# Multiscale characteristics of mechanical and compositional properties in Mancos shale

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NNSA National Nuclear Security Administration

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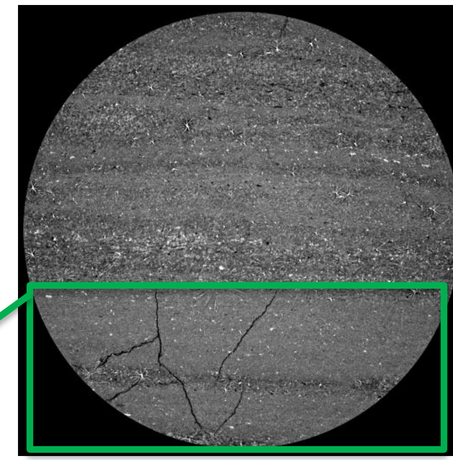
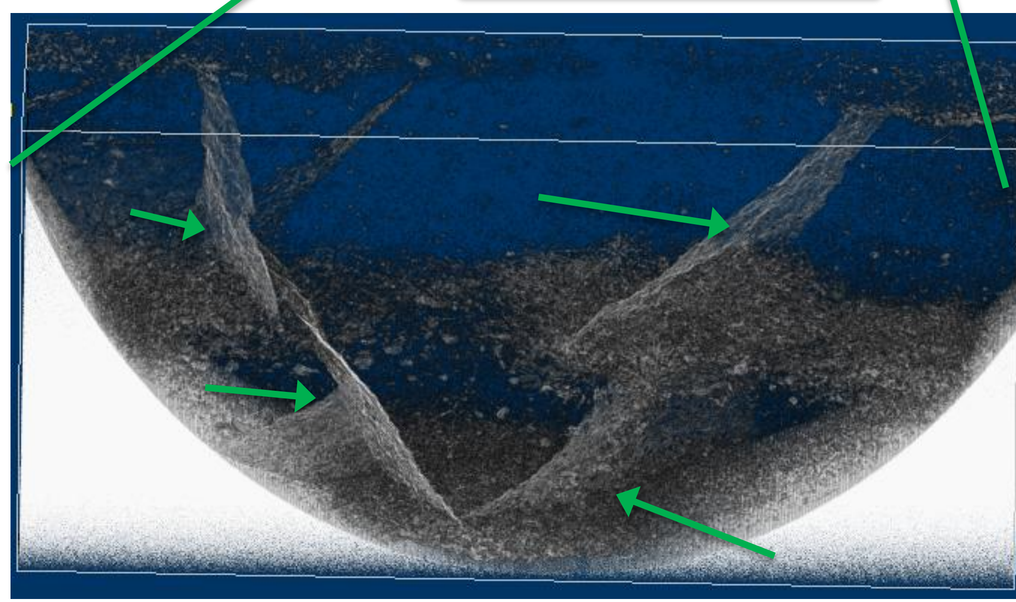
# Shale Poromechanics: Multiscale Heterogeneity in Compositions, Pore structure, and Mechanical Properties

► Understand how heterogeneity, pores, cracks, flaws etc. contribute to shale poromechanics over scales and provide physical basis for core-scale measured deformational and transport constitutive behavior

► Develop novel and cutting edge techniques and workflow for a linked imaging, experimental, and modeling-based advancement of shale poromechanics

MicroCT Image of 1" core Mancos shale (17 microns resolution)

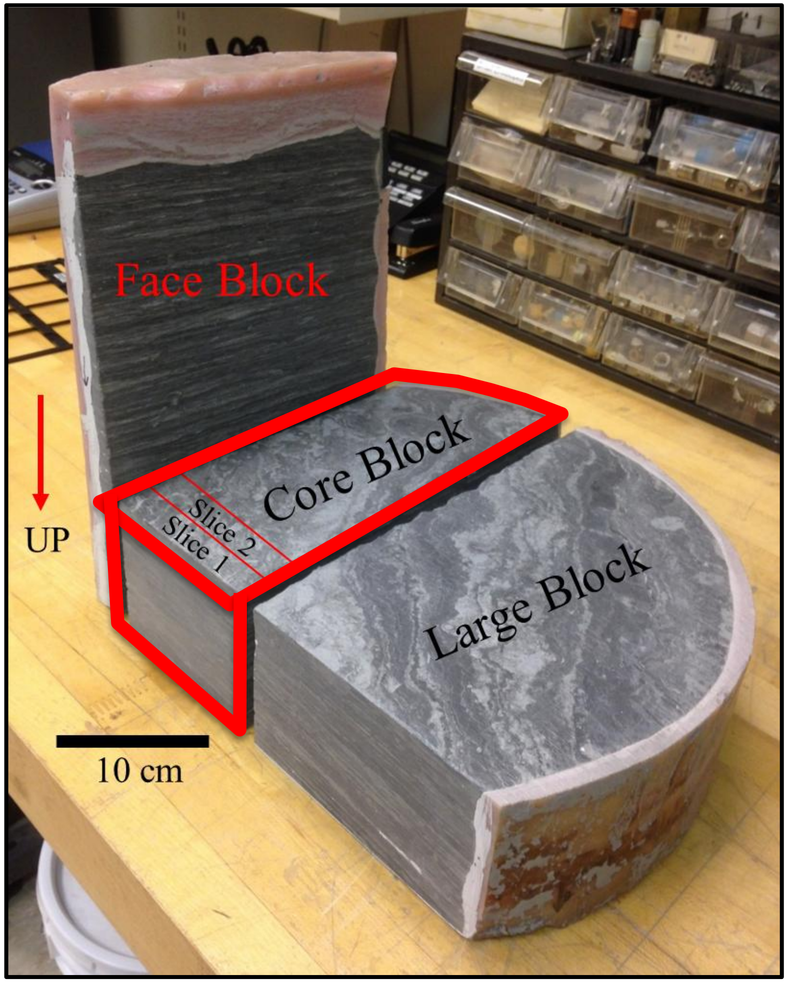




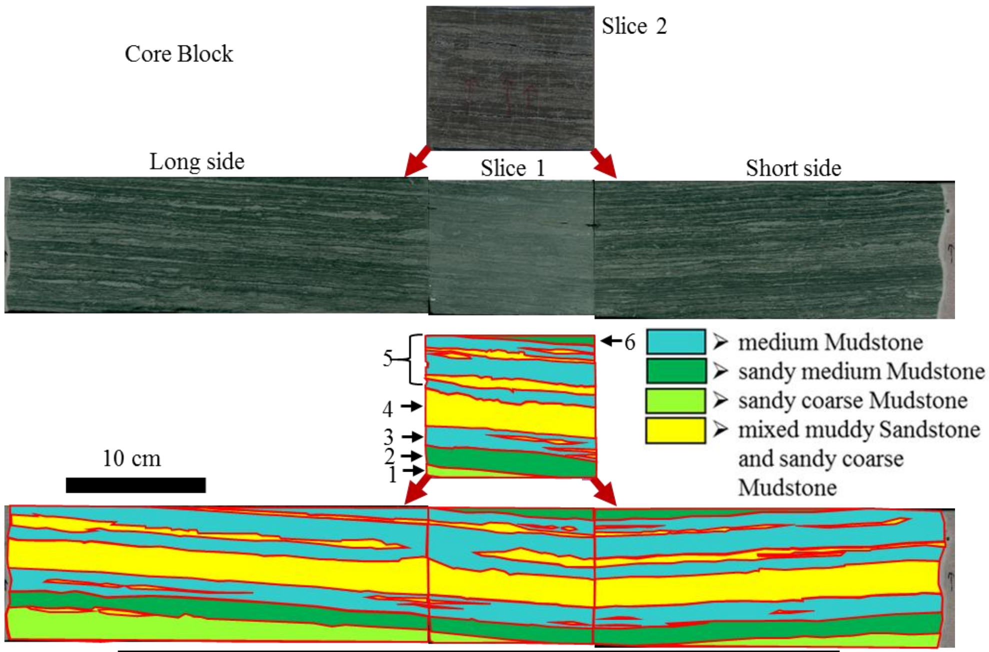
Courtesy: *N. Chakraborty on PSU's GEv|tome|x L300 multi-scale nano/ microCT system at the Center for Quantitative Imaging*

# Multiscale Approach

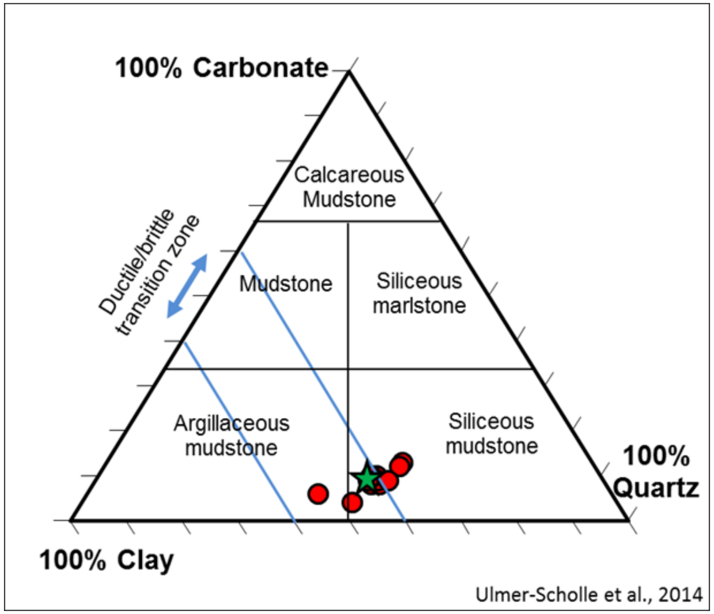
- 40 cm diameter core of Mancos Shale
- Mineralogical and textural characterization
  - – Macroscopic
  - – Optical petrography/microscopy
  - – Micro-CT
  - – FIB-SEM
  - – BSE, X-ray mapping
  - – MAPS Mineralogy
- Mechanical tests
  - – Uni-/Tri-axial compression (1x2”)
  - – Brazilian Test (1x0.5”)
  - – Nano-indentation
- Mechanical modeling



# Cretaceous Mancos Shale (Macro-lithofacies)




► Heterolithic facies [Grigg, MS thesis, 2016]
- Interlaminated fine mud, medium/coarse mud (Lazar et al., 2015), and very fine sand
- 1-3 mm laminae
- Parallel lamina, wavy lenticular lamina, ripple forms, and bioturbation

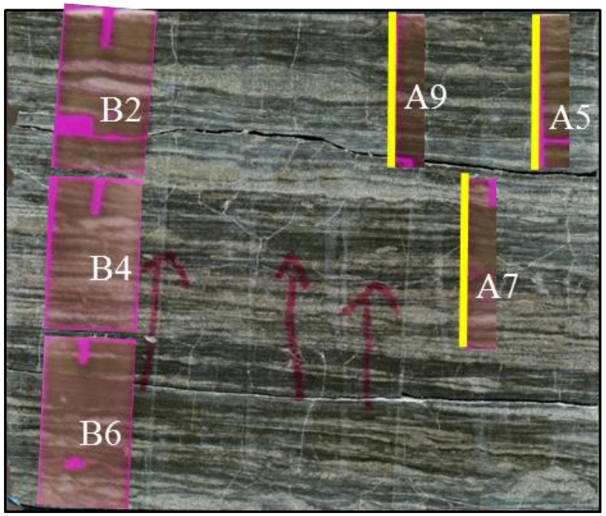


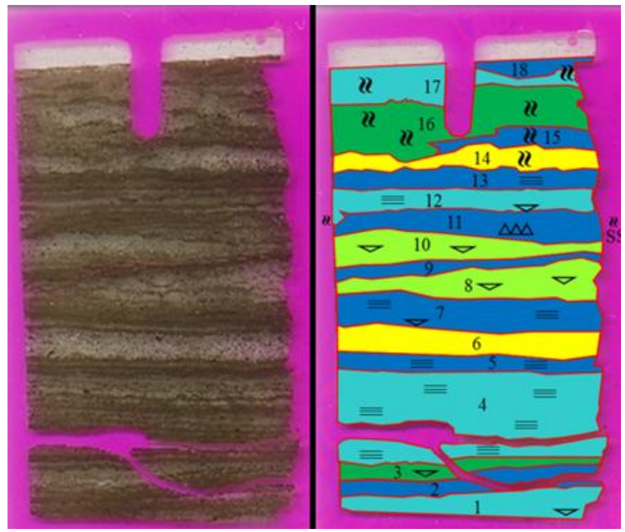

Macrolithofacies composition (XRD)

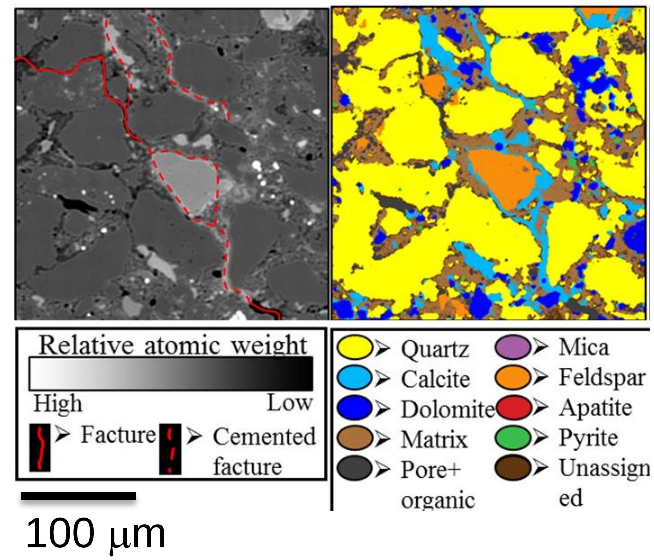
► Color-coded map of macro-lithofacies superimposed onto the scans of the Core Block as listed above

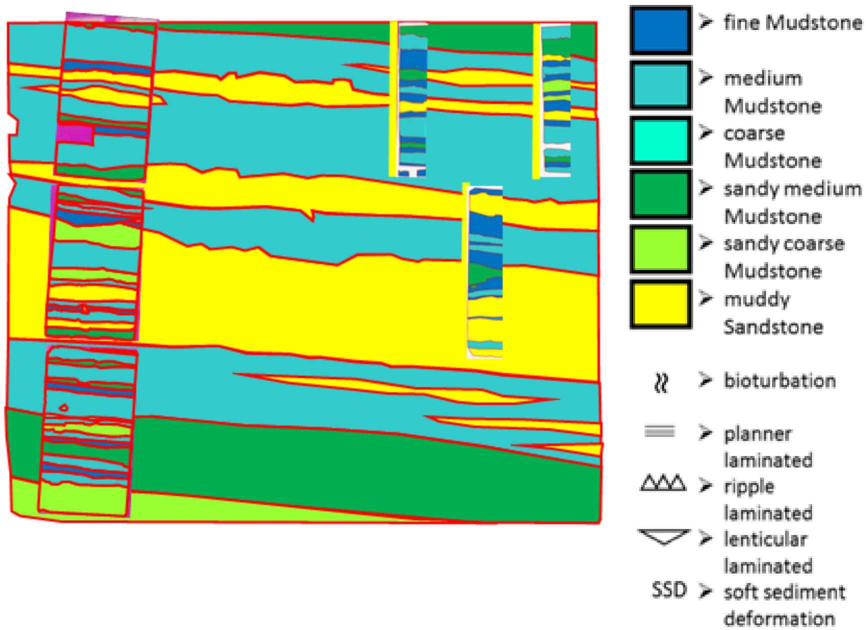
► Four macro-lithofacies are identified as above and numbered on the Slice 2 scan

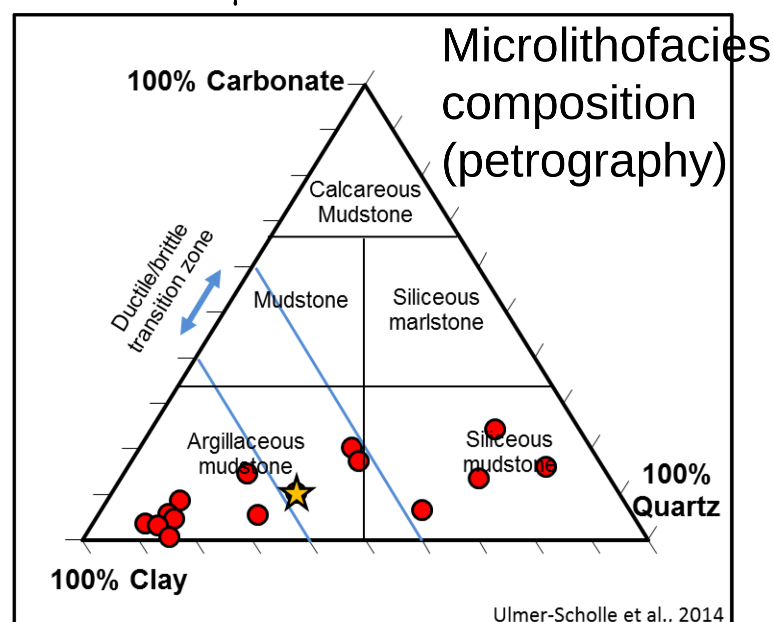
# "Micro-lithofacies" Interpretation: Optical Petrography



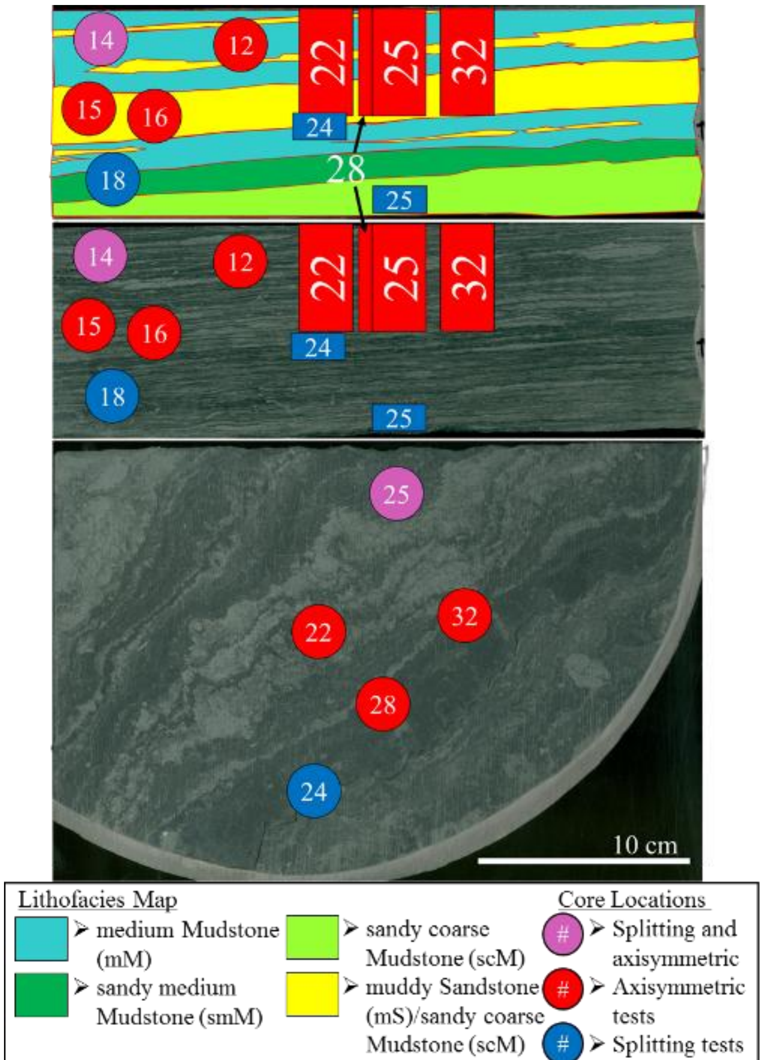



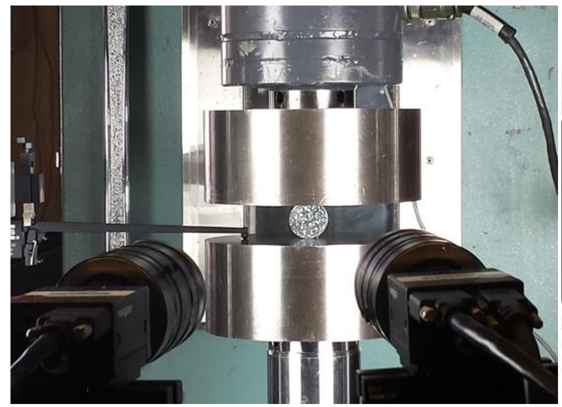



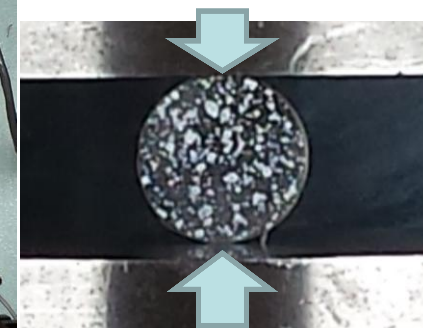



# Mechanical Testing: Brazil or Cylinder Splitting Tests with Phase Field Model




Indirect Tensile (Brazilian) Test

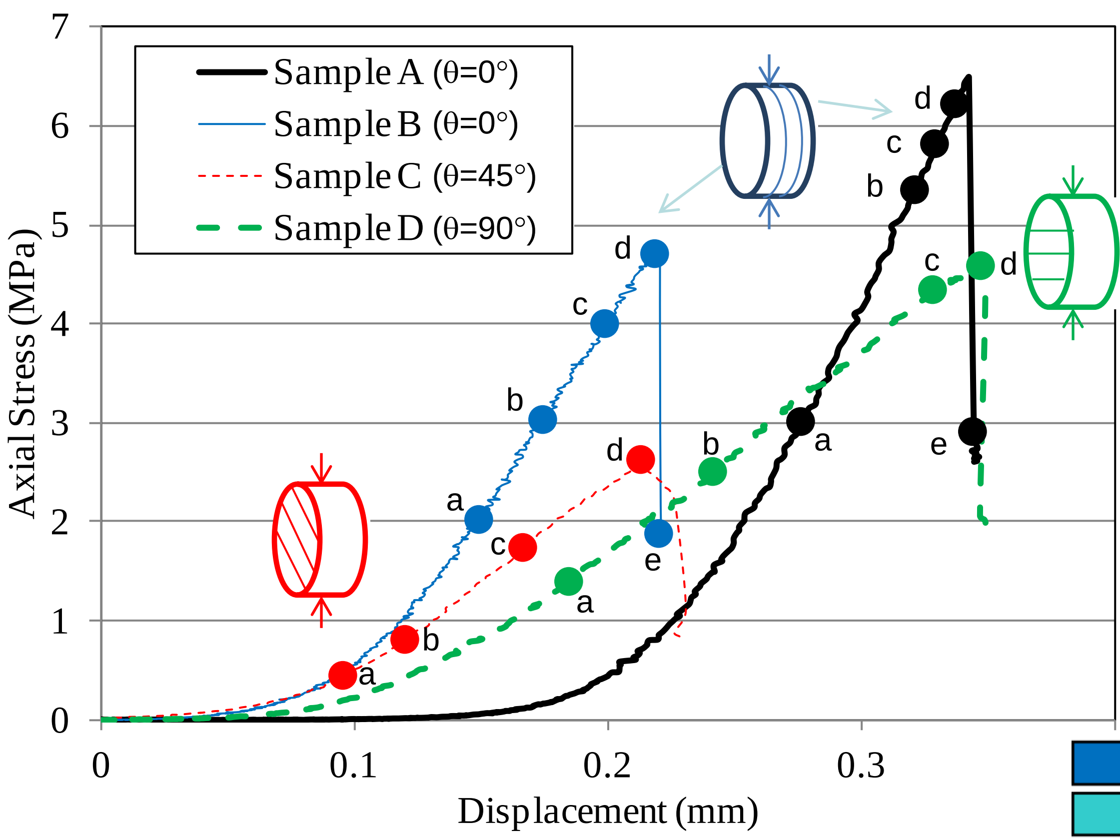


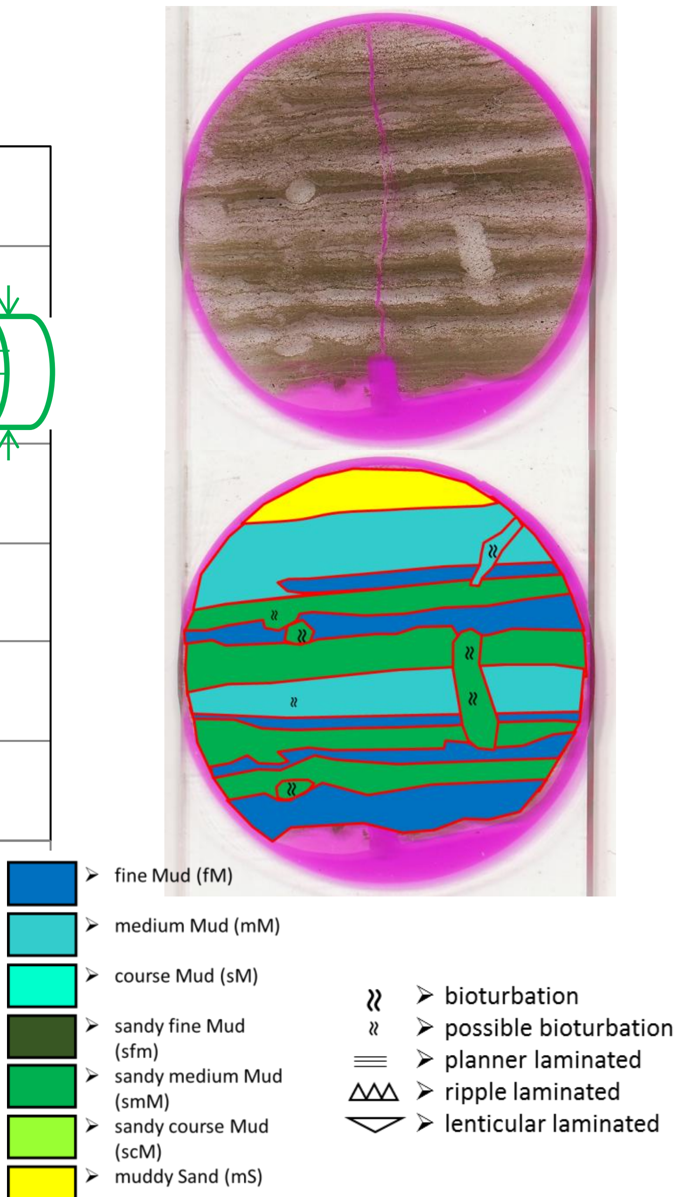


Paint markers: Digital Image Correlation to estimate 2D strain on the surface

Na et al. (2016, JGR under review)

# Indirect Tension Results



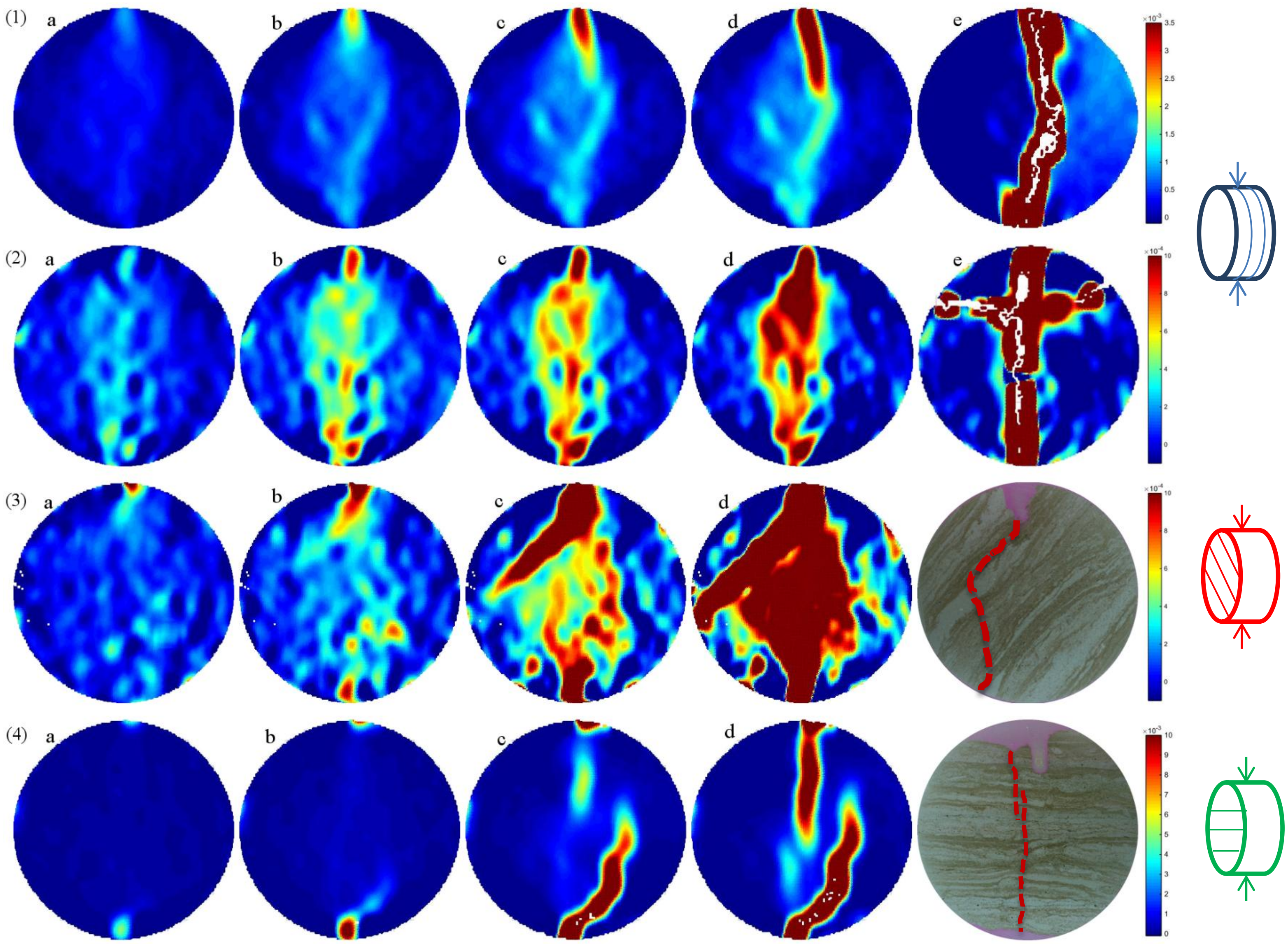

$$\sigma_t = \frac{2P}{\pi D t}$$

P: Loading

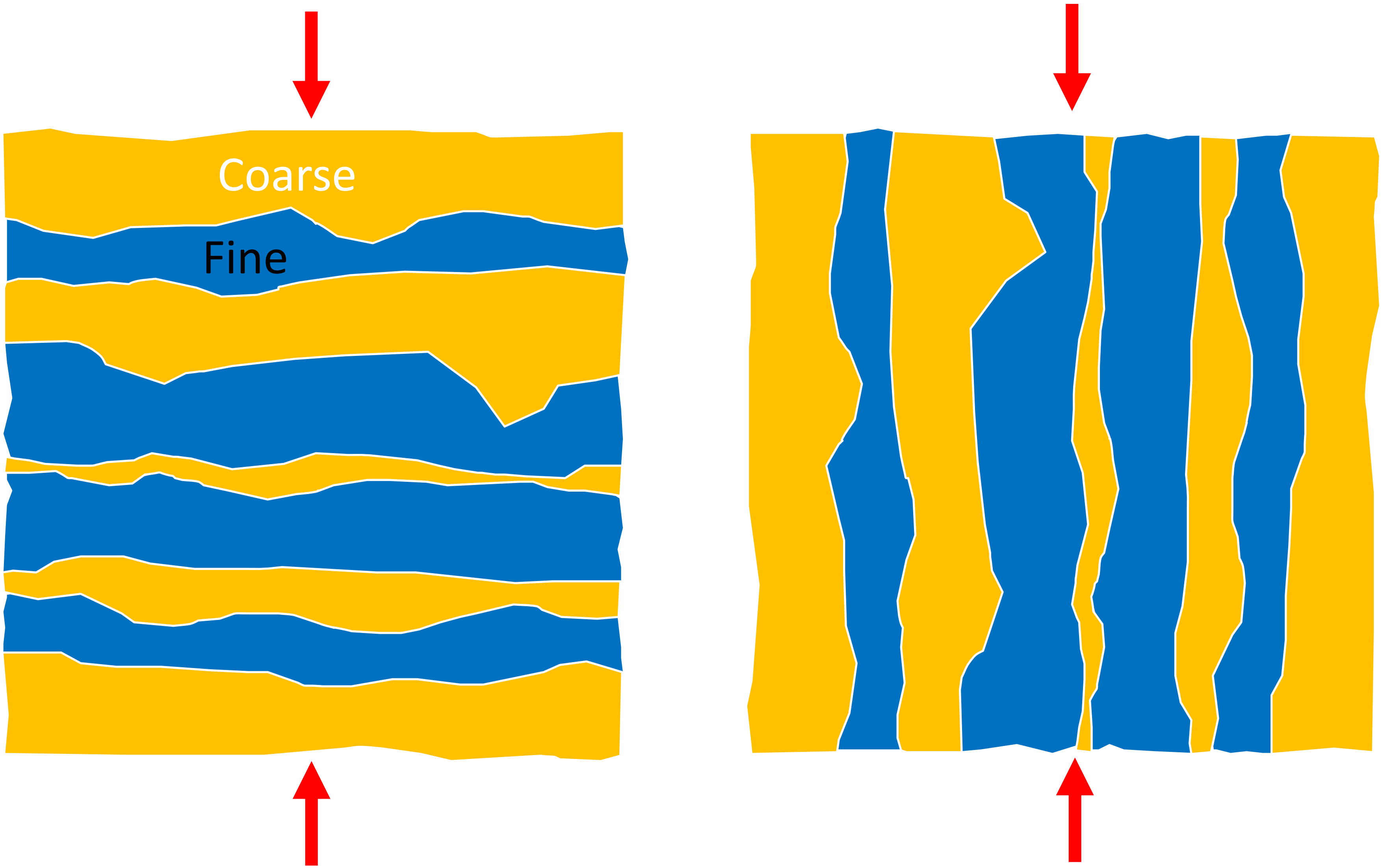
D: Diameter

t: thickness

# Tensile Strain Distribution
# (Digital Image Correlation)



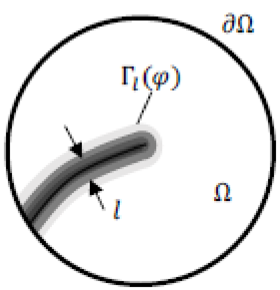
# Conceptual Model of Layered System

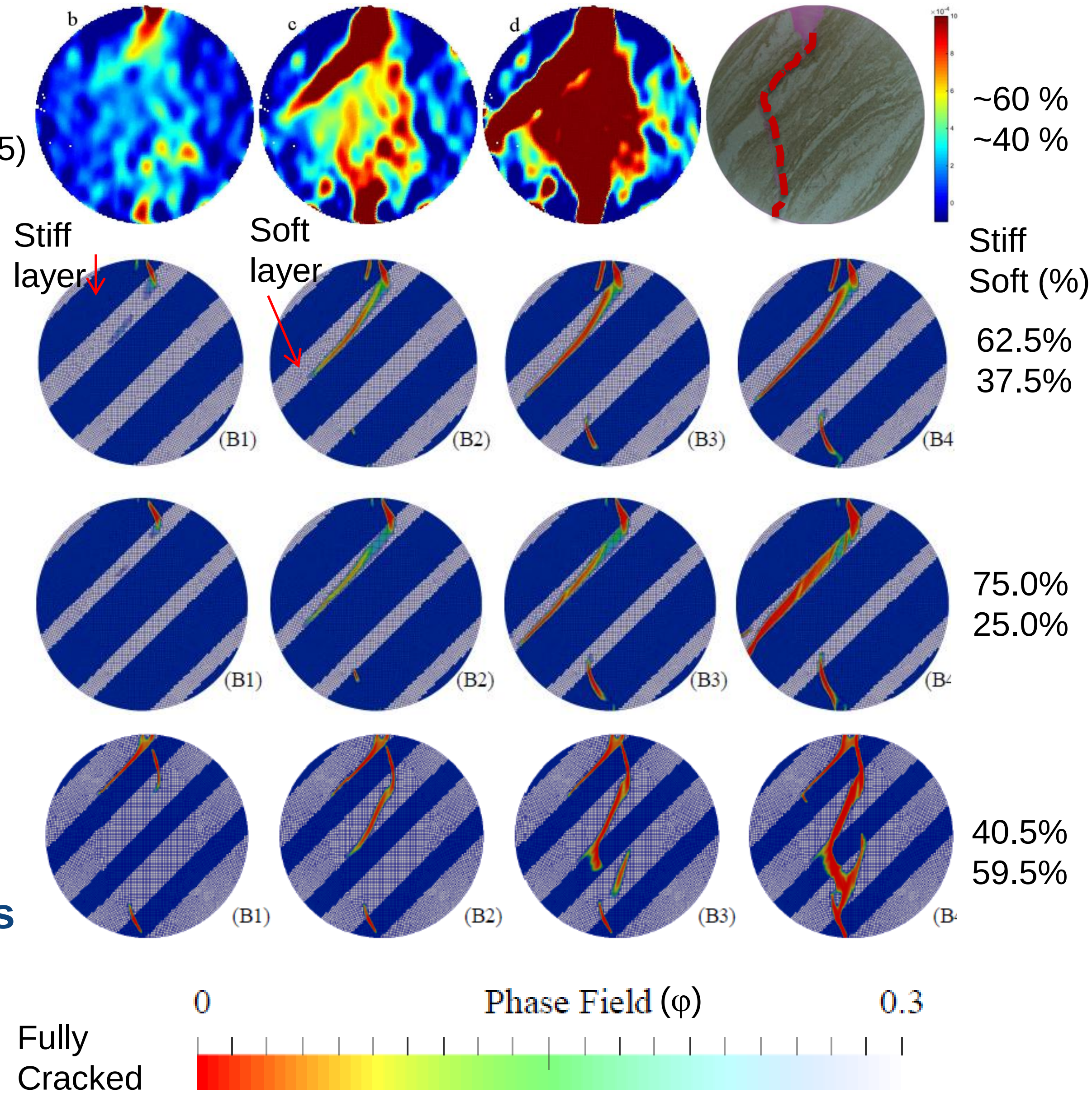


# Numerical Simulations of Brittle Fracturing

- Phase field model for crack representation (Heister et al,2015)
- Shale is modeled as two-constituent brittle materials with stiff and soft layers:
  - Young's Modulus
  - (Pore pressure)
  - (Chemo-mechanical coupling)

Crack phase field (φ)

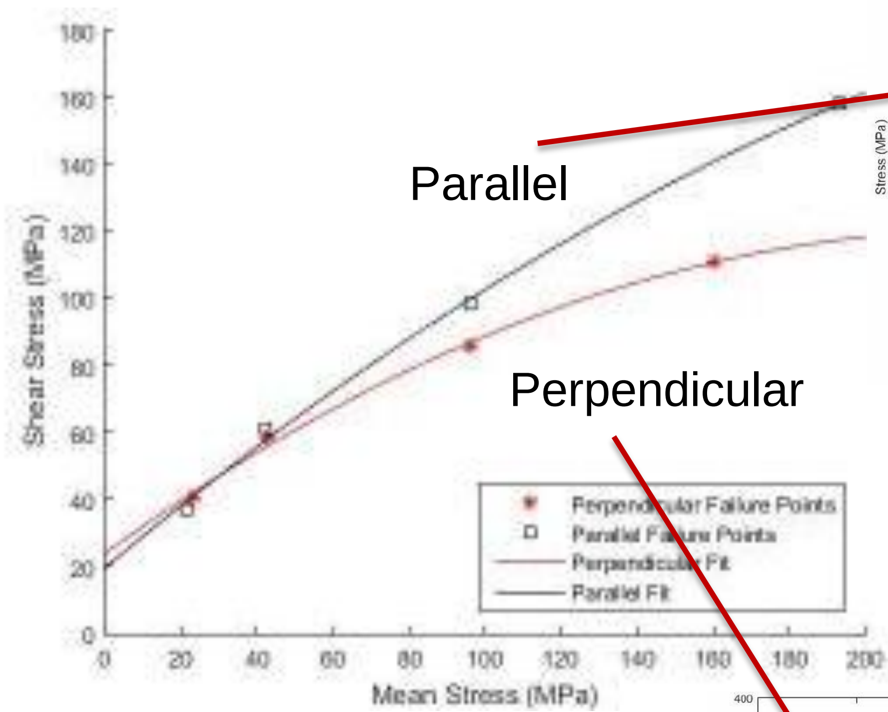



**Differential Equations Analysis Library. II** (Bangerth et al., 2007; 2013)

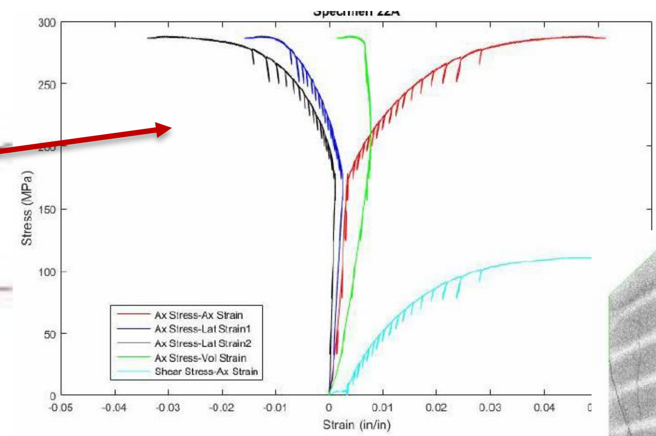
**DEAL.II Open Source Finite Element Library**

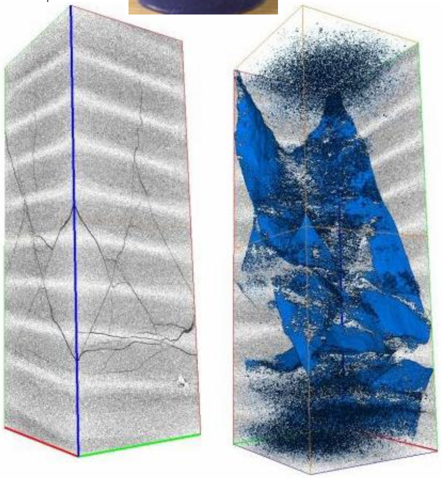
# Axisymmetric Testing Results




Parallel

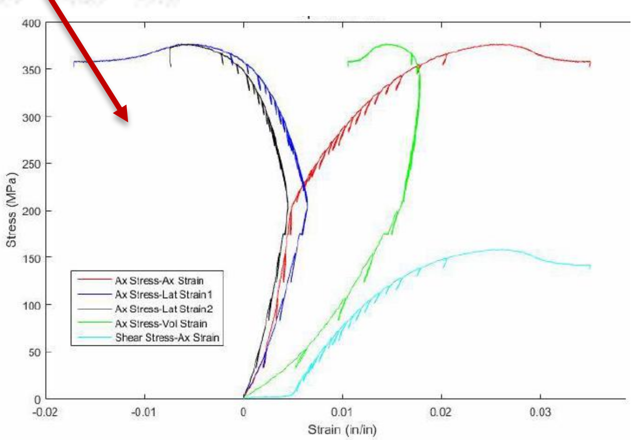
Perpendicular

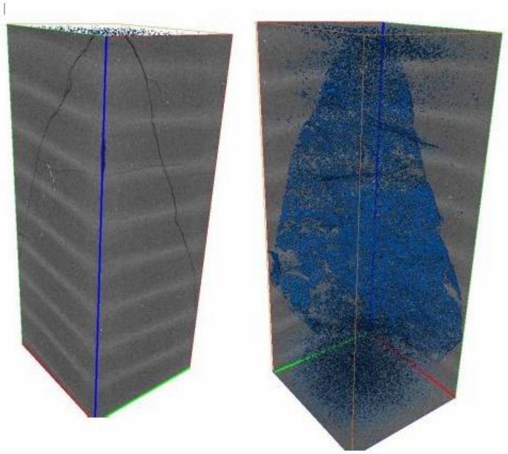


Loaded parallel to bedding

Loaded perpendicular to bedding

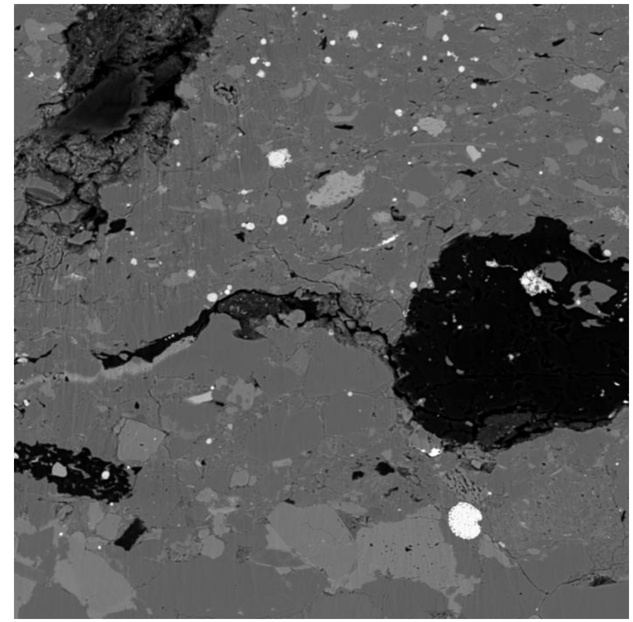


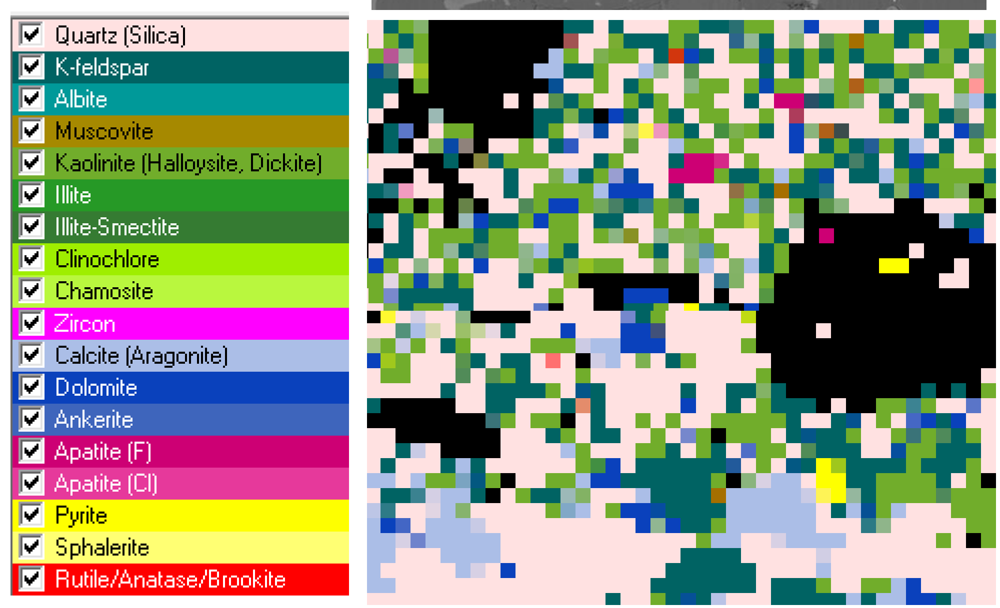
# MAPS Mineralogy

- FEI developed a new spatial mineralogy platform

- SEM-based automated mineralogical measurement, analysis, interpretation, data integration
  - Collection, overlay and re-registration of multiple images from different modalities
  - SEM, SEM-EDS, optical, CL, EBSD
  - QEMSCAN measurement algorithms

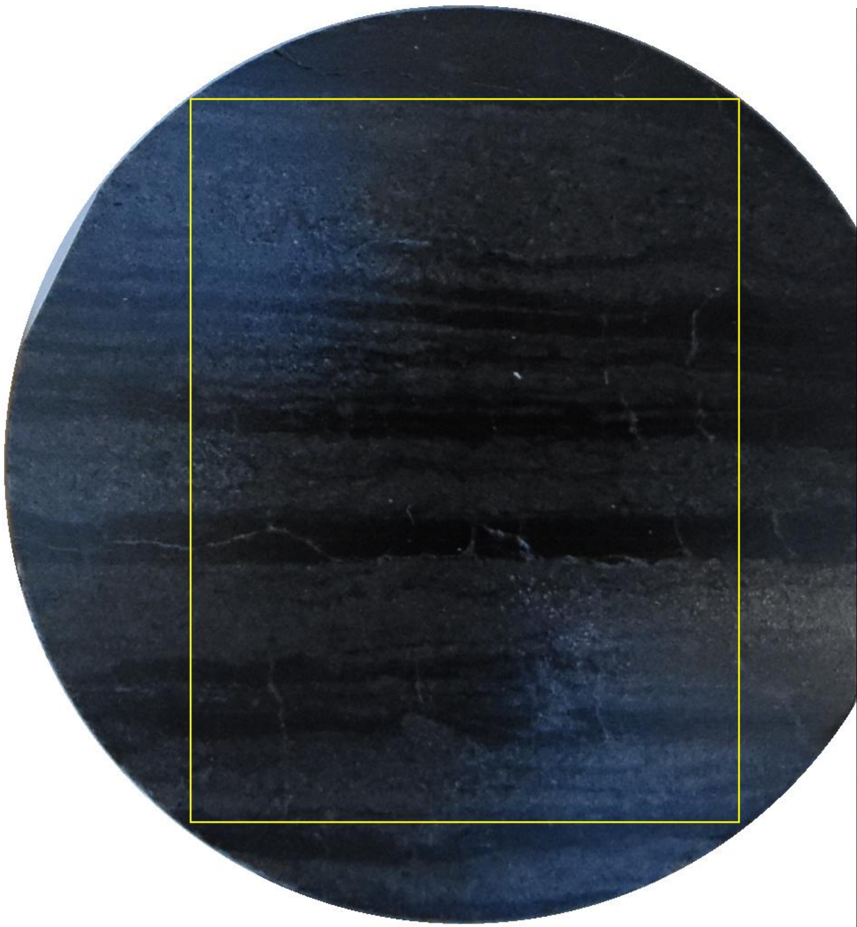


- Mineral identification
  - Spectral matching
  - Each pixel can be a single mineral or multiple minerals
  - Ideal for minerals that show elemental substitutions
  - Simultaneous mineral, element and count maps

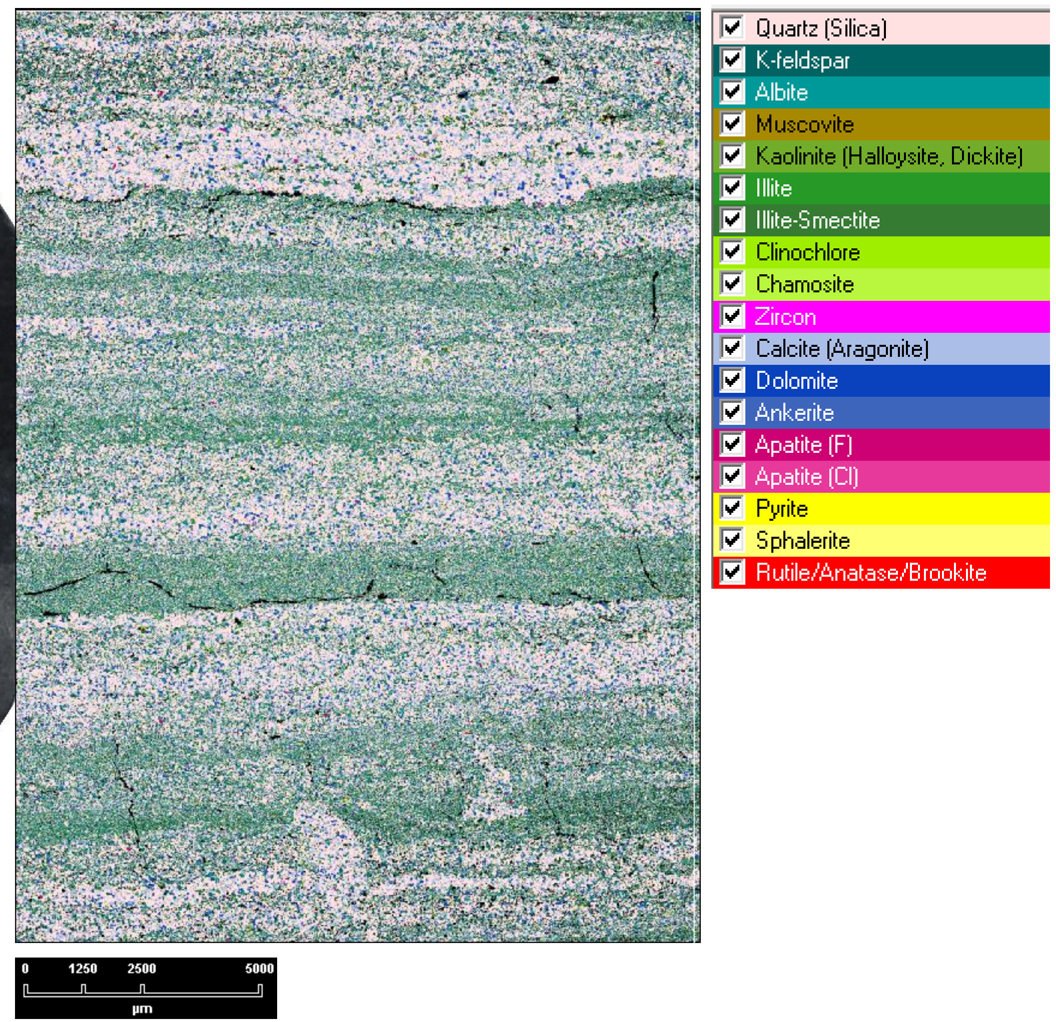


# Mineralogy Mapping & Nanoindentation

Ion-milling polished Mancos

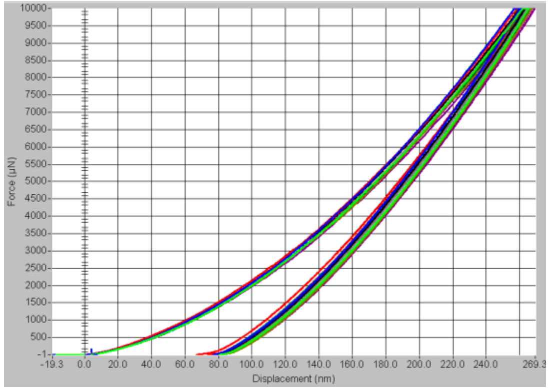


Yellow Box:
Mineral mapping area

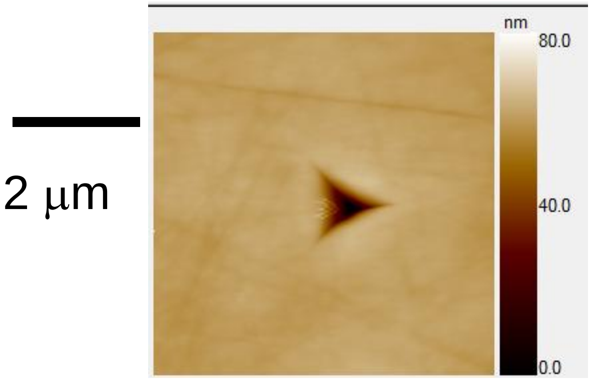


# Nano-indentation Results

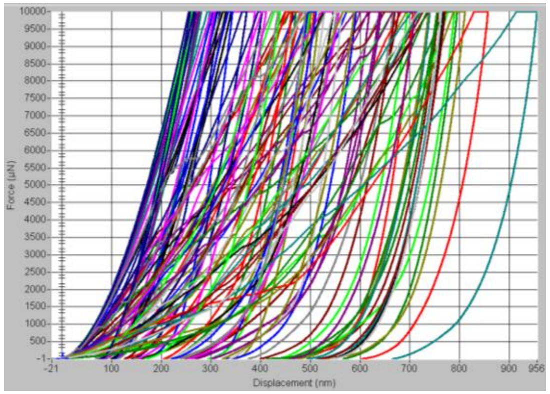
Polished quartz area, 20 indents

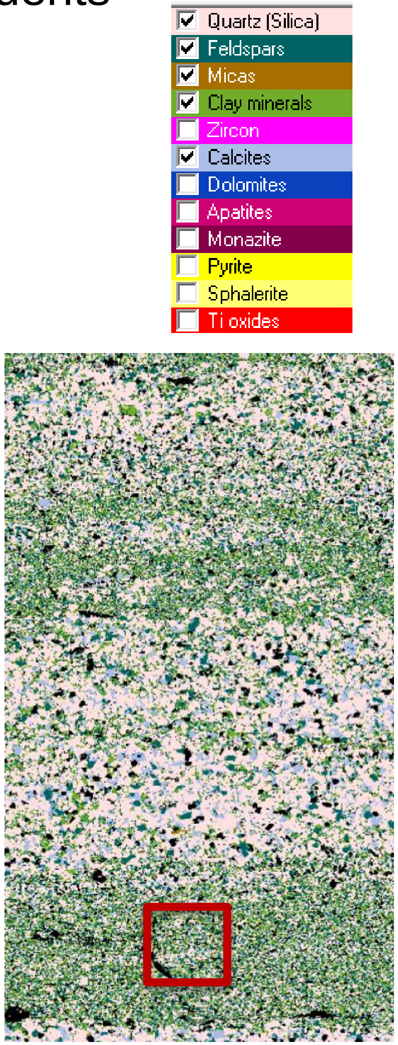


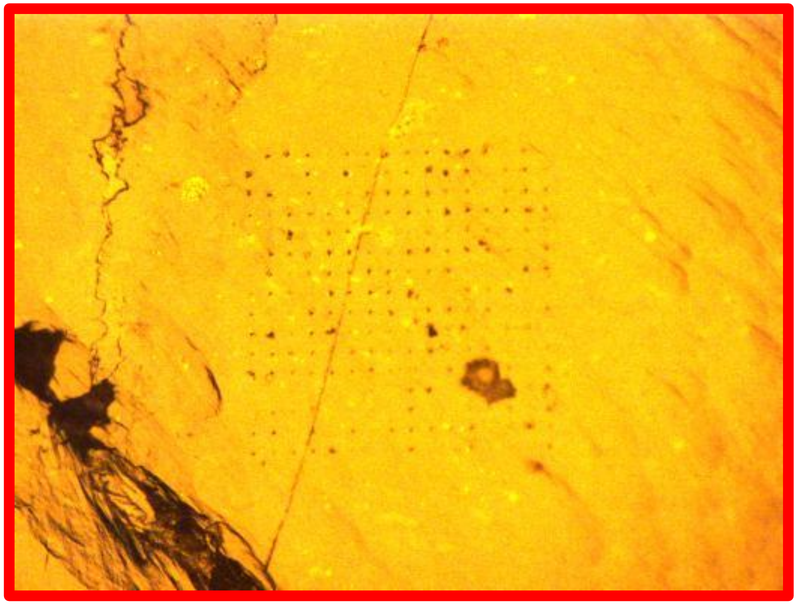

E (Gpa) = 80.8 ± 1.3




Polished Clay-rich area, 64 indents



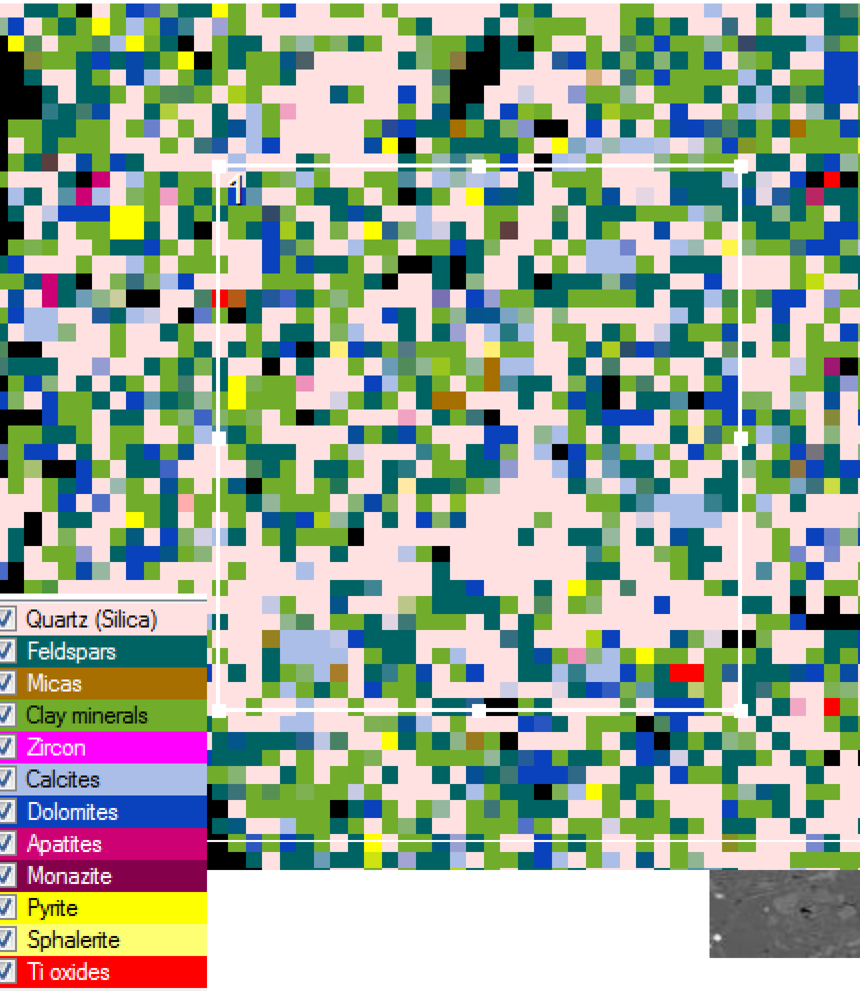



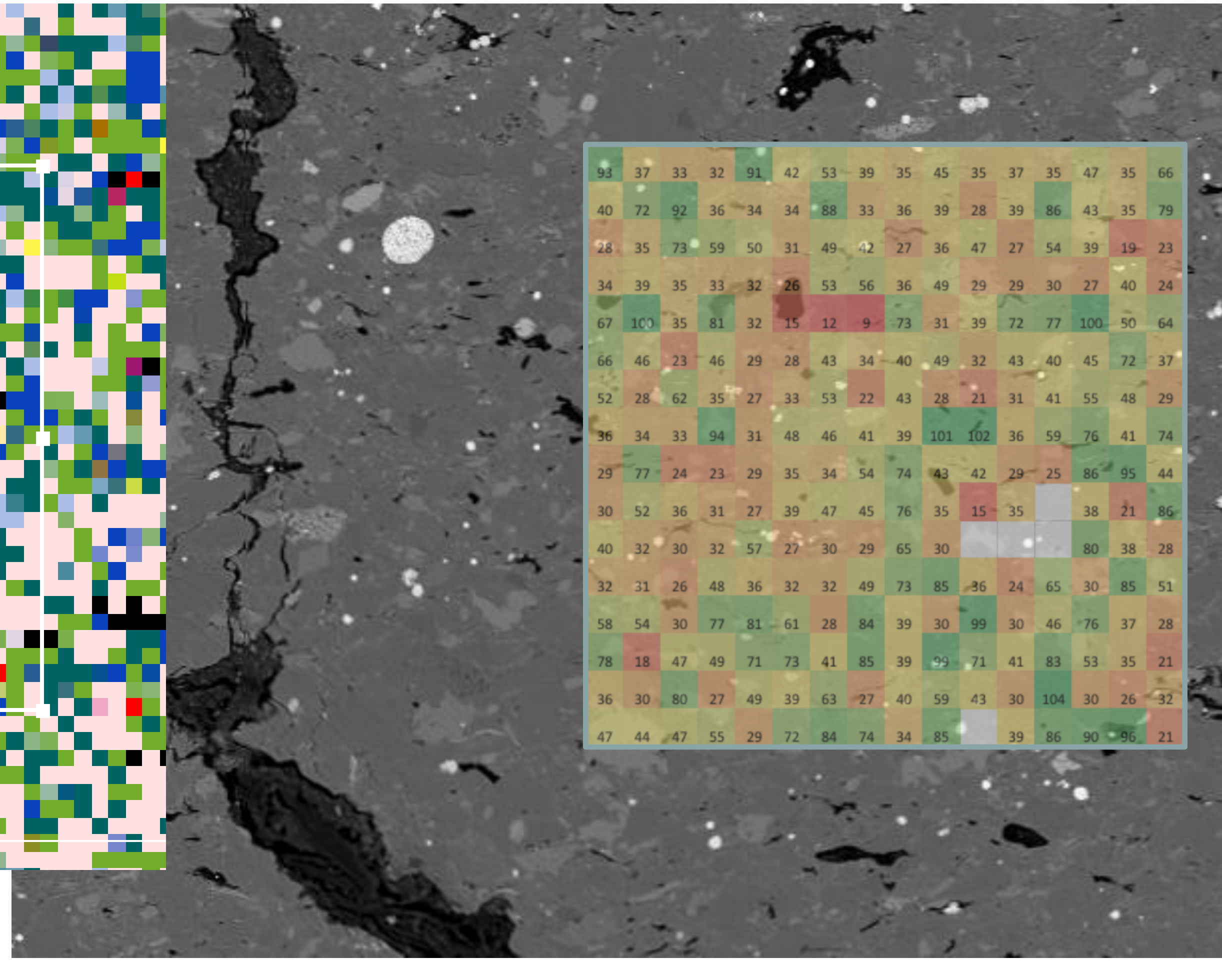
Indentation strain rate = 0.1

Maximum load = 10 mN

Indentation array: 16 x 16, 20 um spacing

# Nano-indentation Results



# Summary

- Texture/mineralogical characterizations
  - – Considerable heterogeneity within macroscopic and sometimes microscopic facies
  - – Relationship with grain size: finer facies have more clay and less quartz, suggesting that coarser facies should be stronger than finer
- Mechanical tests
  - – Macroscopic and microscopic lithofacies have distinctively different mechanical properties
  - – Bulk properties may be misleading as they can represent averages of mechanically heterogeneous rock
  - – Microscopic heterogeneity controls the spatial distribution of fractures
  - – This heterogeneity should be taken into account for realistic mechanical modeling and can scale up by examining other common lithofacies
- Integrated multiscale imaging and mechanical testing with numerical simulation provides a robust approach to advancing our understanding of shale poro-mechanics

# Thank You