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Multiscale Imaging of Carbonate Rocks and Representative Sampling for Digital Rock Physics

Hongkyu Yoon[1](hyoon@sandia.gov), Thomas Dewers[1]

[1] Geomechanics Department, Sandia National Laboratories, Albuquerque, NM

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

- To characterize multiscale physical and chemical heterogeneity of nano-porous geomaterials for enhancing quantitative understanding of flow and poromechanical responses in nano-porous geomaterials
- To develop a workflow for digital rock physics to upscale petrophysical and elastic properties for multiphase flow and reactive transport

Multiscale Imaging and Analysis

- Characterization of pore structures, compositional distribution, and surface properties using multiscale imaging techniques (optical and confocal microscopy, x-ray microprobe, QEMSCAN, microCT, FIB-SEM, BIB-SEM, TEM, EDS)
- Small and ultra-small angle neutron scattering (SANS and USANS) analysis for multiscale heterogeneous pore structures and their impact on chemo-mechanical coupling for (shale and) carbonate rocks from the nanometer to the millimeter scale.

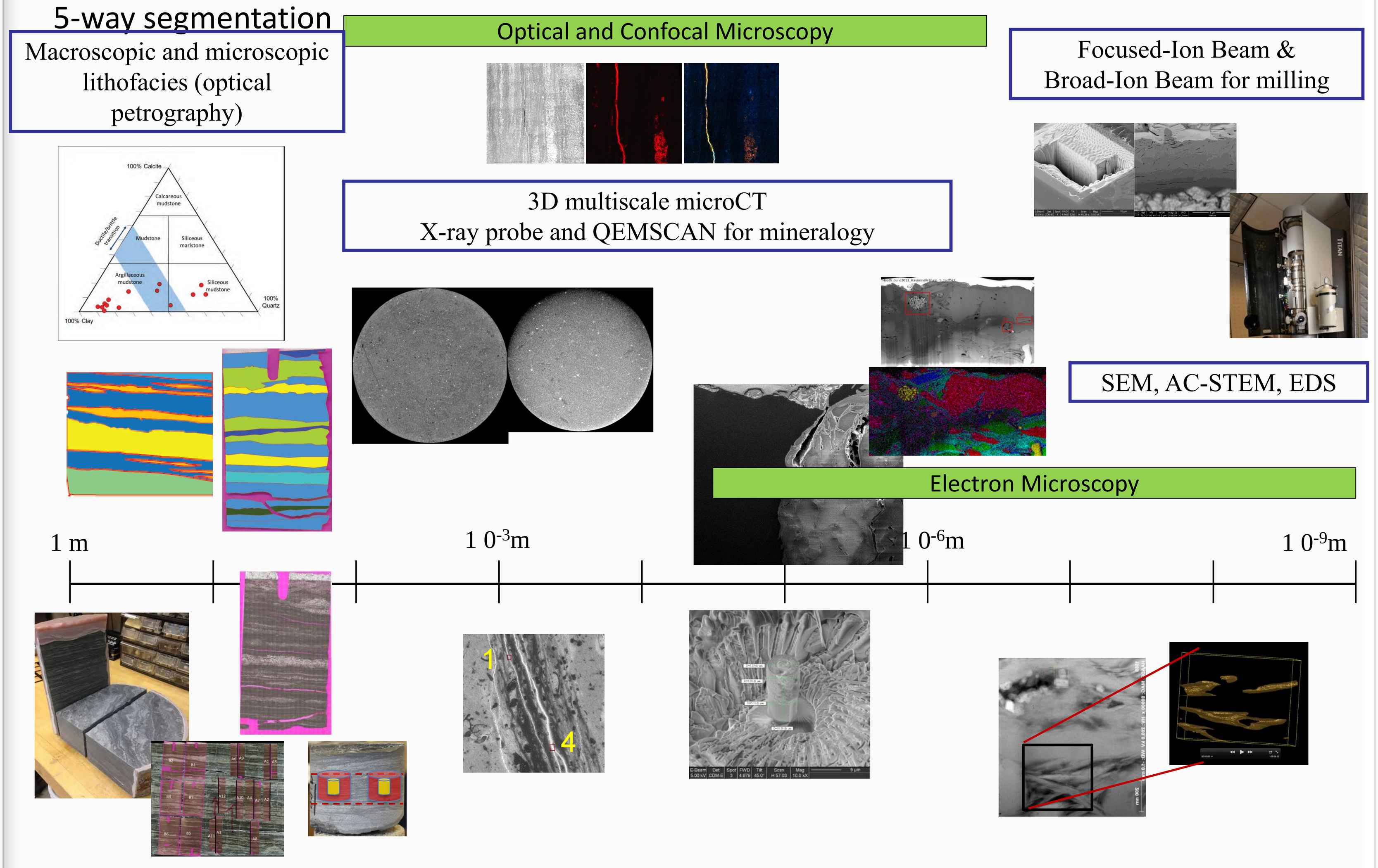
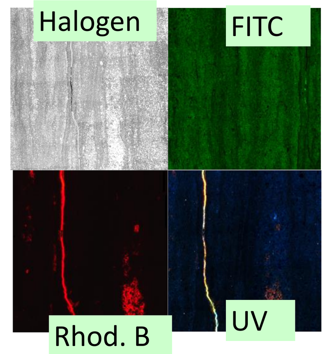


Image Analysis and Multiscale Sampling

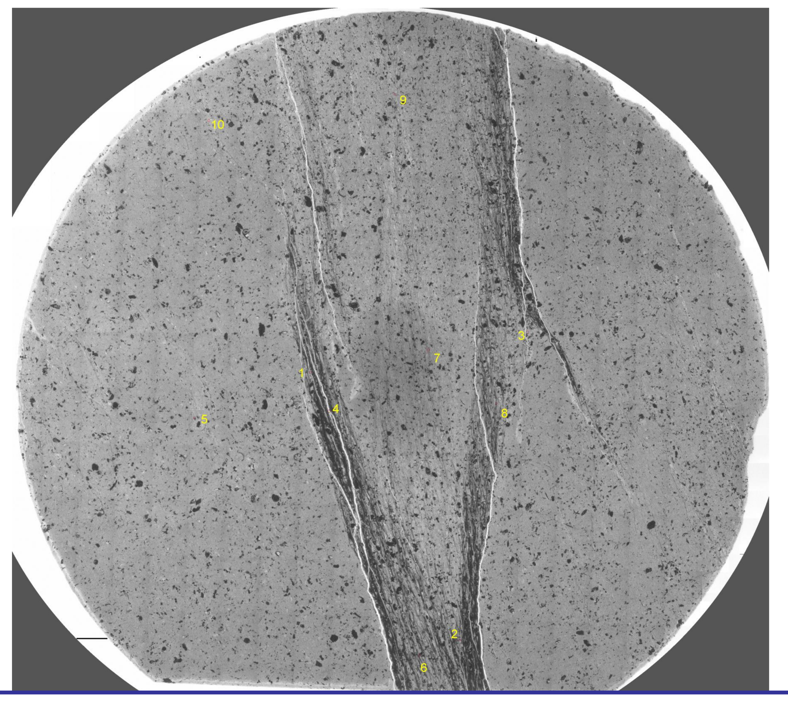
Micromapping of lithofacies with fluorescent/laser microscopy:
Standard thin sections with rhodamine-B dyed epoxy impregnation

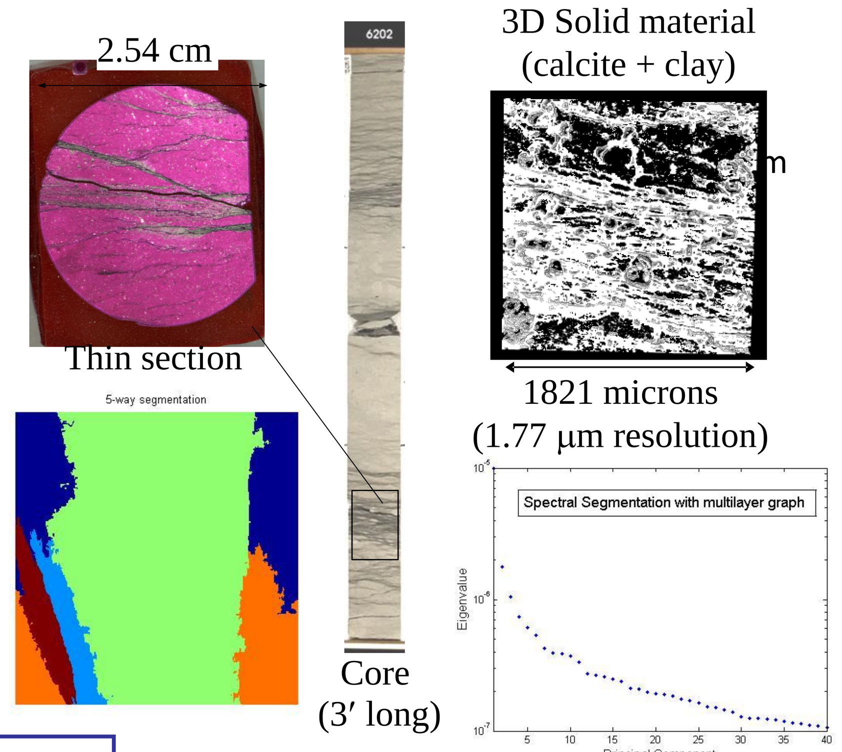
- Halogen illumination = "natural light"
- UV useful for oil and kerogen fluorescence
- "Rhodamine B" filter set excites fluorochrome in epoxy and thus useful for sub-micron connected pore detection
- "FITC" filter set mainly used to detect fluorescein dye tracers but can discern epoxy & some organics



- Fluorescence Mapping and Graph Based Multiscale Spectral Segmentation

- Fluorescence detection of fluorochromes impregnated in nanopores
- Spectral segmentation algorithm "FN-CUT" [Kim et al. 2013]
- Used as a basis for FIB/SEM sampling
- Fast route to upscaling?
- Example: Selma chalk as the secondary "seal" for CO_2 injection into Lower Tuscaloosa (NETL's SEACARB)

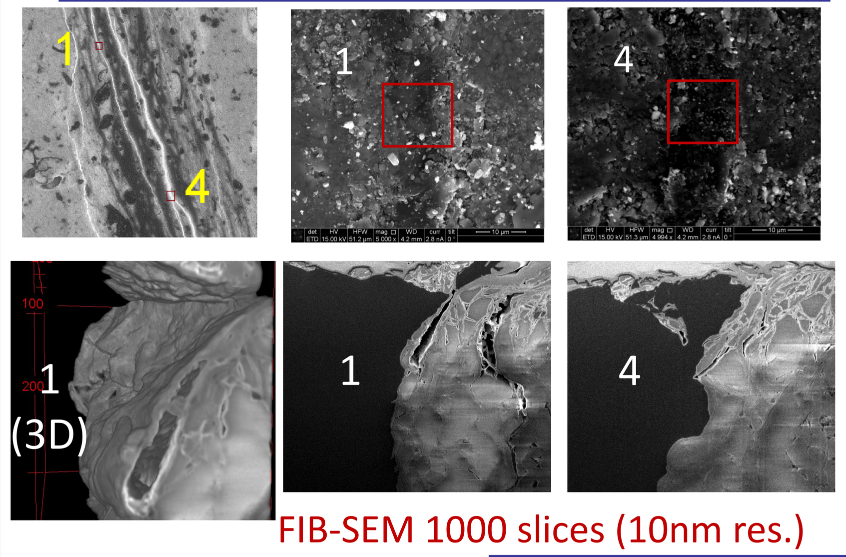




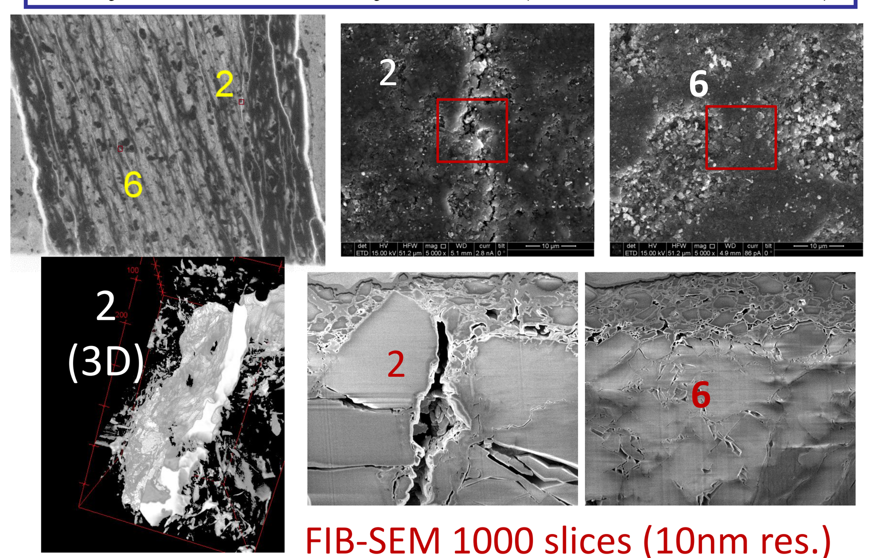
Rhodamine-B scan of thin section & FIB-SEM Locations

- Representative microfacies based on FIB-SEM analysis

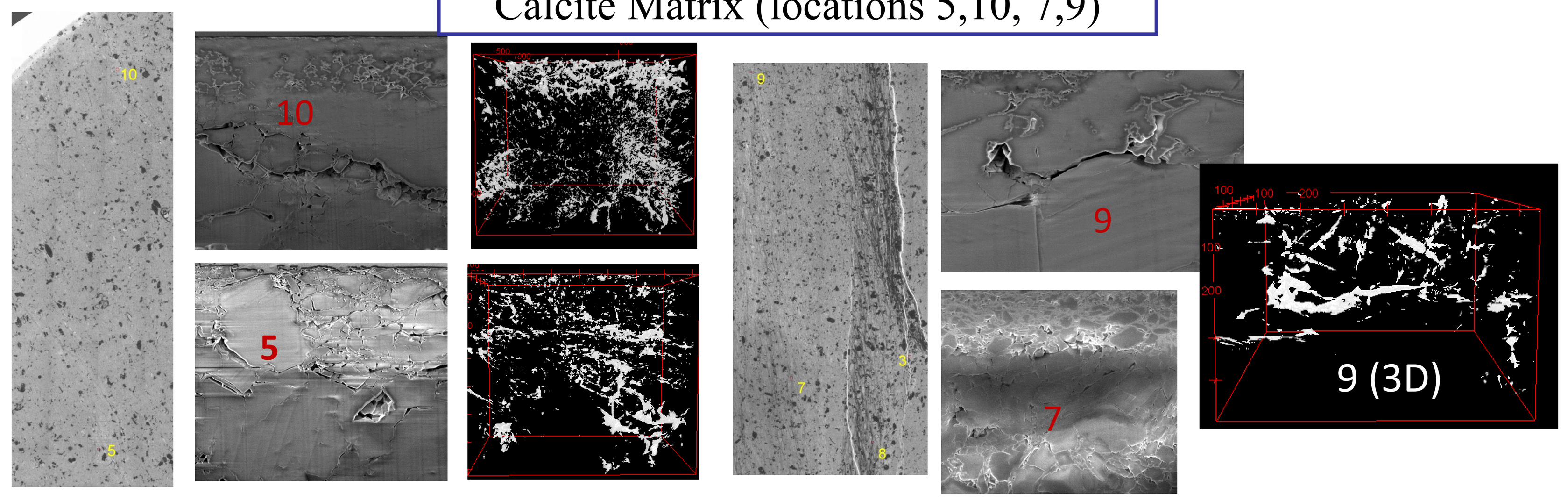
Micro-fractured pores (locations 1,3, 4)



Clay Seam and Stylolitic (locations 2, 6, 8)



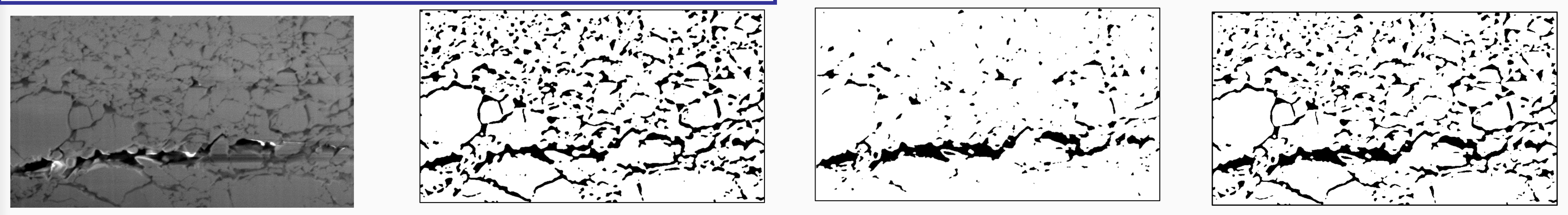
Calcite Matrix (locations 5,10, 7,9)



Workflow for Digital Rock Physics

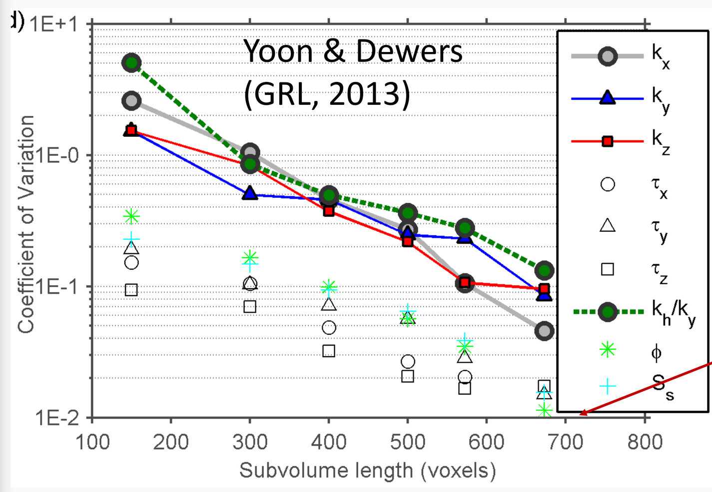
Rock Sample → Multiscale image → Image Process → Flow and Transport Properties → Static Effective Elastic Properties → Wave Propagation

- Image registration and segmentation

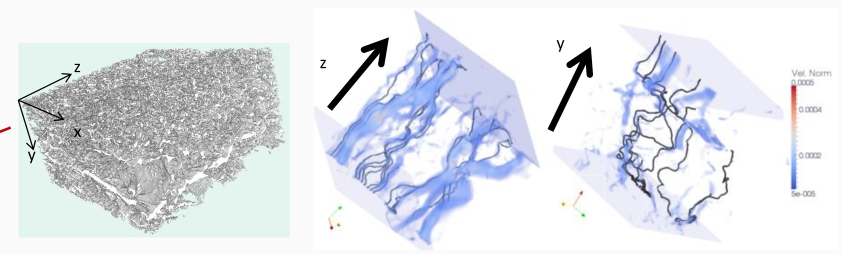


Raw image:	Small pores captured	Large fractures captured	Connectivity recovered
Uneven background; Uneven illumination & horizontal scan lines; Charging effect	Background correction; FFT bandpass filter; Median filter; Thresholding	Background correction; Median filter; Higher threshold value	Combine two binary images; Dilate & Erode (twice)

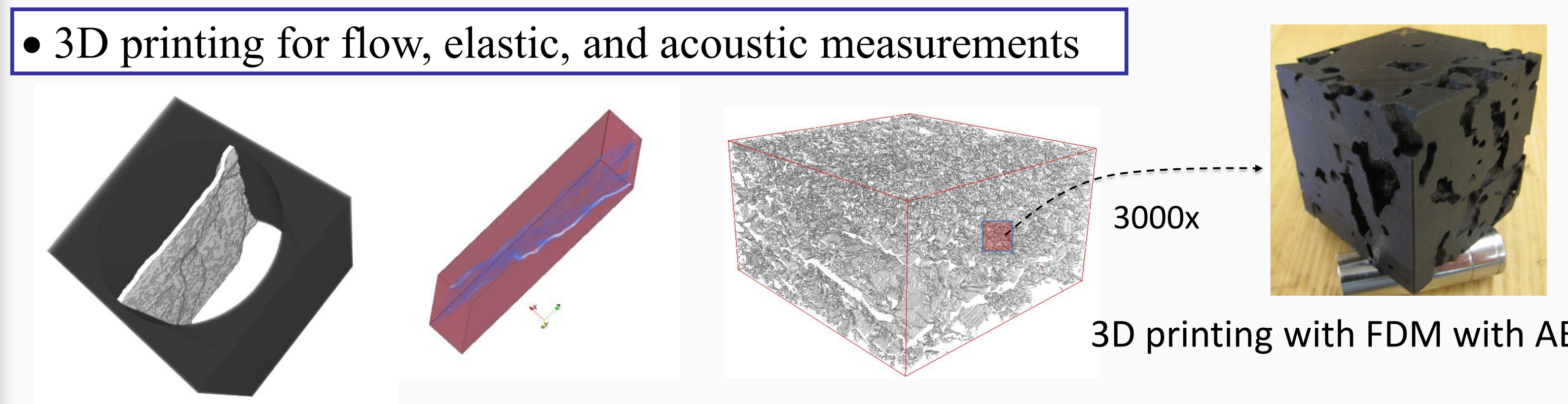
- Reconstructed 3-D pore structures and pore scale modeling



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



- 3D printing for flow, elastic, and acoustic measurements



- Applicability of different printing materials for mechanical, acoustic, and multiphase flow
- Proof of concepts such as multisclae pore reconstruction with 3D printed materials
- Reproducibilty of printed materials will be tested at different printing resolutions
- Estimation of elastic properties using digital rock physical method (e.g., Knackstedt et al., 2009)

Summary & Future Works

- Multisclae image processing to identify primary clustering representing main features
- 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 for stochastic digital rock reconstruction
- An integrated multiscale imaging techniques coupled with neutron scattering methods will be used to seamlessly characterize 3-D structural and mineralogical heterogeneity of nano-porous geomaterial

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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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