Exploring the behavior of shales as seals and storage reservoirs for CO2

Project Number: Car Stor_FY131415

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USDOE/NETL/ORD

U.S. Department of Energy

National Energy Technology Laboratory
Carbon Storage R&D Project Review Meeting
Developing the Technologies and
Infrastructure for CCS

August 20-22, 2013

Project Overview: Goals and Objectives

- Program Goals
  - Support industry's ability to predict CO_2 storage capacity in geologic formations to within ±30 percent.
  - Develop technologies to improve reservoir storage efficiency while ensuring containment effectiveness
- Project Objectives
  - Assess how shales behave as caprocks in contact with CO_2 under a variety of conditions
  - Assess the viability of depleted gas shales to serve as storage reservoirs for sequestered CO_2
  - Determine economic usefulness of CO_2 for enhanced oil or gas recovery in shales

Benefits to the Program

- **Greater confidence of seal integrity in the presence of CO_2**
- **Reduced uncertainty about what type of shale seal should be sought for CO_2 geologic storage**
- **Develop a methodology to assess basin-scale storage resources in shales using publicly-available data under defined conditions.**

Technical Status

- Understanding shale pore structure
  - Shale pore types and how to visualize
  - Devonian shales have pores in the 5 to 15 nm range
  - How are these pores connected?
- Pores and fluids
  - Capillary pressure and relative permeability of gas versus liquid
  - Behavior of methane versus CO_2 – molecule size, chemical properties
  - Gas adsorbed on organics and clays or dissolved into organics
- Understanding petrophysical behavior of shale
  - Horizontal versus vertical anisotropy
  - Sensitivity to stress
  - Dealing with really low permeability

Pore Sizes

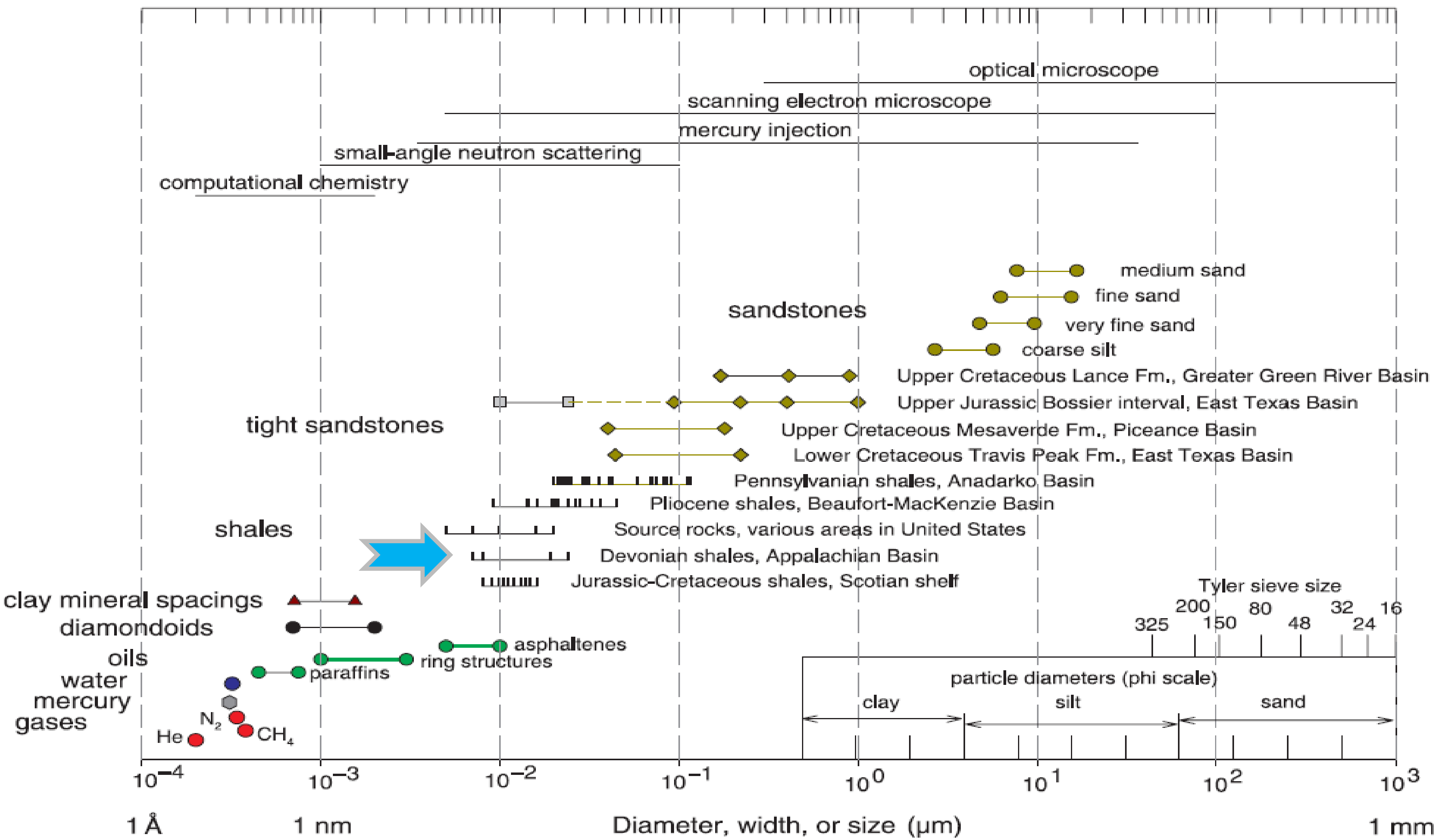
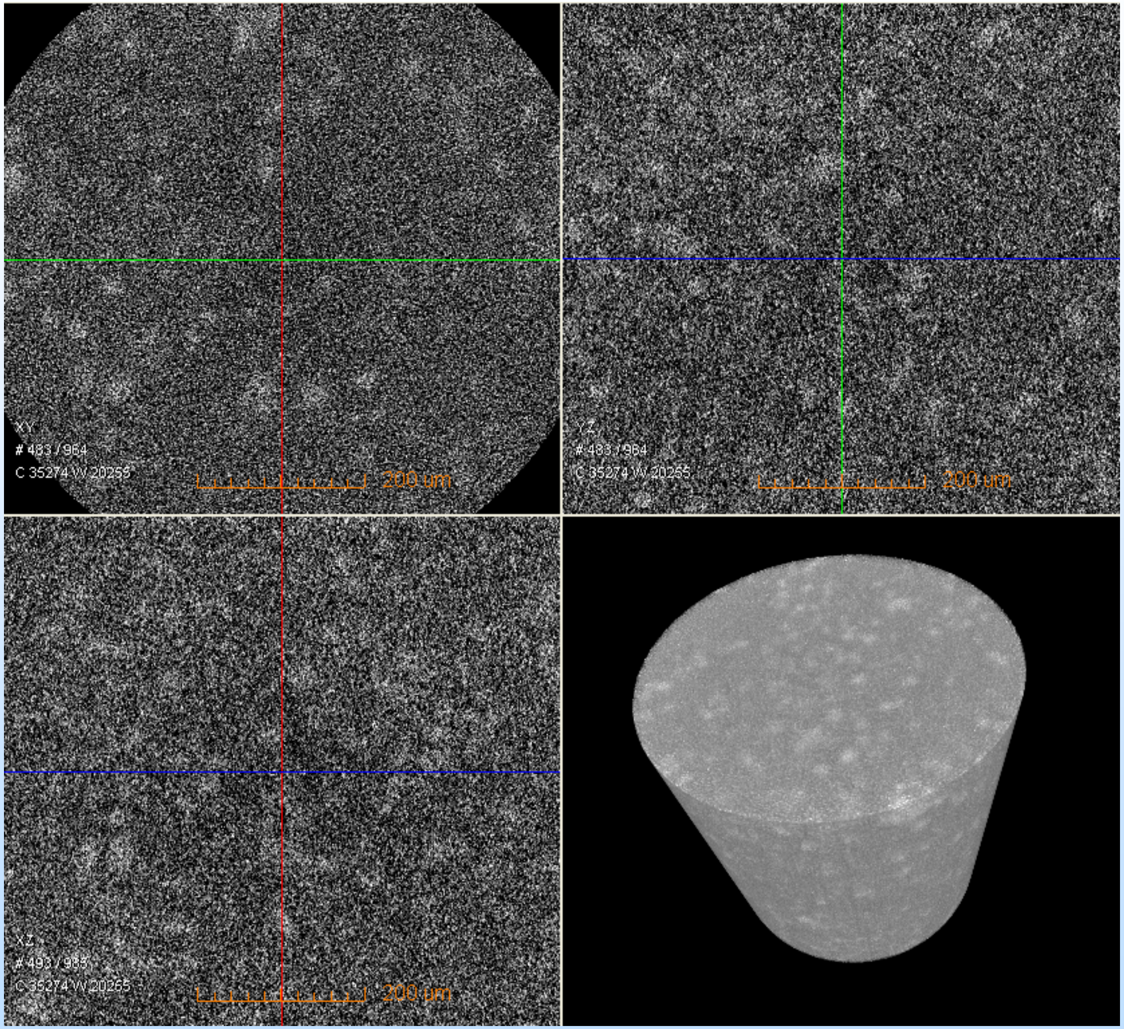


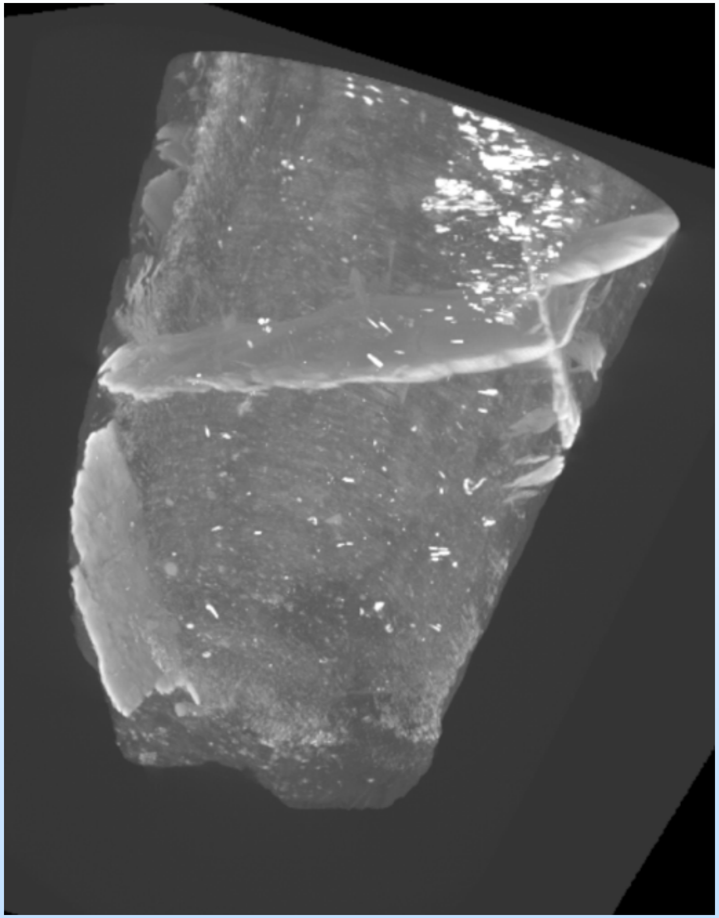
Figure 2. Sizes of molecules and pore throats in siliciclastic rocks on a logarithmic scale covering seven orders of magnitude. Measurement methods are shown at the top of the graph, and scales used for solid particles are shown at the lower right. The symbols show pore-throat sizes for four sandstones, four tight sandstones, and five shales. Ranges of clay mineral spacings, diamondoids, and three oils, and molecular diameters of water, mercury, and three gases are also shown. The sources of data and measurement methods for each sample set are discussed in the text.

Nelson, Philip H., 2009: Pore-throat sizes in sandstones, tight sandstones, and shales: AAPG Bulletin, v. 93, no. 3 (March 2009), pp. 329–340

Micro CT Results

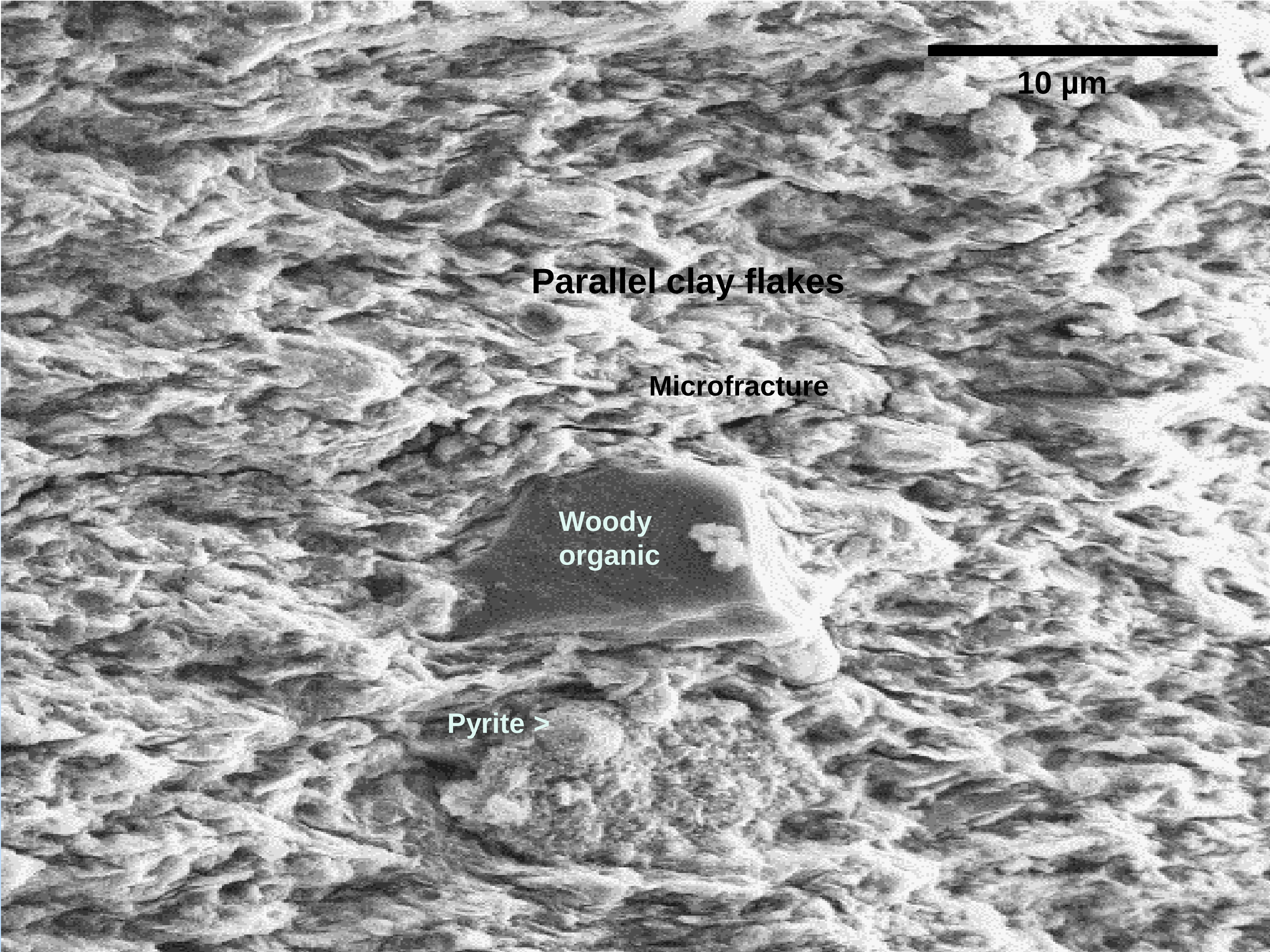


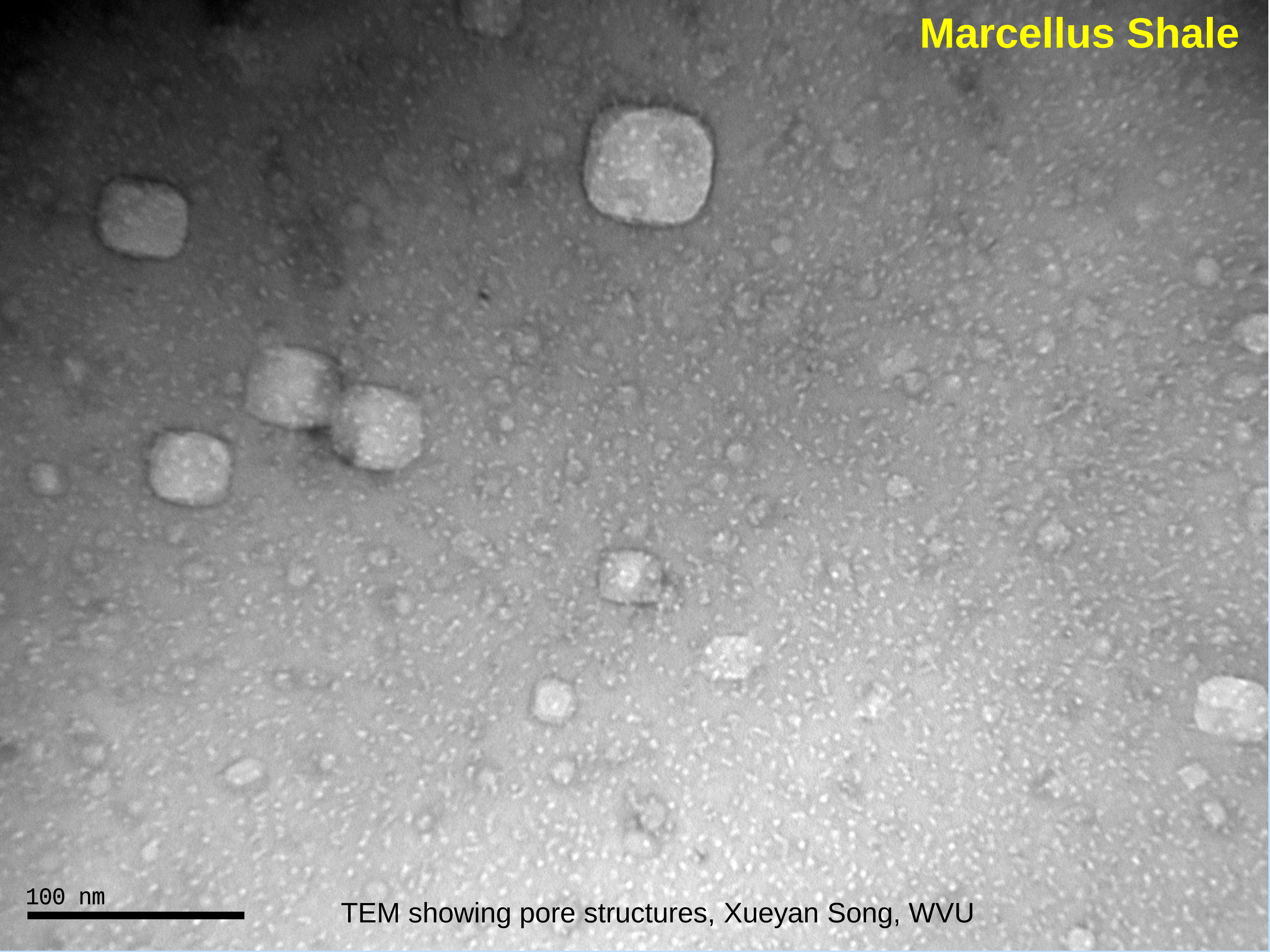
CT scanning allows for 3D reconstruction of density contrasts.



Larger flowpaths can be recognized and analyzed.

Micro CT images by Rebecca Rodriguez, ORISE


10 µm
Parallel clay flakes
Microfracture
Woody
organic
Pyrite >



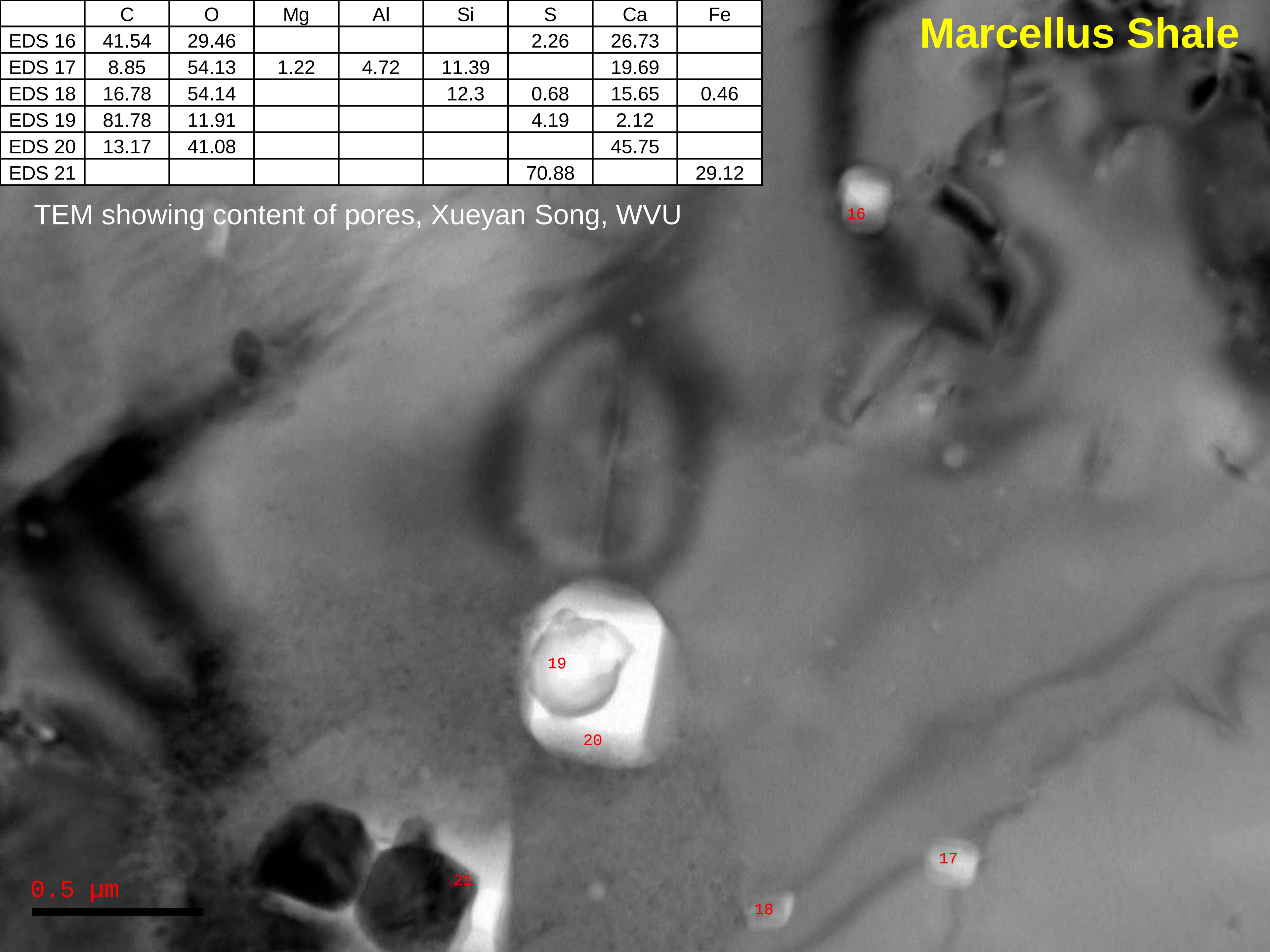
TEM showing pore structures, Xueyan Song, WVU

TEM showing pore structures along grain boundary, Xueyan Song, WVU

Marcellus Shale

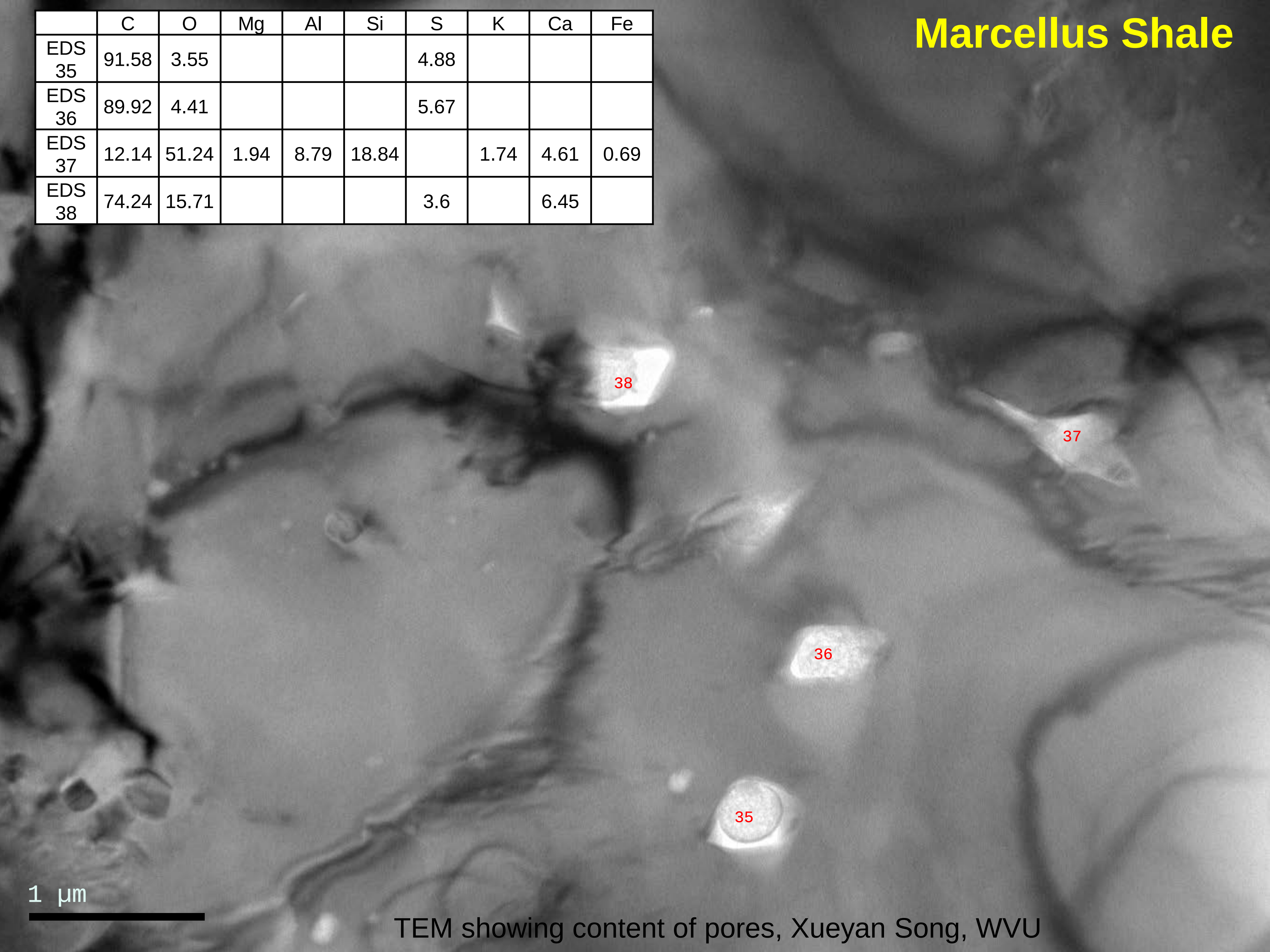
	C	O	Mg	Al	Si	S	Ca	Fe
EDS 16	41.54	29.46				2.26	26.73	
EDS 17	8.85	54.13	1.22	4.72	11.39		19.69	
EDS 18	16.78	54.14			12.3	0.68	15.65	0.46
EDS 19	81.78	11.91				4.19	2.12	
EDS 20	13.17	41.08					45.75	
EDS 21						70.88		29.12

TEM showing content of pores, Xueyan Song, WVU



Marcellus Shale

	C	O	Mg	Al	Si	S	K	Ca	Fe
EDS 35	91.58	3.55				4.88			
EDS 36	89.92	4.41				5.67			
EDS 37	12.14	51.24	1.94	8.79	18.84		1.74	4.61	0.69
EDS 38	74.24	15.71				3.6		6.45	



TEM showing content of pores, Xueyan Song, WVU

Petrophysical Behavior

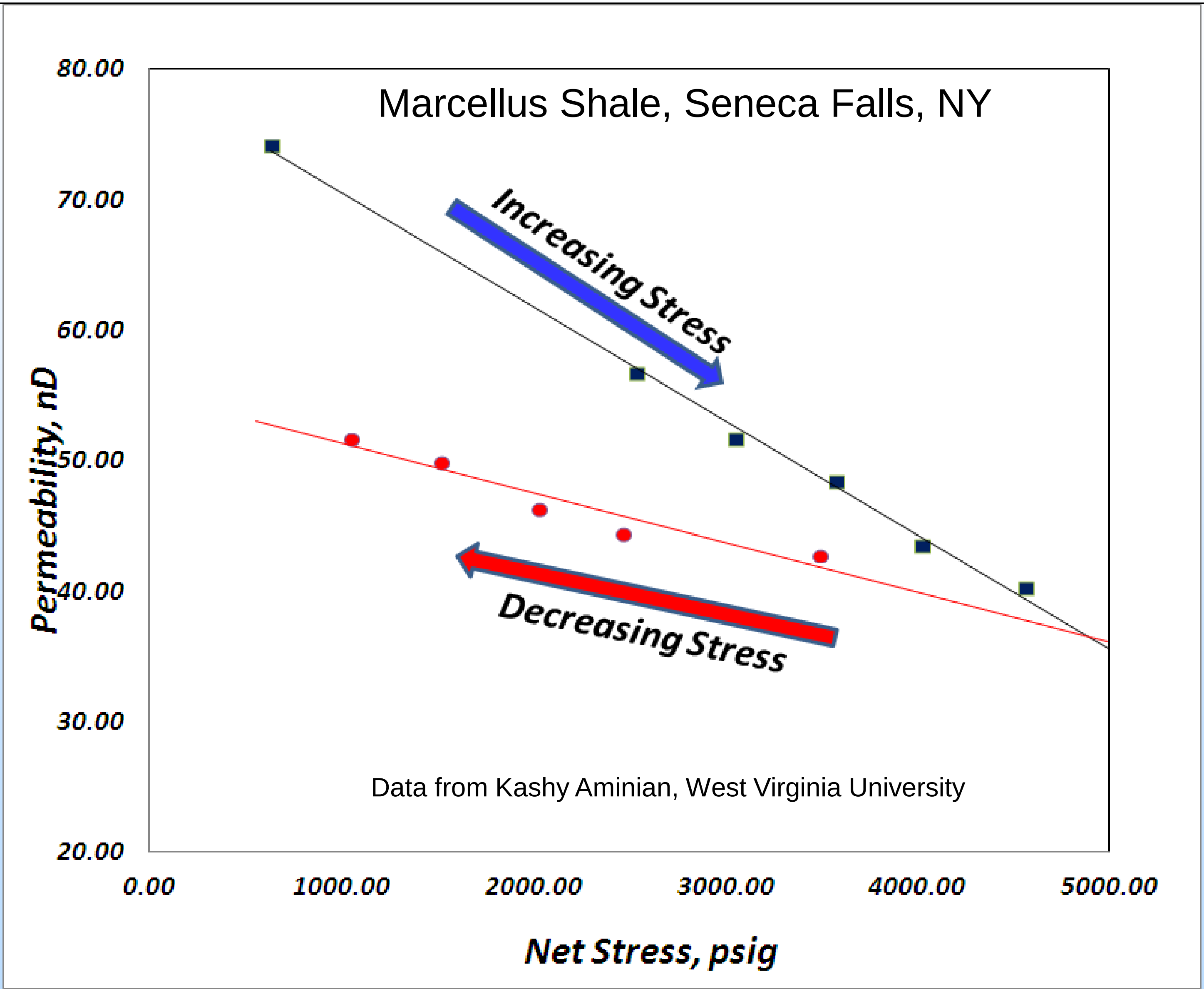
- Very low permeability to gas – nanodarcy range
- Mass flow versus diffusion; movement of gas through nanopores on a molecular scale
- Importance of the Klinkenberg effect and gas slippage
- Exactly how low is a permeability of one nanodarcy? Is molecule size important?
- Oil wet versus water wet (black shale vs. gray)
- High capillary pressures at gas-liquid interface (500 psi to 900 psi typical)

Net Confining Stress

- Drawdown of a deep gas shale can easily double the net overburden stress.
- Measurements have shown that doubling the net stress decreases permeability by 2/3*
- Changes in flowpath aperture and tortuosity occur due to increased net confining stress
  - Average aperture increases (smaller flowpaths close down)
  - Tortuosity increases significantly
- Hysteresis: once permeability is decreased by excursion to high stress, it does not recover

*Soeder, D. J., 1988, Porosity and permeability of eastern Devonian gas shale: SPE Formation Evaluation, Vol. 3, No. 2, p. 116-124, DOI 10.2118/15213-PA.

Hysteresis in shale



Technical Challenges

- Obtaining shale core samples
- Core sample bias? Clay vs. silica vs. carbonate
- Measuring flow through shale within a human lifetime
- Separating out actual petrophysical effects from low permeability
  - Capillary pressure: is it really that high, or does it just take a long time to equilibrate because of the low permeability?
  - Swelling of shale with CO_2 in the pores – how much is real, how much caused by CO_2 escaping very slowly?
- Methane and carbon dioxide behave differently in shale – why and how?
- CO_2 physical and chemical reactions with the shale
  - Reaction to oil-wet versus water-wet shales
  - Reaction to mineralogy (clays, carbonate, sulfides, etc.)

Accomplishments to Date

- Samples have been obtained
  - Ohio Shale, EGSP cores: Huron and Chagrin; Ohio Geological Survey
  - Mowry Shale, SCC core, Colorado, Univ. of Utah
  - Niobrara Shale, USGS core, SD, NE, WY, tribal college project
- Capillary pressure measurements underway
- Pore visualization assessments nearly complete, report in progress.
- New ultra-low permeability, steady-state flow lab under design for B-17 at NETL in Morgantown.

Summary

- Performance of shale as a seal (caprock) is influenced by
  - Mineralogy and CO_2 reactivity
  - Pore geometry and related permeability
  - Fluids in pores and capillary entry pressure
- Performance of shale for geologic storage of CO_2 is influenced by:
  - Bulk volume of rock
  - Percentage of porosity in that bulk volume
  - Percentage of accessible porosity from total
  - Factors that alter accessibility (liquids, hysteresis, etc)

Organization Chart

- Dan Soeder (DOE), Rebecca Rodriguez (ORISE), Dustin Crandall (URS), Roger Lapeer (URS), Dustin McIntire (DOE), Kashy Aminian (WVU), Xueyan Song (WVU), Henk Verweij (Ohio State)
- Key Pieces of Equipment: Precision Petrophysical Analysis Lab (PPAL), Micro CT Scanner, SEM, TEM, Threshold Pressure Tester, optical microscopes