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Quantitative analysis of nano-pore geomaterials and representative sampling for digital rock physics

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Motivation

- **Plenty of pores at sub-micron scale** (nano-pores) in shales and carbonate rocks have become increasingly important for emerging problems such as unconventional gas and oil resources, enhanced oil recovery, and geologic storage of CO_2
- **Advances in analytical capabilities** with X-ray, electron, and ion beams offer emerging tools for characterizing pore structures, mineralogy, and reactions at the sub-micron scale
- **Multiscale imaging capabilities** – integration of experimental and numerical tools to probe the structure and properties of materials across scales (e.g., core to nanometer scale) are rapidly advanced
- **Digital rock physics** – data interrogation about how to take nanometer scale information and apply it to the thin-section or larger scale for accurate prediction of coupled geophysical, mechanical, and chemical processes

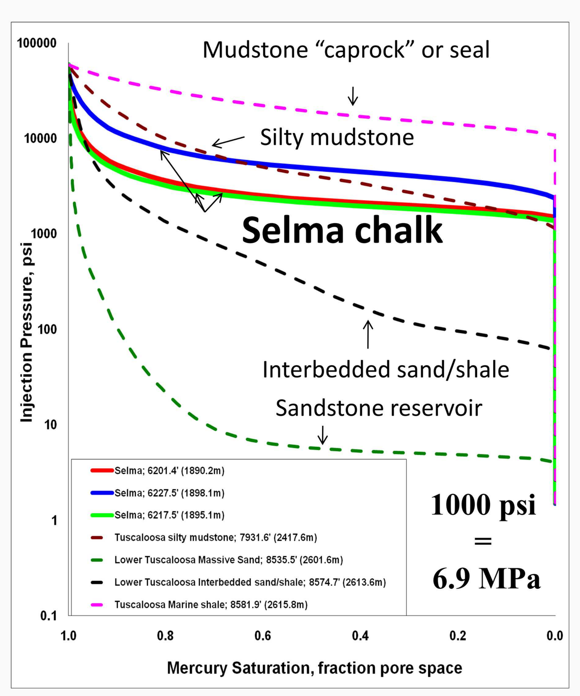
Objectives

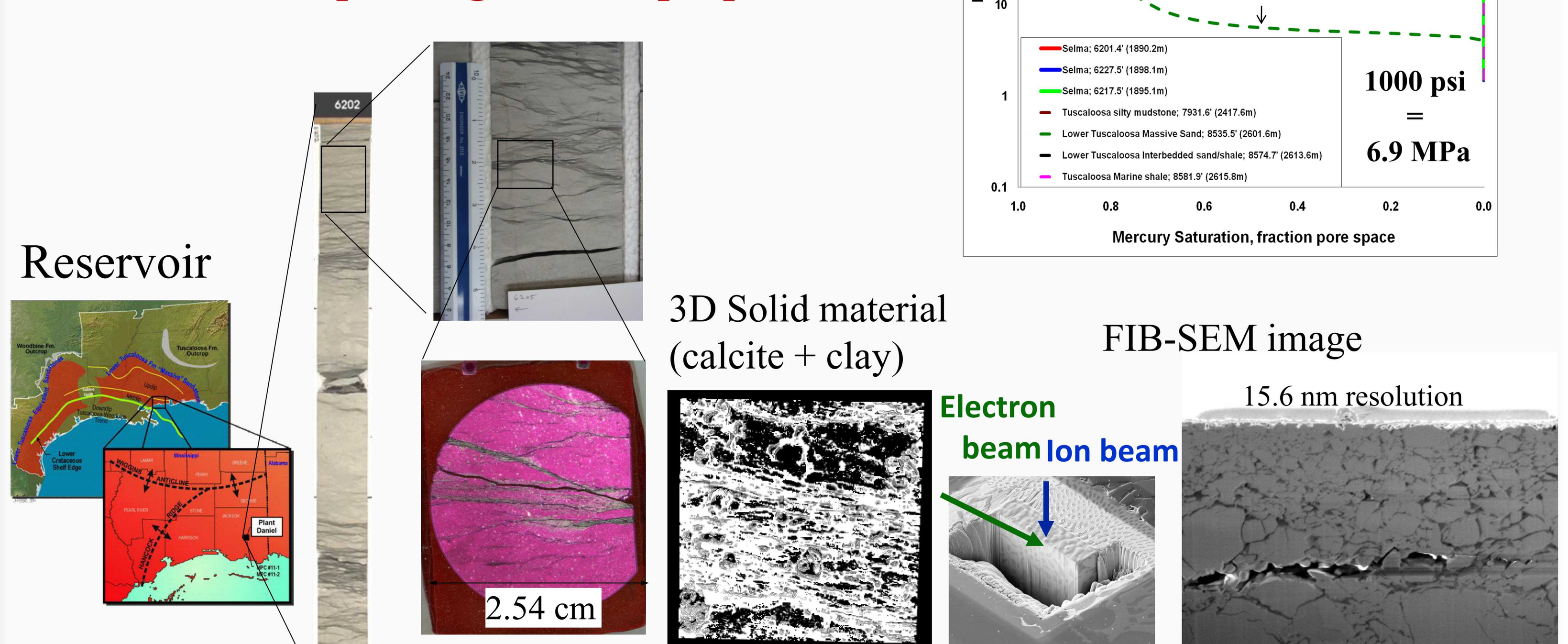
- Determine appropriate sample volumes for carbonate rock with focused ion beam-Scanning electron microscopy (FIB-SEM) analysis
- Develop a workflow for digital rock physics to upscale petrophysical and elastic properties for multiphase flow and reactive transport

Multiscale Imaging and Analysis

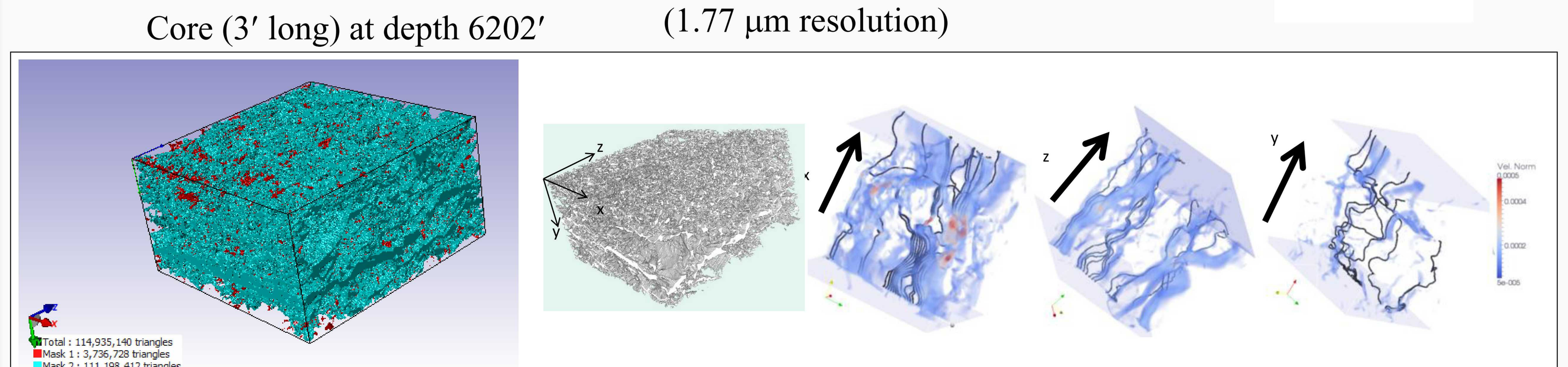
- Selma chalk: Secondary "seal" for NETL's SEACARB Phase II Plant Daniel site for CO_2 injection into Lower Tuscaloosa
- Of interest as "leaky caprock" to mitigate injection pressure hazard

Reservoir rock samples at the resolution needed to compute digital rock properties





Core (3′ long) at depth 6202′ — Thin section — 1821 microns (1.77 µm resolution)

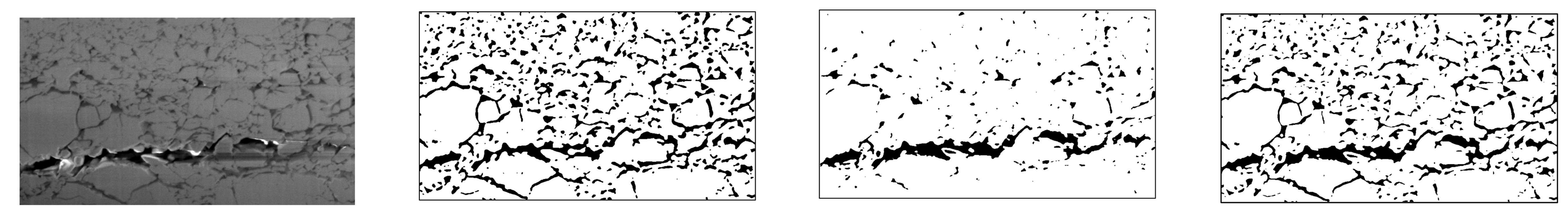


Reconstructed 3D pore network showing connected and unconnected porosity (left) and binary image (right)

Pore scale modeling with lattice Boltzmann model and directional flow showing strong anisotropy

Image Analysis and Multiscale Sampling

- Image segmentation



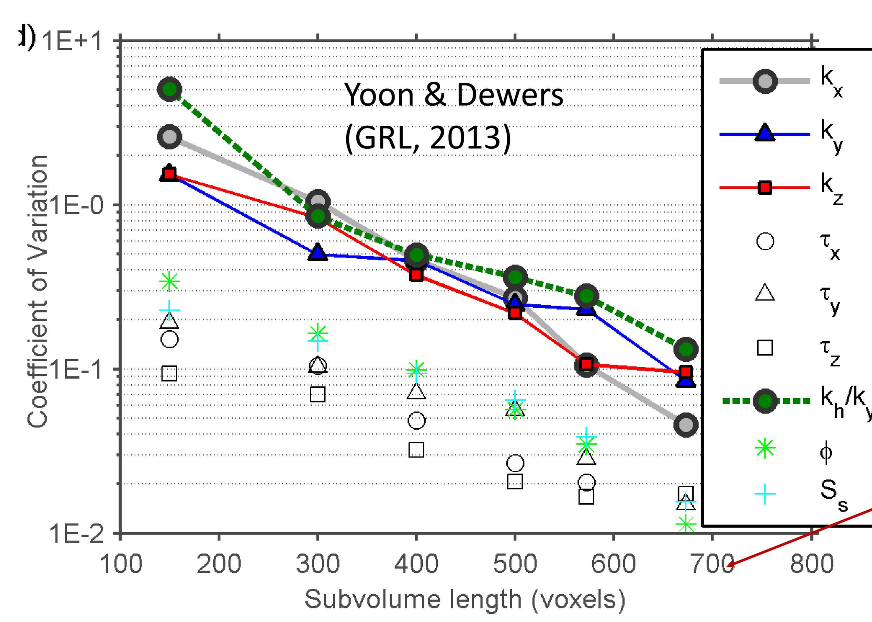
Raw image:
- Uneven background
- Uneven illumination & horizontal scan lines
- Charging effect (bright white spots)

Small pores captured
- Background correction
- FFT bandpass filter
- Median filter
- Thresholding

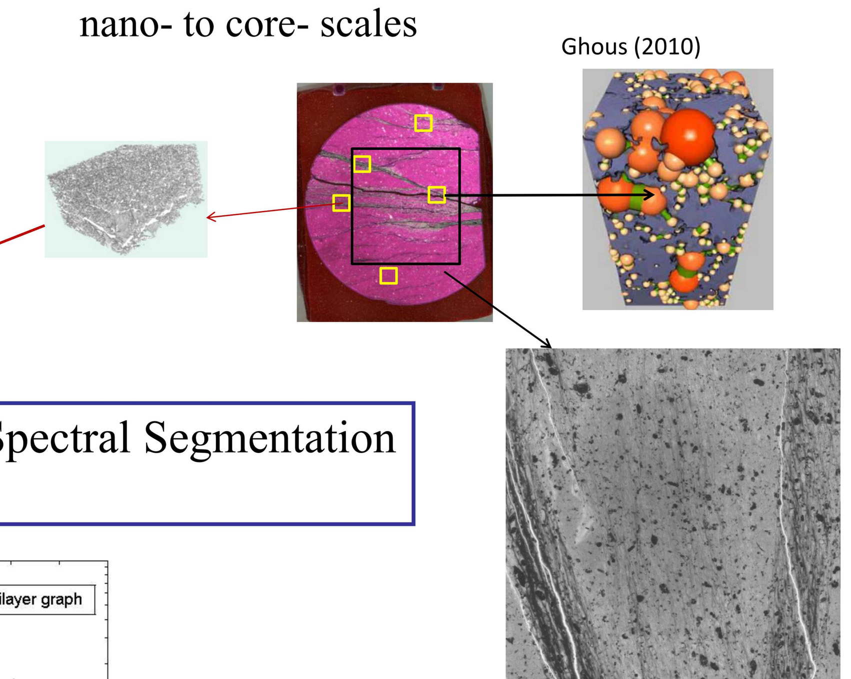
Large fractures captured
- Background correction
- Median filter
- Higher threshold value

Connectivity recovered
- Combine two binary images
- Dilate & Erode (twice)

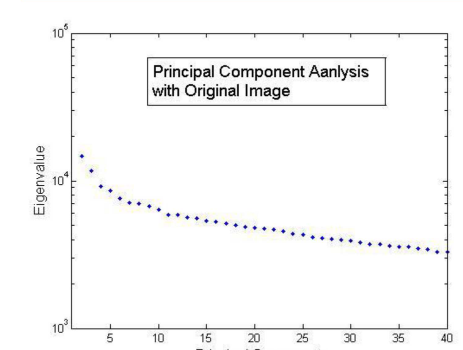
- Reconstruct 3-D pore structures and multi-scale pore networks



- FIB-SEM sample volume has a size of statistical elementary volume at ~ 10 µm
- 4-6 representative sampling
- Reconstruction of multi-scale rocks from nano- to core- scales



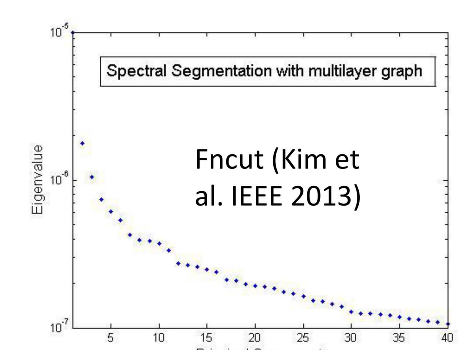
- Principal Component Analysis



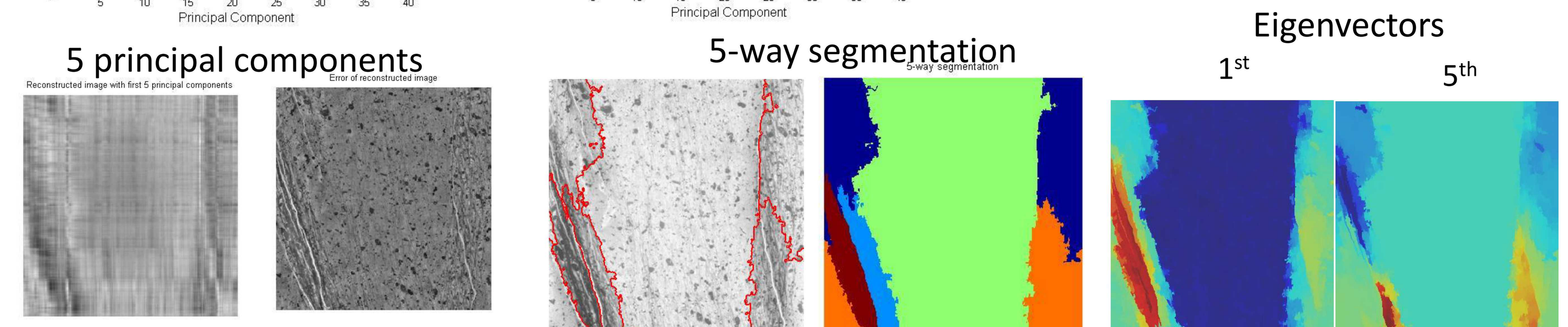
5 principal components

L₂ norm error = 2.44 %

- Graph-based Spectral Segmentation Algorithms



5-way segmentation



Eigenvectors 1st 5th

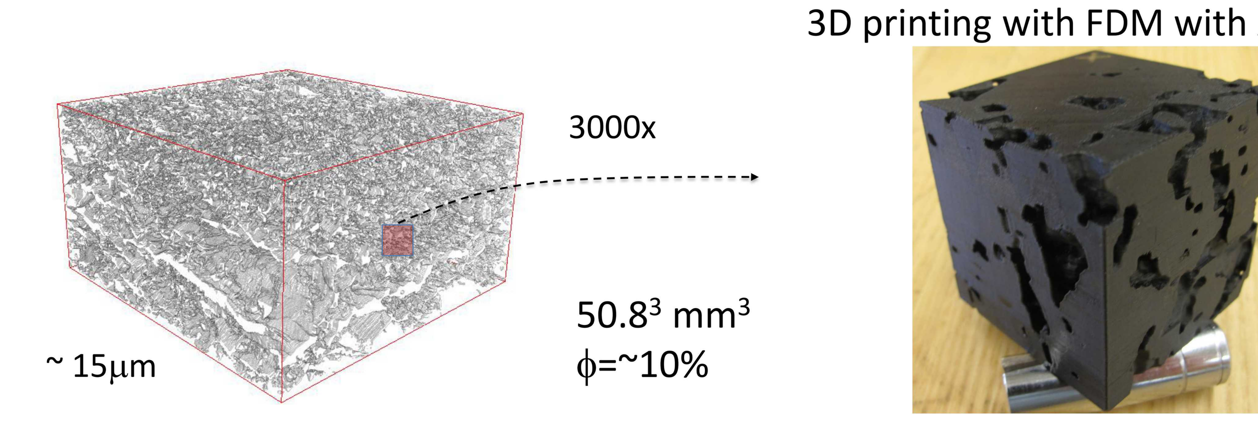
- With the Fncut algorithm, the thin section image can be segmented into primary clustering representing main features
- Microfracture can be treated as inclusion of local heterogeneity in addition to main clusterings
- Based on this analysis, 4-7 spots can be selected to account for nanopore structures which can not be resolved at the thin section scale
- Primary spots can be selected to represent one microfracture network and one around the microfracture, one from central region, and the last one from secondary microfracture networks
- Support vector machine (SVM) will be used for texture classification in the following analysis

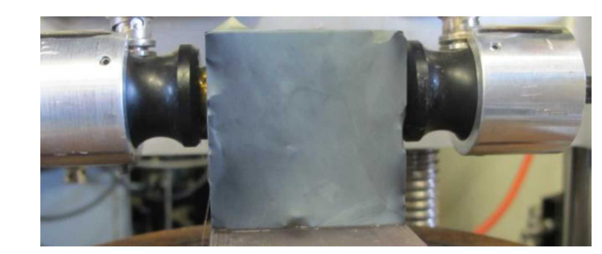
Workflow for Digital Rock Physics

Rock Sample → Multiscale image → Image Process → Flow and Transport Properties → Static Effective Elastic Properties → Wave Propagation

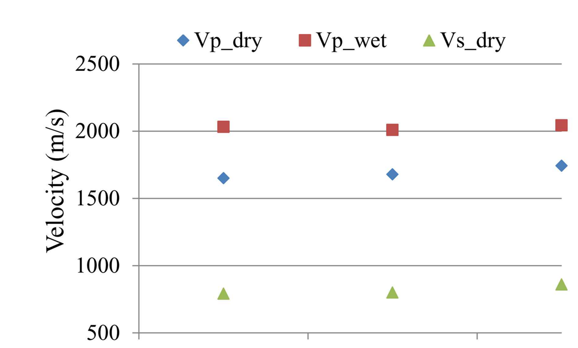
- 3D printing for flow and acoustic measurements

3D printing with FDM with ABS





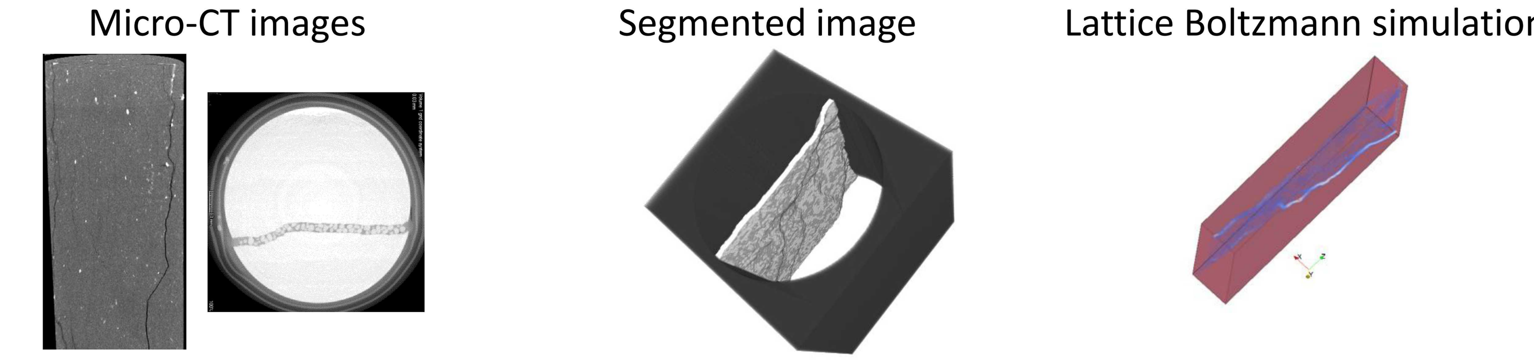
Acoustic emission testing



- Applicability of different printing materials for mechanical, acoustic, and multiphase flow will be tested
- Proof of concepts such as multisclae pore reconstruction will be tested with 3D printed materials
- Reproducibilty of printed materials will be tested at different printing resolutions

- Hydraulic fracturing test

Flow of "frac" fluid in proppant-containing fracture



- Elastic properties will be estimated using digital rock physical method (e.g., Knackstedt et al., 2009)
- Undrained, drained, partially drained conditions will be tested with a set of representative pore structures synthesized by 3D printing
- Surface properties of 3D printed materials will be altered to accommodate different wetting properties

References

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- Knackstedt, M.A., S. Latham, M. Madadi, A. Sheppard, T. Varslot, 2009, Digital rock physics: 3D imaging of core materials and correlations to acoustic and flow properties

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