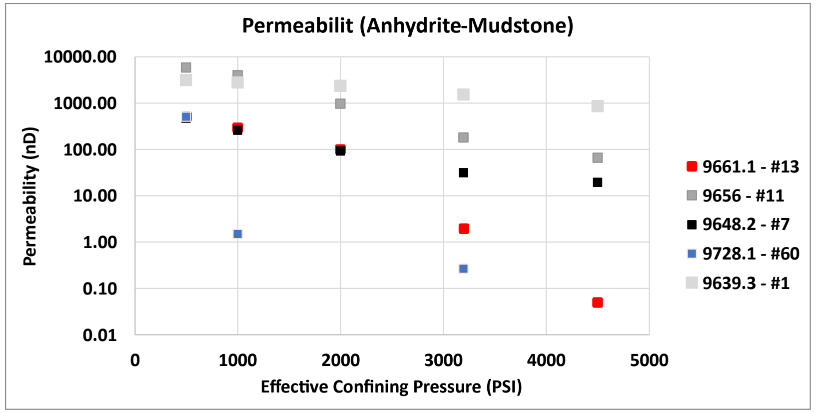
Peff (psi)	9639.3 - #1		9648.2 - #7		9661.1 - #13		9656 - #11		9658.1 - #12		9663.1 - #14		9664.4 - #15		9665.8 -#17		9670.1 - #20		9695.9 - #37	
	k (nD)	Stdev	k (nD)	Stdev	k (nD)	Stdev	k (nD)	Stdev	k (nD)	Stdev	k (nD)	Stdev			k (nD)	Stdev	k (nD)	Stdev	k (nD)	Stdev
500	3142.58	26.86	467.40	2.73	513.10	7.55	5918.30	157.30			1054.69	7.17							40.76	0.52
1000	2788.42	8.66	261.75	1.47	297.11	18.07	3962.17	73.68			932.52	8.02							24.04	0.54
2000	2359.38	13.30	93.17	9.19	101.35	10.05	971.46	286.18			746.21	14.70	390.08	25.10					20.23	0.39
3200	1542.40	16.18	31.20	X	1.96	X	179.12	31.17			569.92	17.03							15.24	0.34
4500	852.95	15.65	19.27	6.23	0.05	X	65.59	18.47	113.81	1.99	360.25	10.01	6376.11	229.71					8.44	0.40

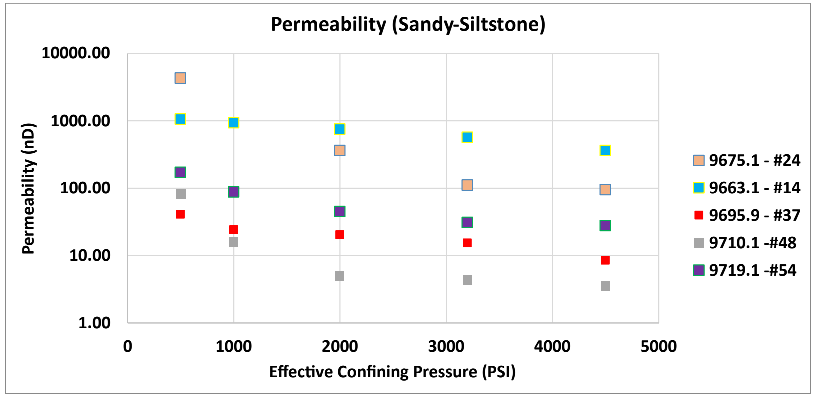
Peff (psi)	9710.1 -#48		9719.1 -#54		9718.1 - #53		9675.1 - #24		9728.1 - #60	
	k (nD)	Stdev	k (nD)	Stdev	k (nD)	Stdev	k (nD)	Stdev	k (nD)	Stdev
500	81.35	39.34	169.71	4.58	105.50	1.04	4257.25	441.85	507.50	68.63
1000	15.84	2.05	87.64	0.63	20.22	1.57			1.48	0.40
2000	4.96	0.15	44.53	2.11	0.47	0.38	363.16	6.50		
3200	4.28	0.30	30.69	2.66			110.73	4.34	0.27	-
4500	3.53	0.20	27.51	1.53			94.94	12.36		

One measurement only

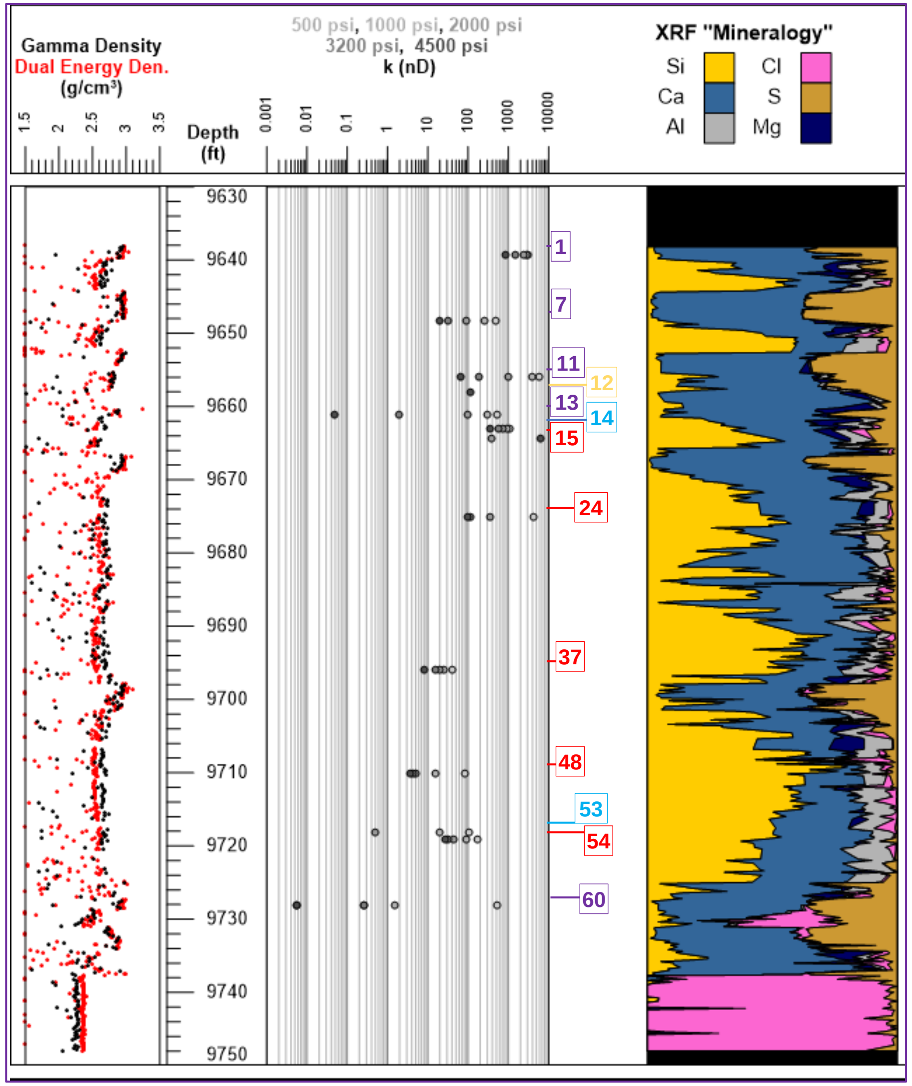
Still in sharp decline when finalized

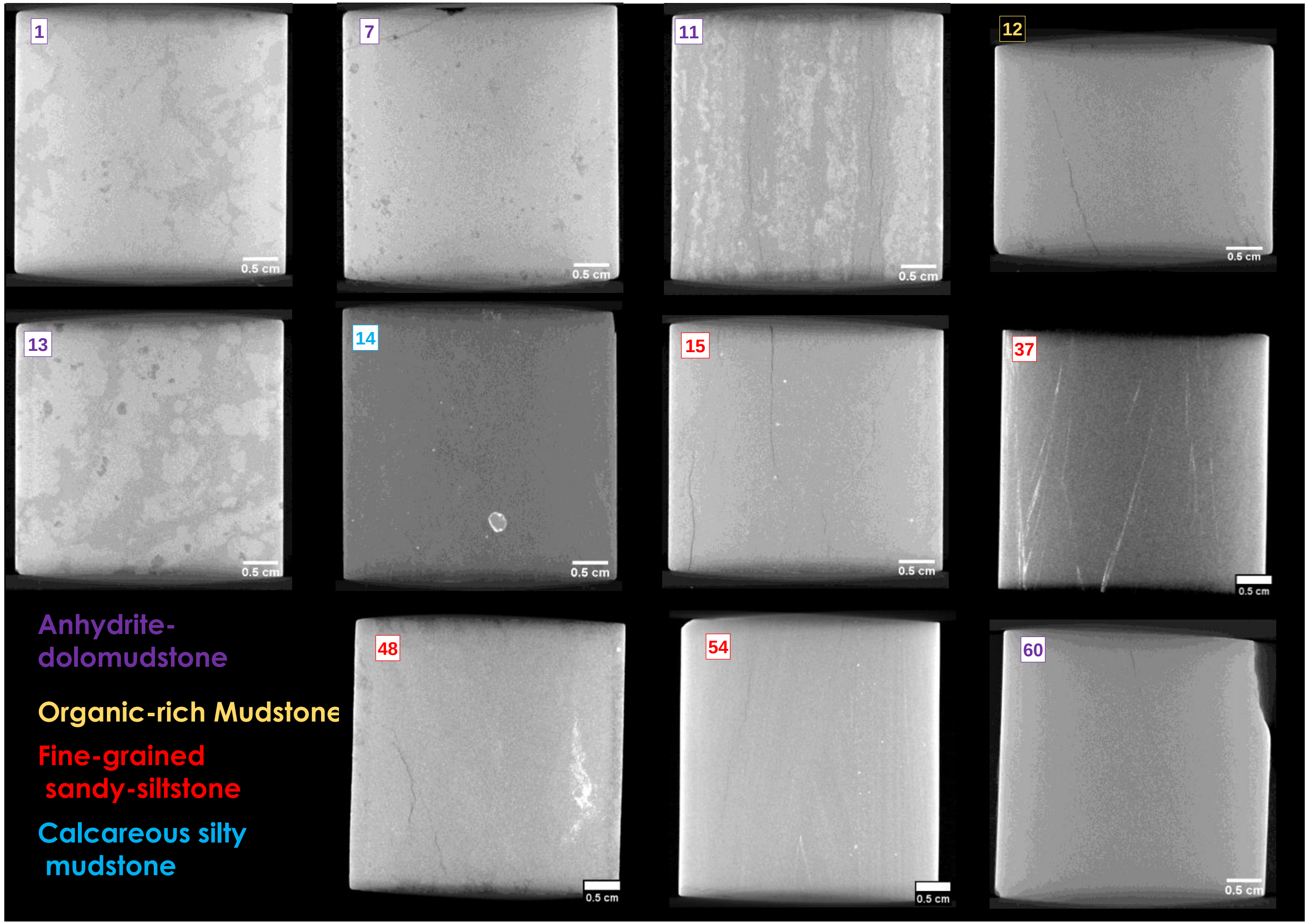






Permeability Measurements (continued)





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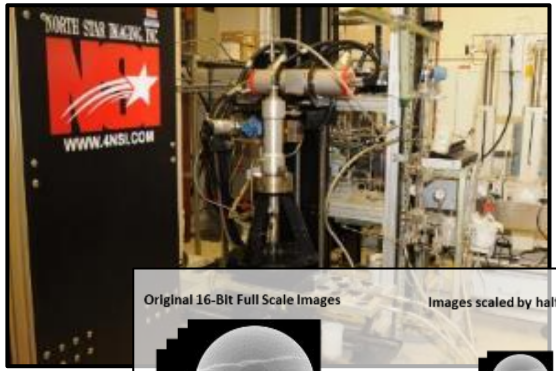
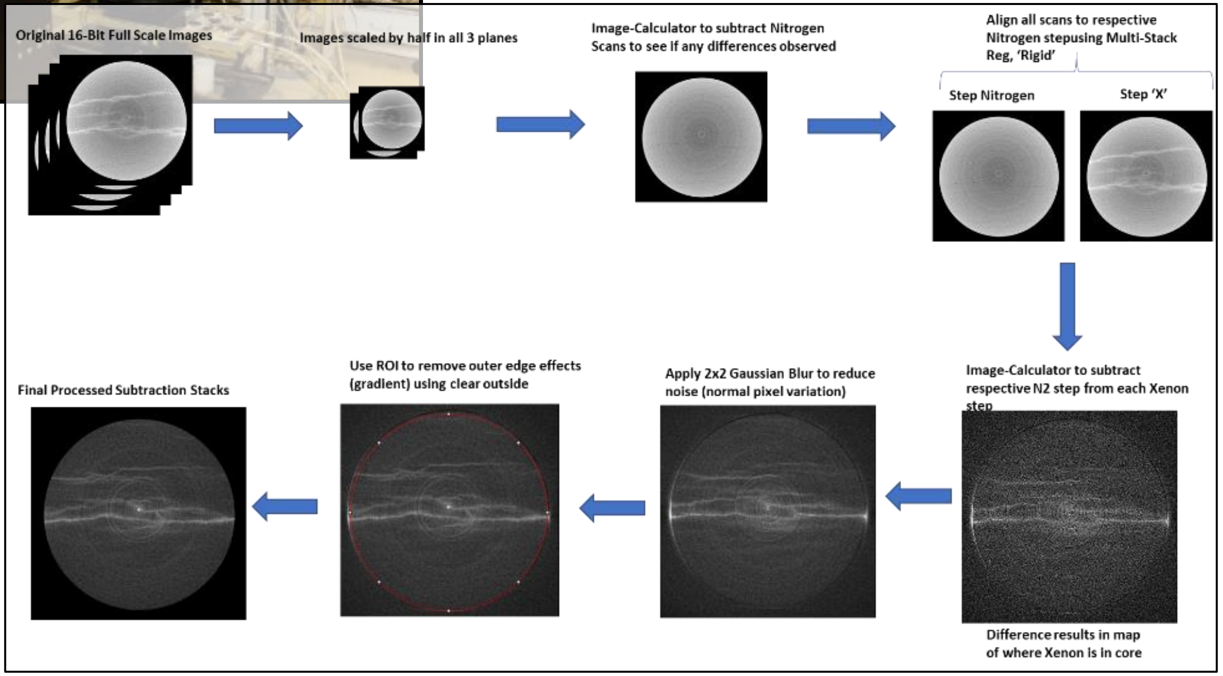
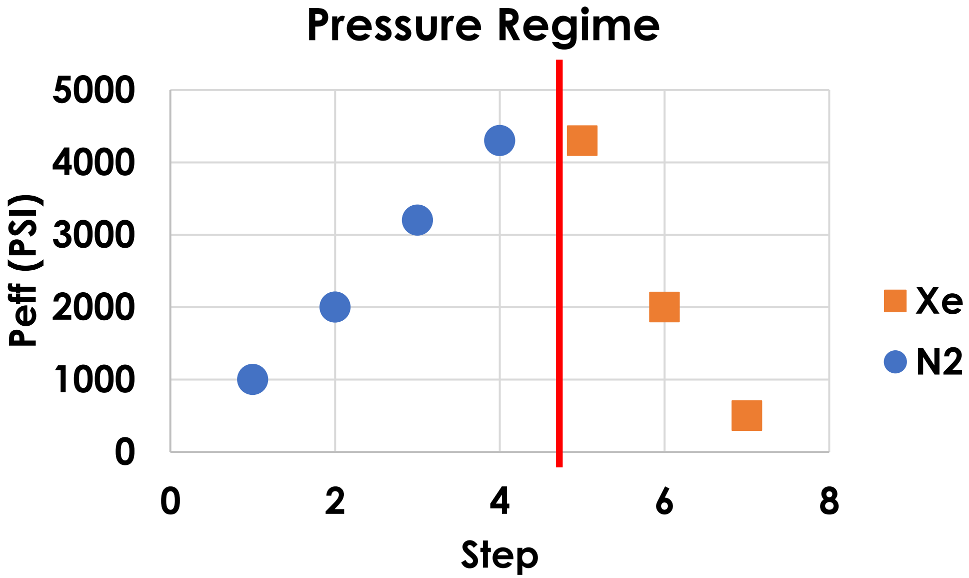
Compression CT Test with Xenon

- Xenon attenuates X-rays significantly; therefore, it is an excellent inert gas to highlight flow pathways (fractures)
- Using core holders and NETL's Industrial CT scanner







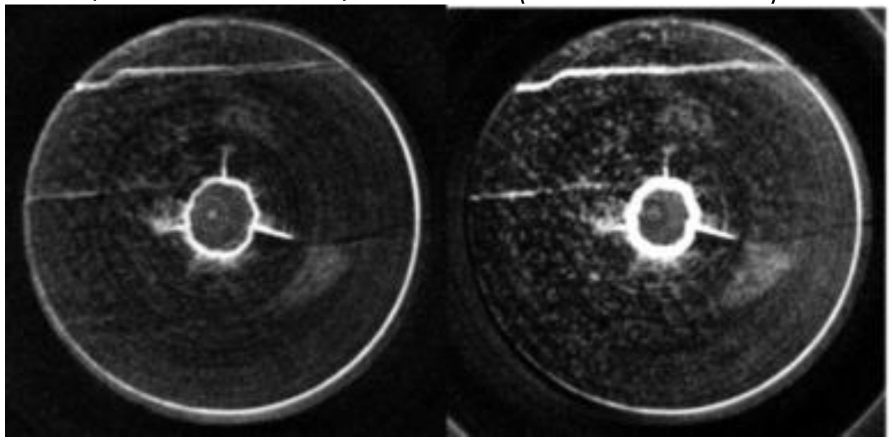
- Maintain pore pressure of 600 psi with N_2
- Slowly raise confining pressure
  - Obtain CT scans at four steps
- Reduce pore **pressure to zero** at P_{eff} = 4600 psi
- Introduce Xe to system at 4600 psi
  - Obtain CT scan
- Lower confining (P_{eff}) and CT scan at each step

Subtraction Images

Top: Bright zones show fractures in the core that close due to increasing effective pressure

- Pathways apparent with N_2

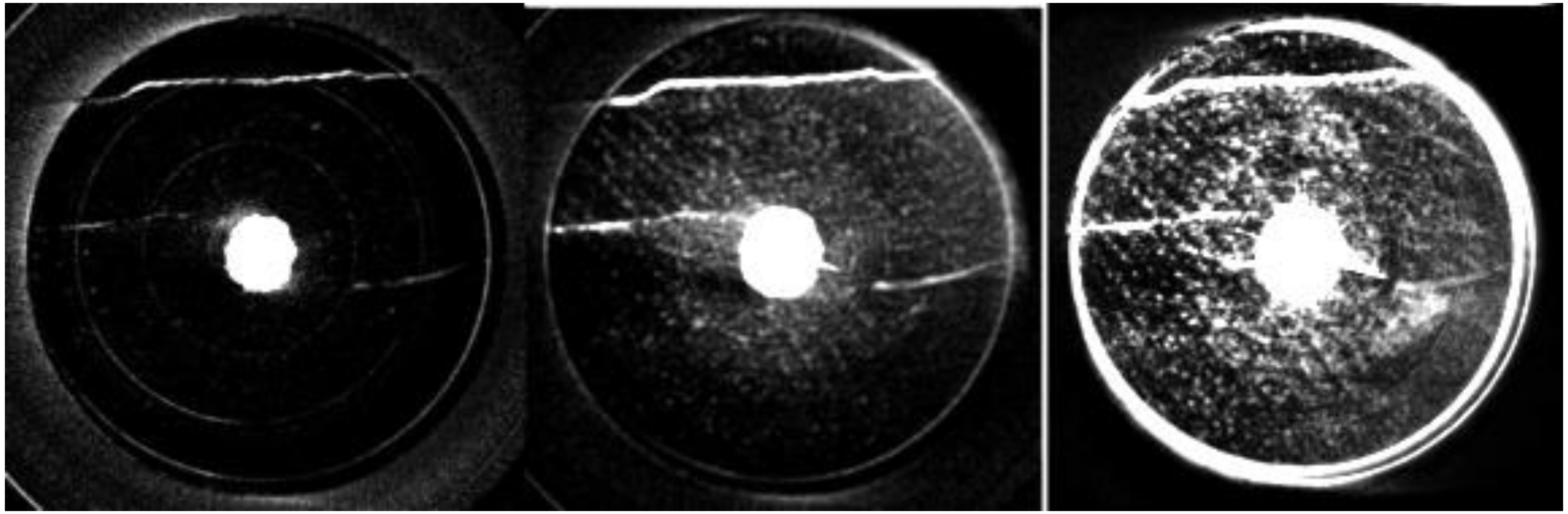
Fracture Reduction (1100 to 2600 PSI) | Fracture Reduction (1100 to 5000 PSI)



Bottom: Xe minus N_2 images at same P_{eff}

- **Initially, no real change from N_2 scans**
- **Once P_{eff} = 1100 psi significant Xe in the matrix was observed, but not uniformly**

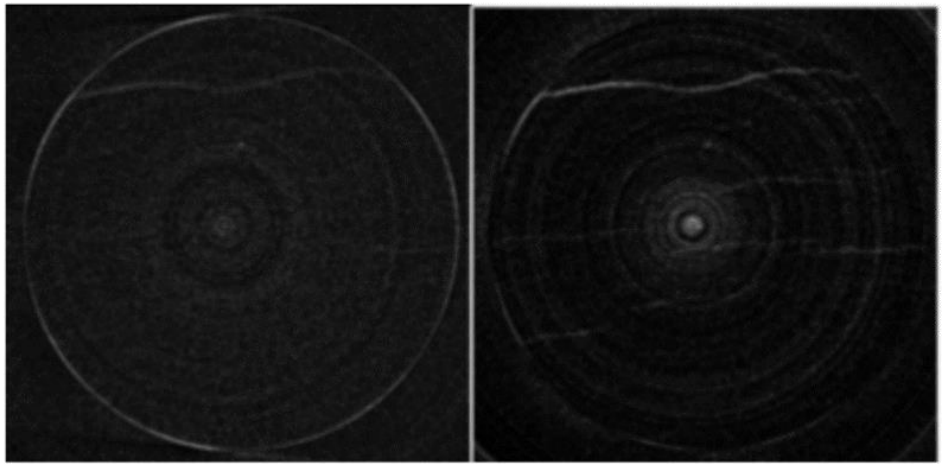
Xenon Infiltration At 4600 PSI Effective | Xenon Infiltration At 2600 PSI Effective | Xenon Infiltration At 1100 PSI Effective



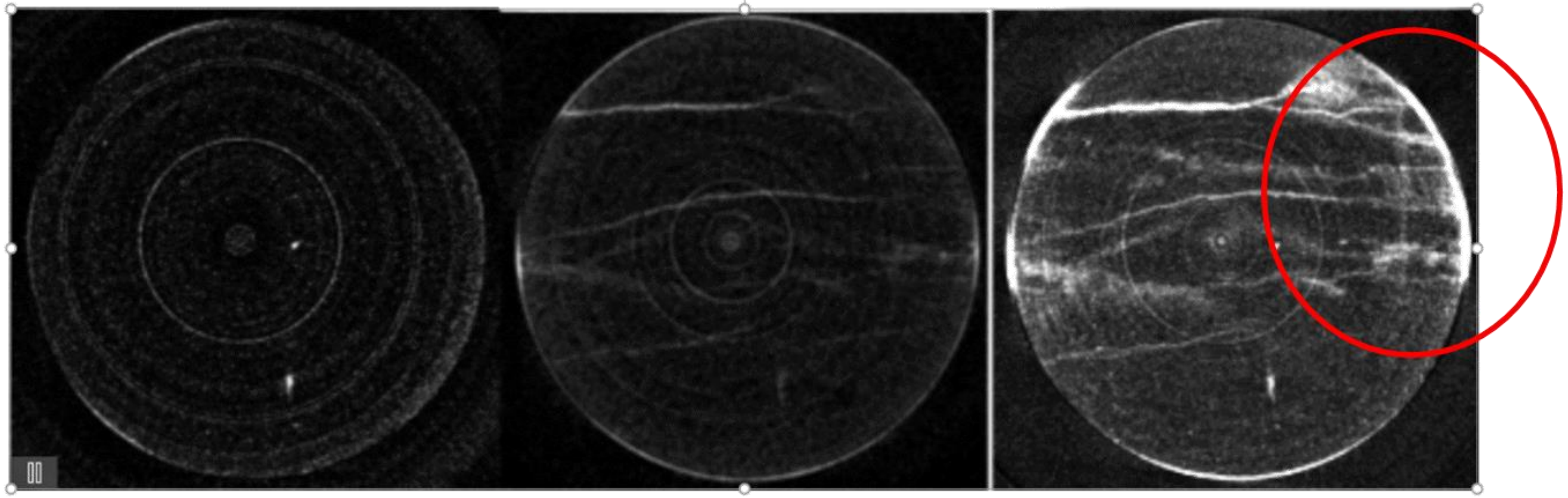
Fracture Network Analysis

- **The non-uniform behavior of the fracture network in response to stress is not surprising**
- **The *very* localized flow into portions of the matrix is surprising**
- Need to further examine what is different about these zones
  - Damaged below resolution of scans?
  - Different mineralogy?

Fracture Reduction (1100 to 2600 PSI) | Fracture Reduction (1100 to 5000 PSI)



Xenon Infiltration At 4600 PSI Effective | Xenon Infiltration At 2600 PSI Effective | Xenon Infiltration At 1100 PSI Effective



Fracture Network Analysis

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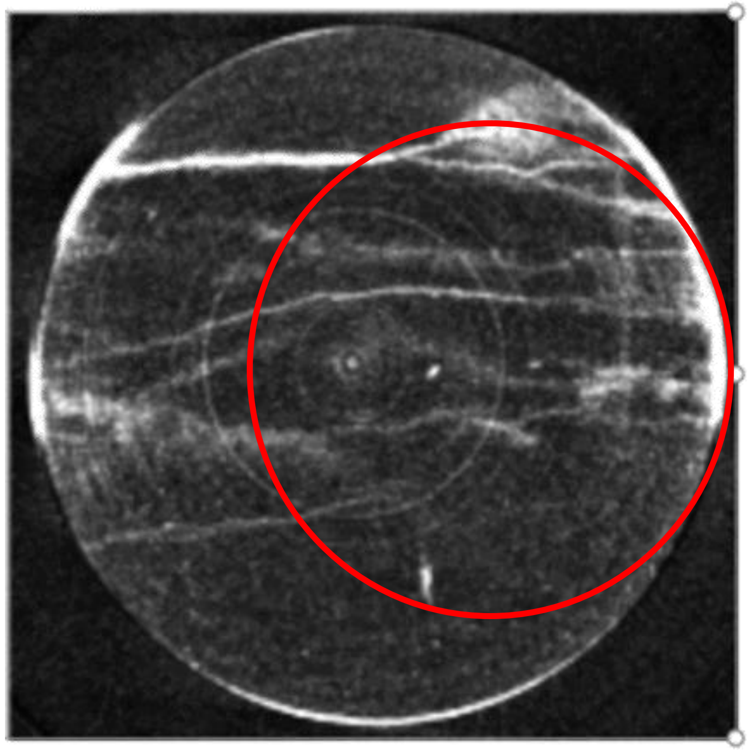
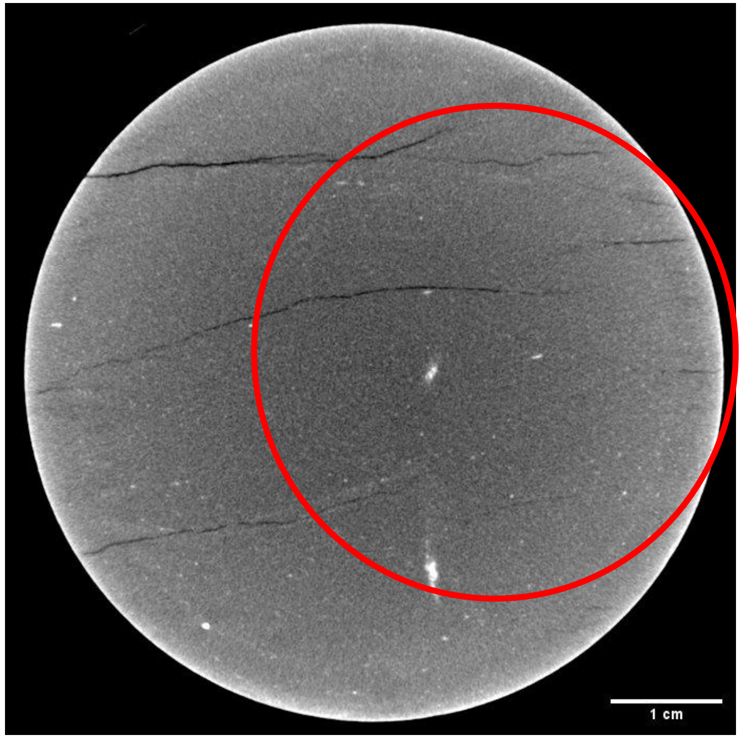
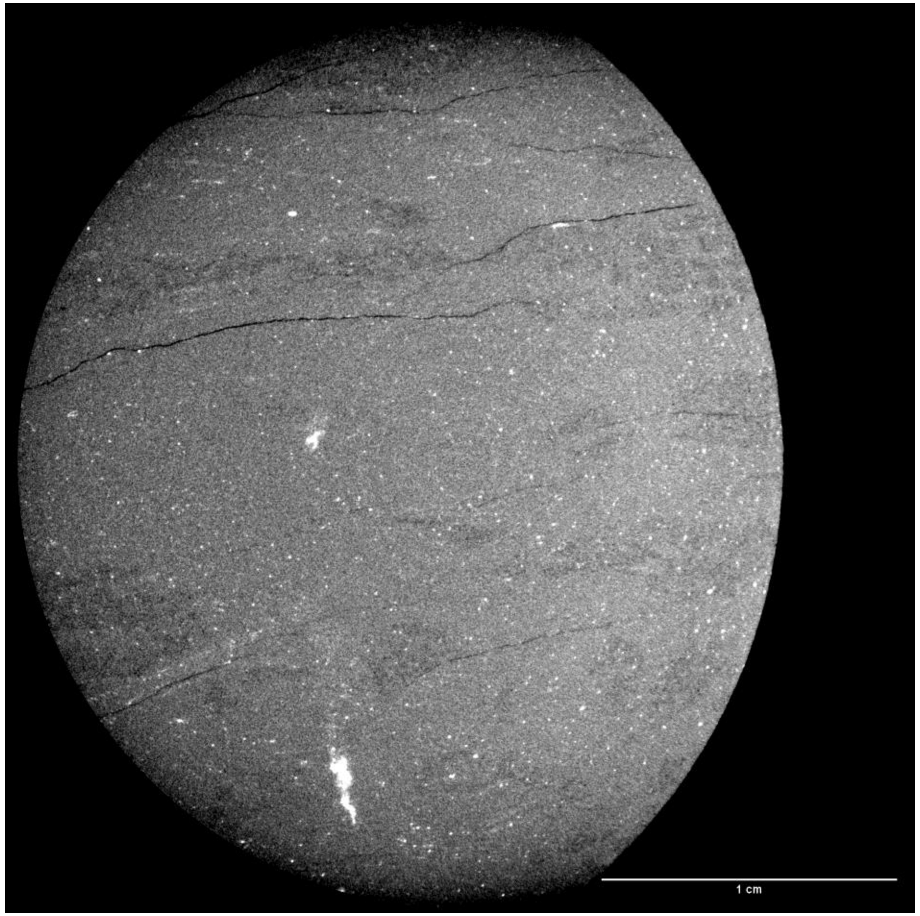
Xenon Infiltration
At 1100 PSI Effective



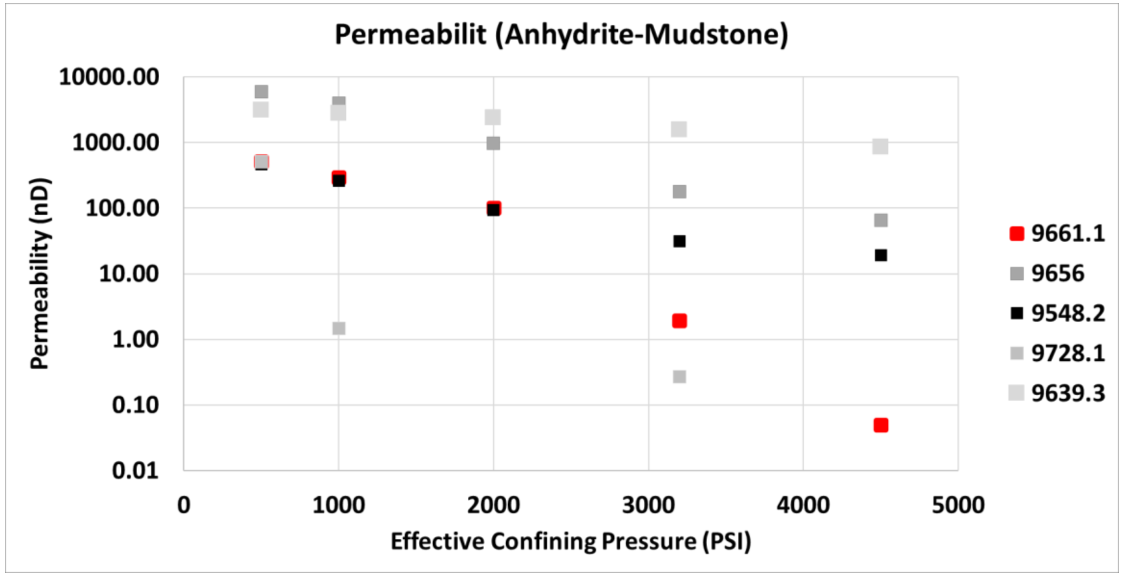
DynaTOM Whole Core plug

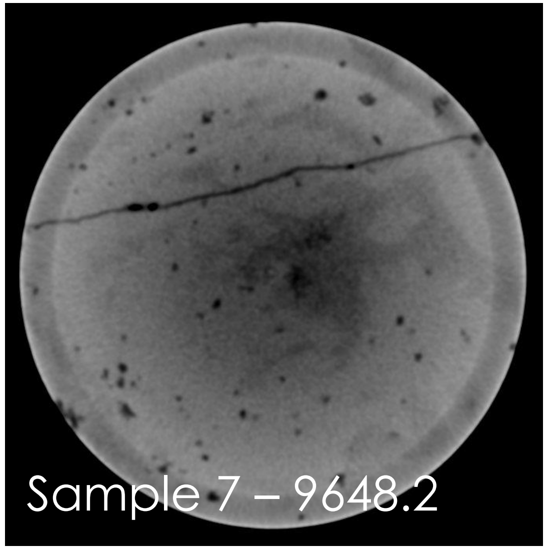


DynaTOM high resolution

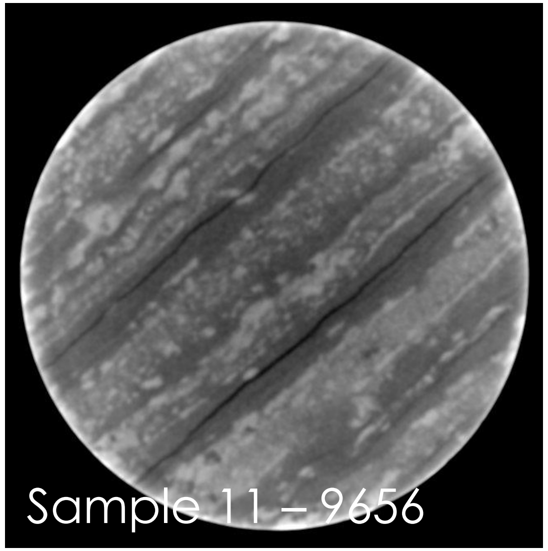


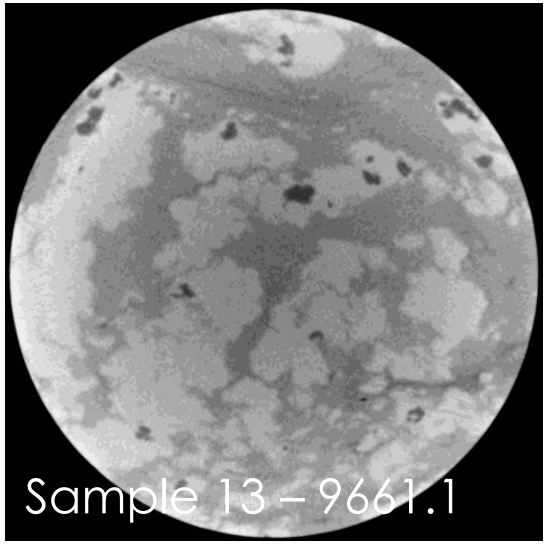
What Might this Mean in Anhydrite Dolomudstone?





- **Samples are heterogeneous in their distribution of mudstone and continuity of dolomite/anhydrite.**
- **Samples with a linear decline appear to have pre-existing fractures and XRF results show less Mg, suggesting less dolomite.**





Conclusions:

- The 110 ft of core from the State 16-2 well was scanned in the CT scanner and the MSCL at 6 cm resolution. The high resolution XRF data was used to differentiate three lithofacies (Halite, Anhydrite-rich zone, Mudstone/sandy-siltstone).
- The sandy-siltstone/mudstone samples showed a rapid decline in permeability followed by a linear decrease; whereas the anhydrite-mudstone samples showed a linear decrease in permeability with increasing effective confining pressure.
- Samples 13 and 60 showed a more rapid drop off in permeability, which is likely due to permeability drivers in mudstone fractures rather than in the anhydrite/dolomite.
- Xenon flood shows fracture network is primarily focused within open fractures at high effective confining pressures, and the addition of prominent, non-uniform matrix diffusion of Xe at 1,100 psi effective pressure.
    - This is likely a combination of edge damage and mineralogical changes, future investigation of higher resolution images should help to resolve this.

Acknowledgments

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