Surface Controls on Storage, Stiffness, and Transport Properties of Rocks

Manika Prasad, Colorado School of Mines

(presenting work of Kumar, Livo, Ou, Panfiloff, Drs. Niu, Saidian, Zargari, Kuila, Rahman)

CENTER FOR ROCK ABUSE

Squeezing Rocks since 1994

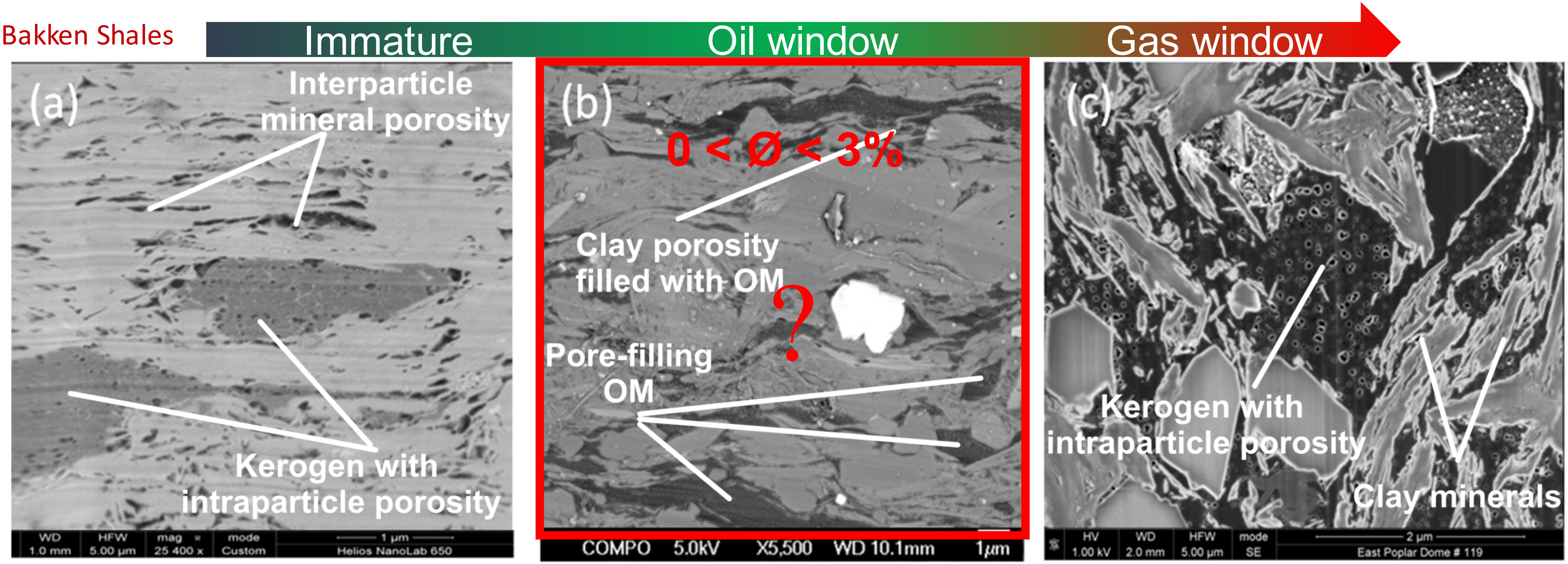
Rockphysics Petrophysics OCLASSH

OUTLINE

- Fluids effects on elastic properties
- Selective sorption of fluids in different components of rocks
- Fluids and CEC effects on dielectric constant
- Specific surface area controls on conductivity
- Clay and Organic Matter Effects on Surface area and CEC
- Specific surface area controls on NMR Surface Relaxivity

POROSITY IN SOURCE ROCKS

Zargari et al., 2015



$R_{o_e} = 0.3$ $R_{o_e} = 0.8$ $R_{o_e} = 3.0$

OM= Kerogen + HC + Bitumen

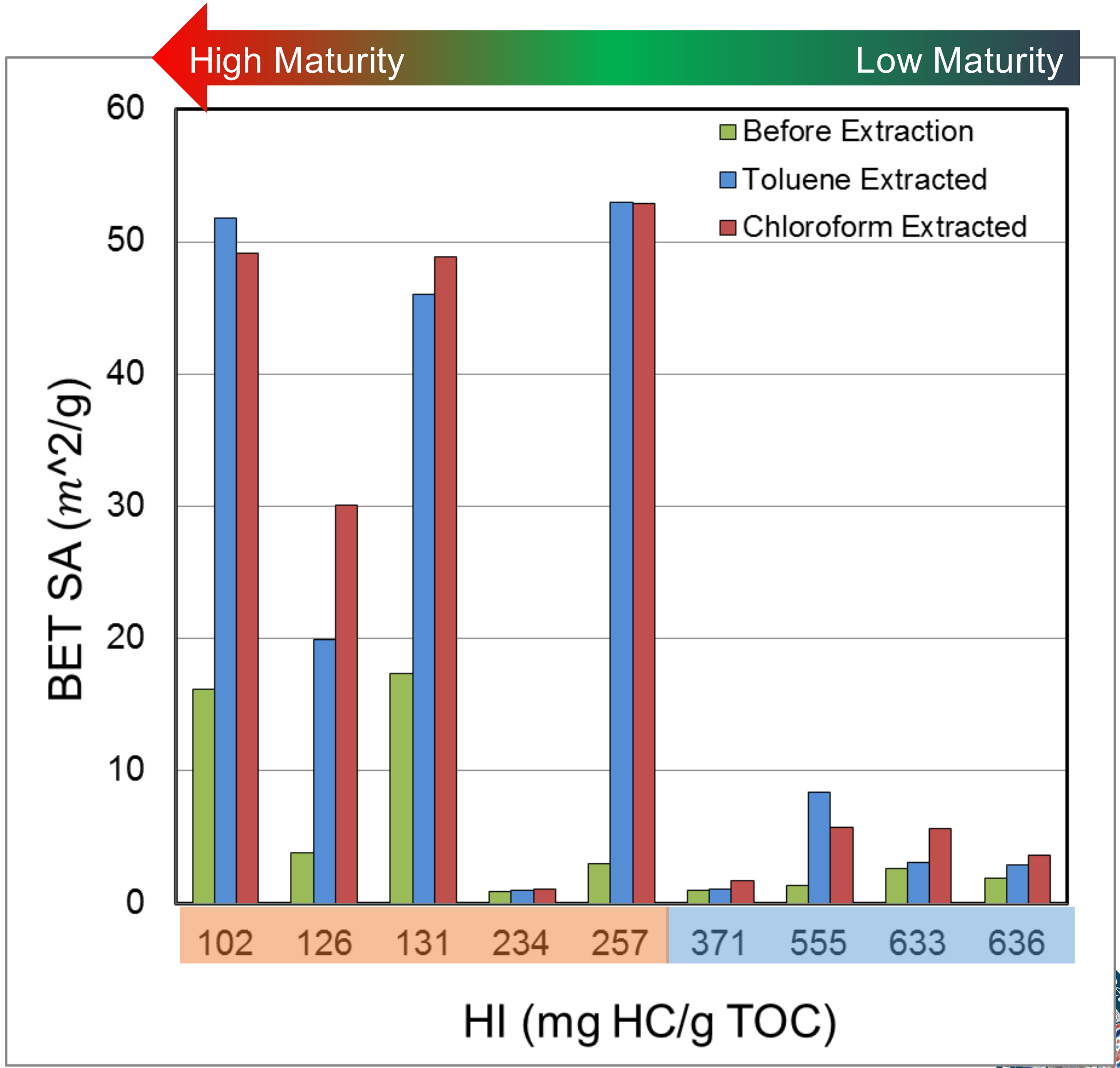
SURFACE AREA / PORE CHARACTERIZATION

Zargari et al., 2015

Gain surface area with solvent extraction

Bakken Shale samples were solvent-extracted using toluene and chloroform

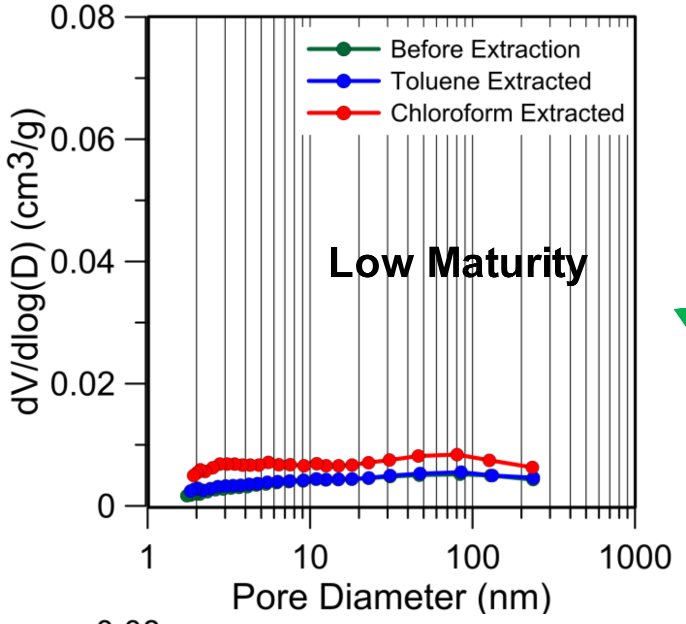
Surface Area and Pore Size Distributions measured using N2 adsorption

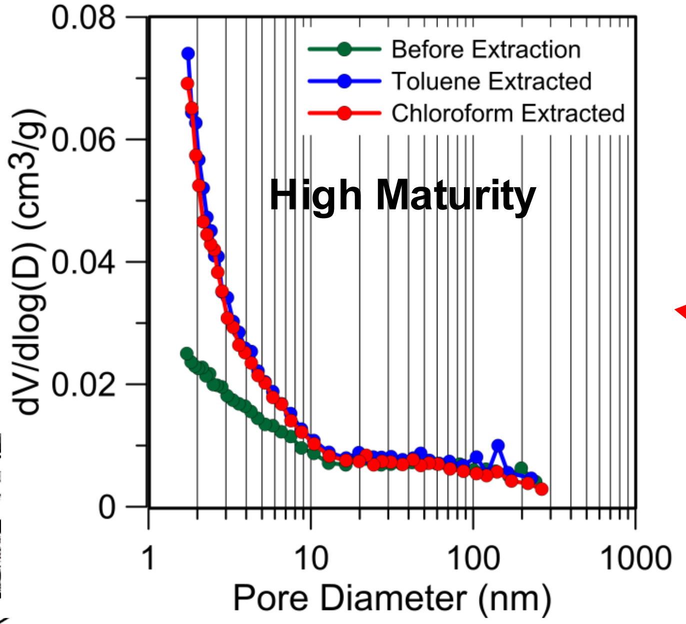


BET: Brunauer–Emmett–Teller theory

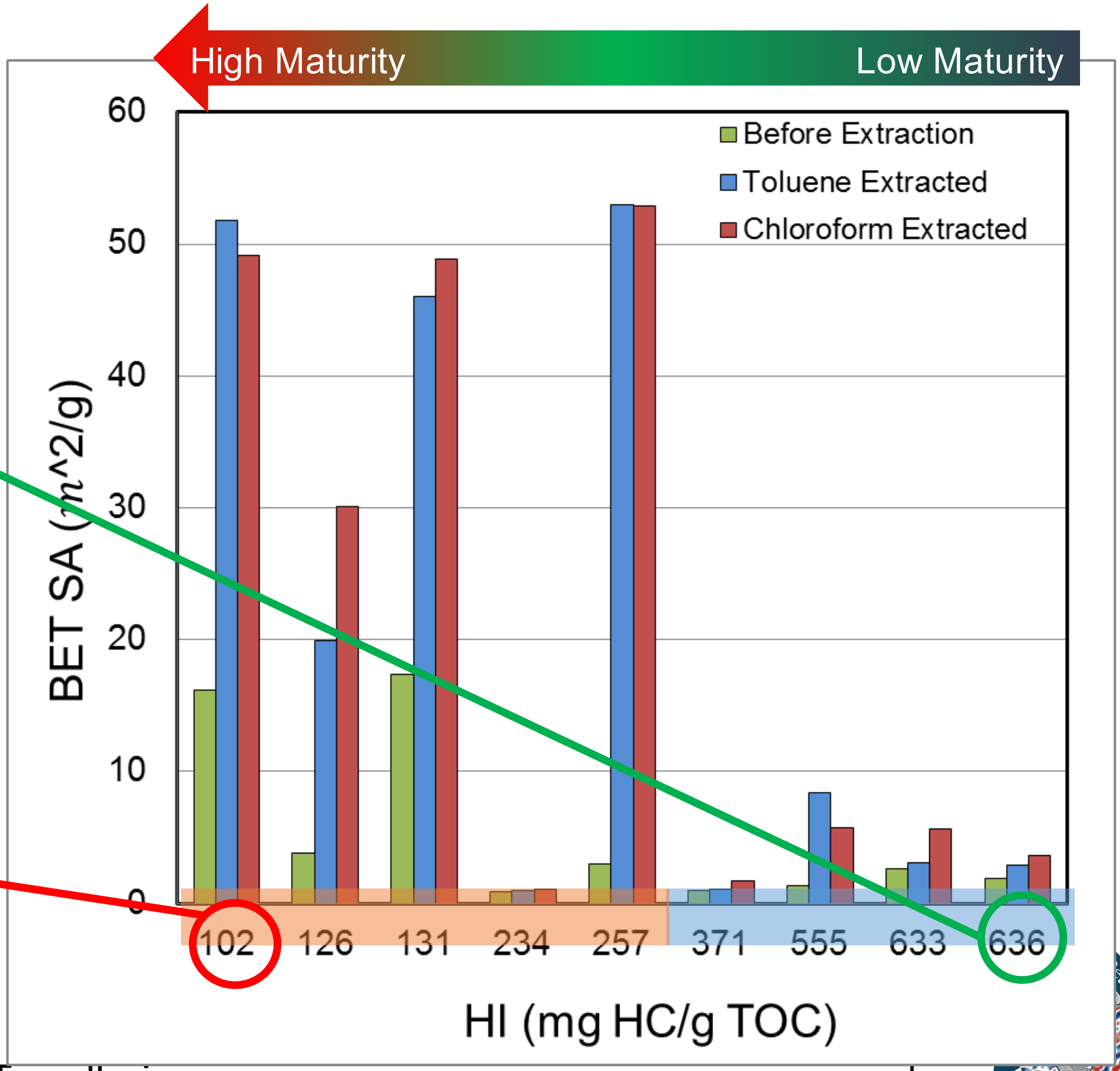
PORE SIZE DISTRIBUTION

Zargari et al., 2015





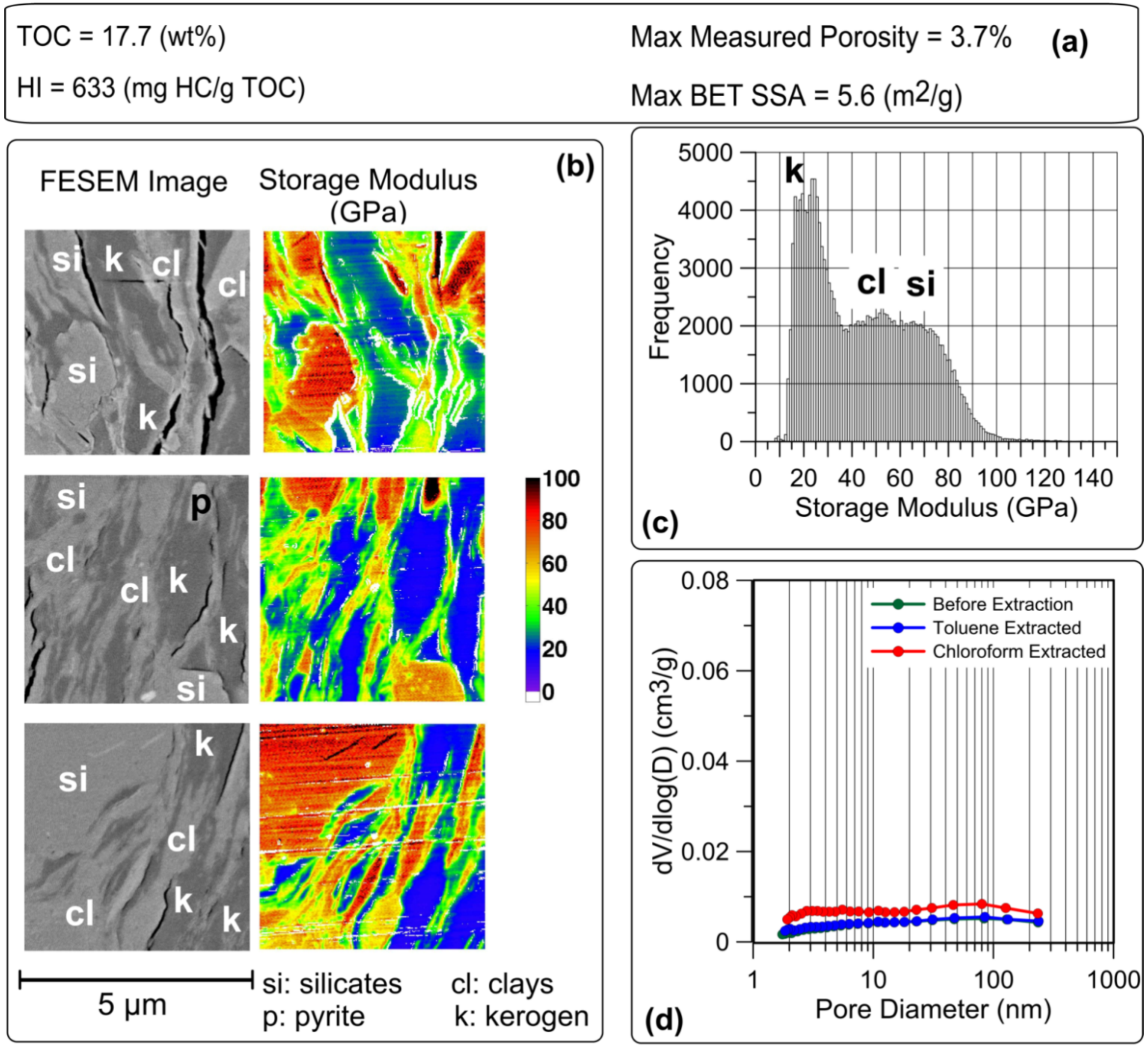
Higher maturity shale shows large change



NANOMECHANICAL MODULUS: IMMATURE

Zargari et al., 2016

Immature Sample

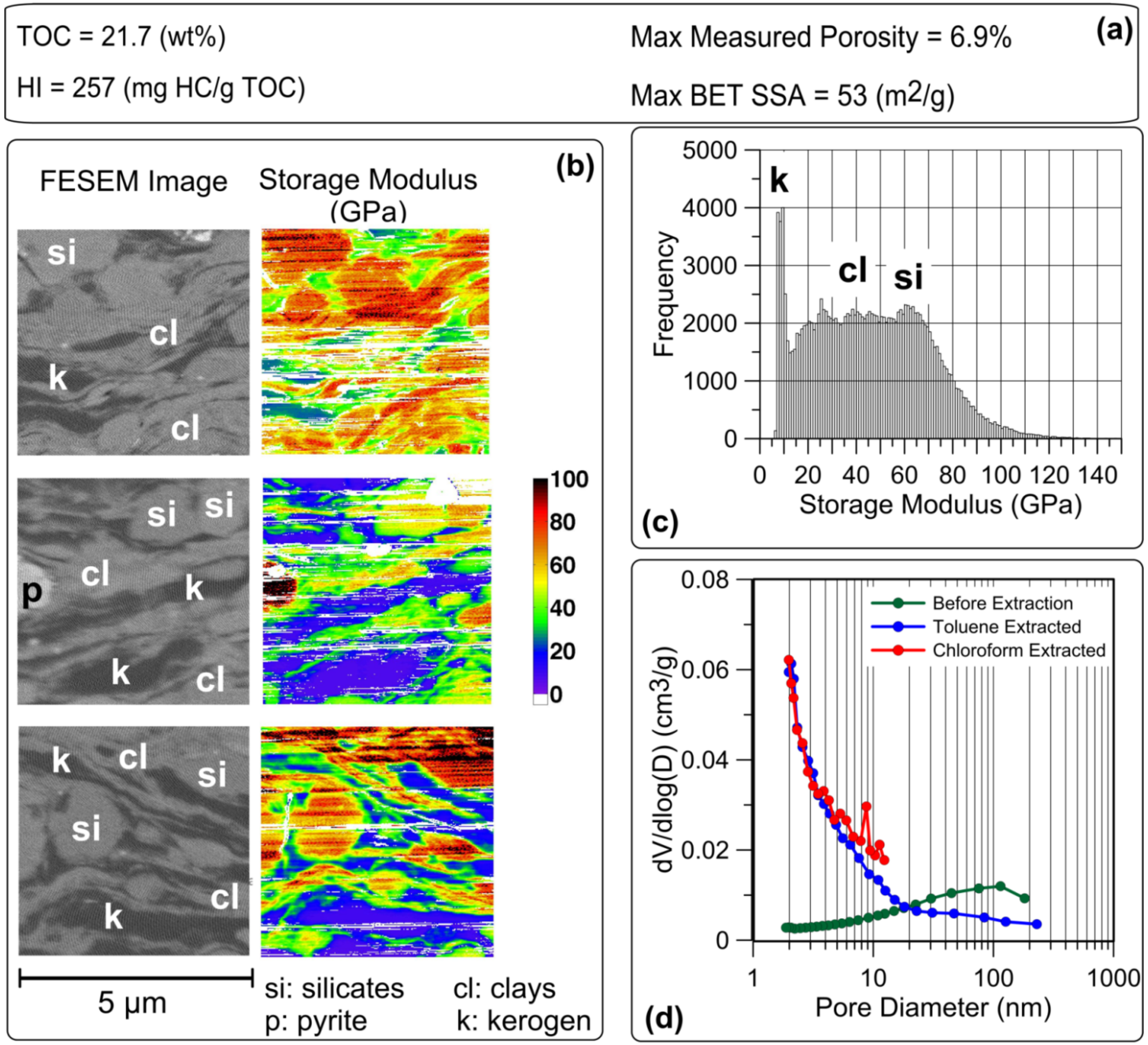


$$E_k = 15 - 20\ GPa$$

NANOMECHANICAL MODULUS: OIL WINDOW

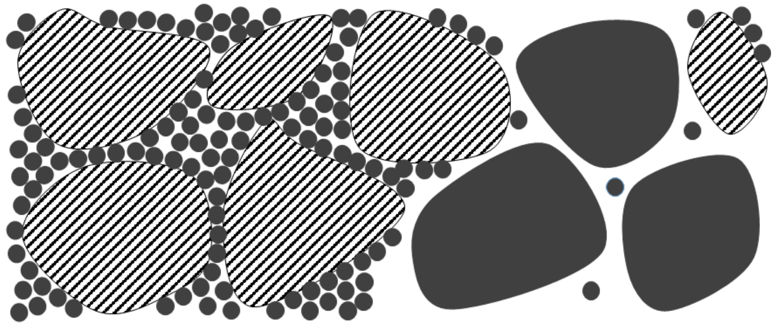
Zargari et al., 2016

Oil Window

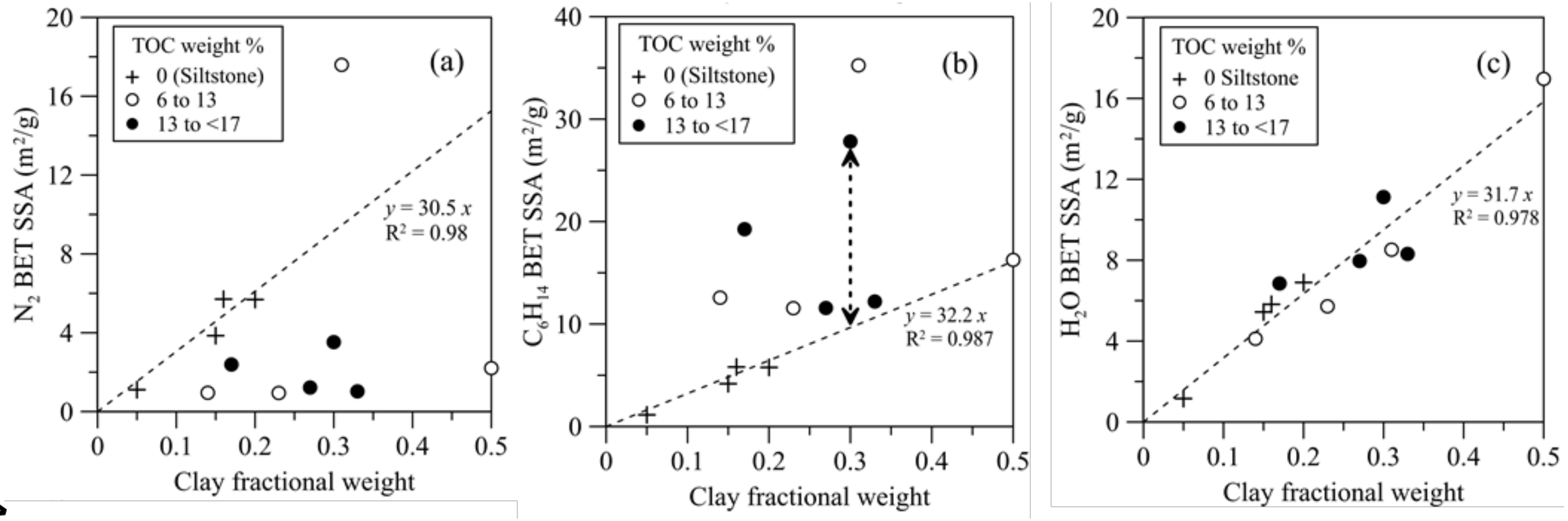


$$E_k = 7 - 10\ GPa$$

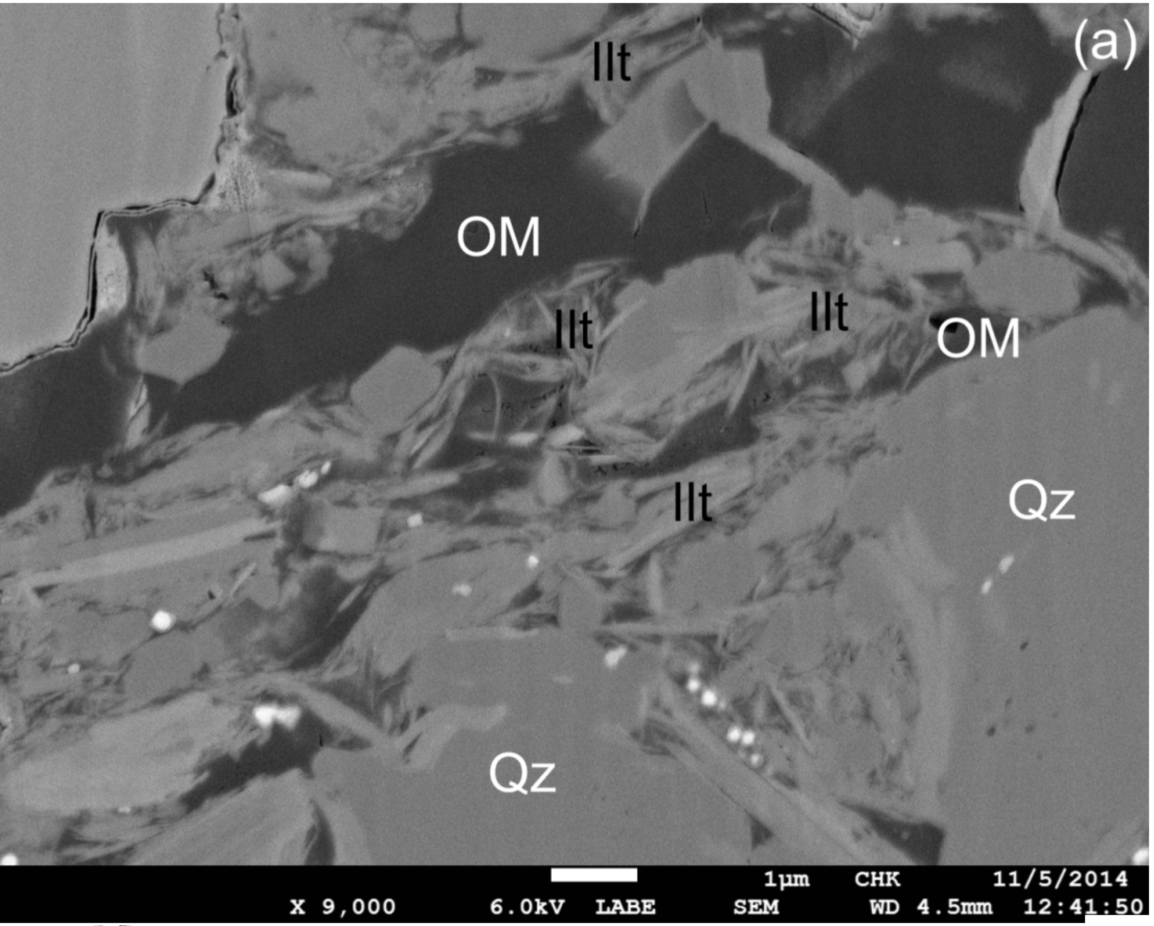
SELECTIVE ADSORPTIVES FOR ASSESSING ORGANIC MATTER PORES SURFACE AREA

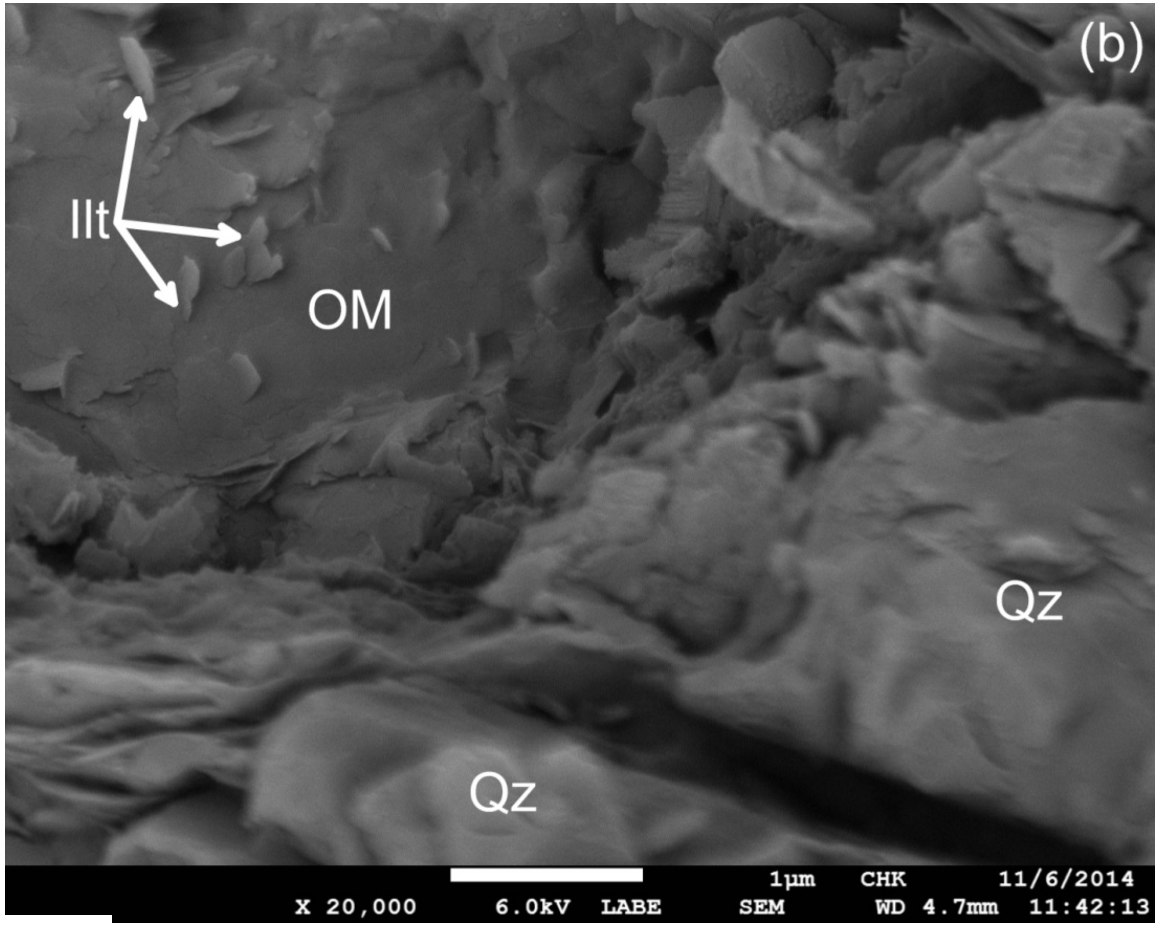


Kumar et al., submitted



COATED CLAYS AND BLOCKED PORES





Silurian

Kuila, 2013; Saidian et al., 2015

EFFECT OF FLUIDS

Clark and Tittman, 1980

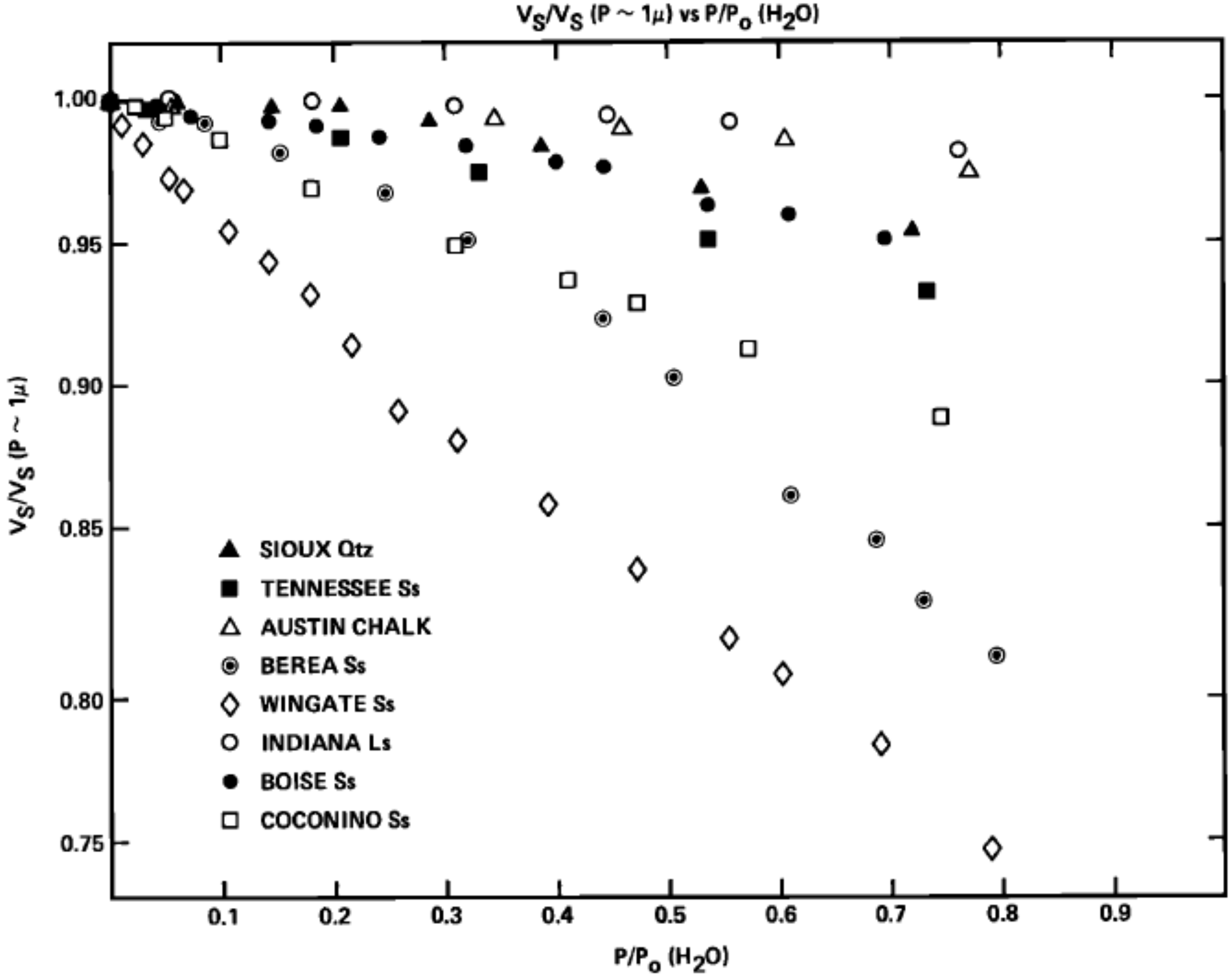
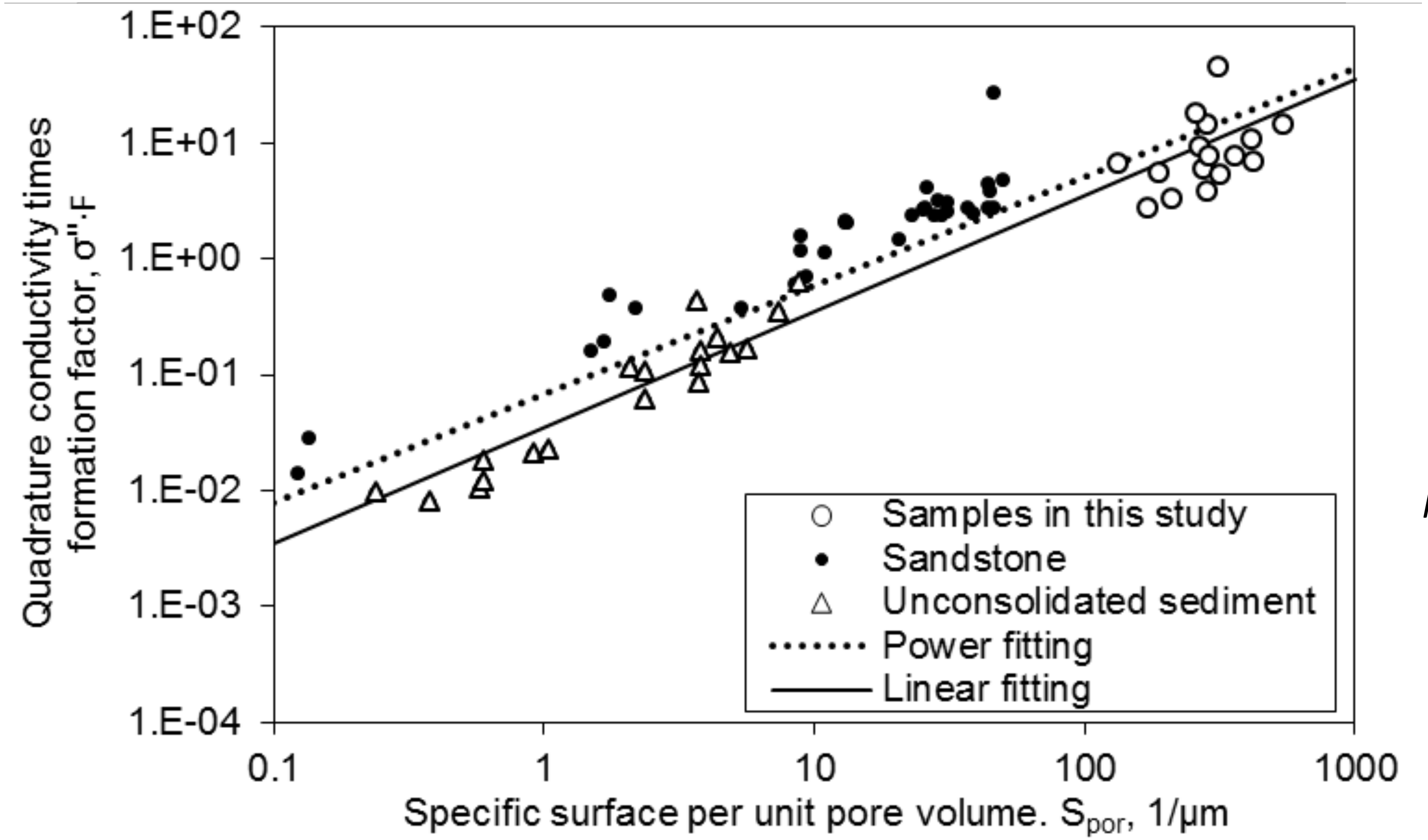


Fig. 7. Shear velocity versus the relative partial pressure of water for the sandstones, the Indiana Limestone, and the Austin Chalk. The velocity is normalized by dividing by the velocity measured in a vacuum of 1 μ.

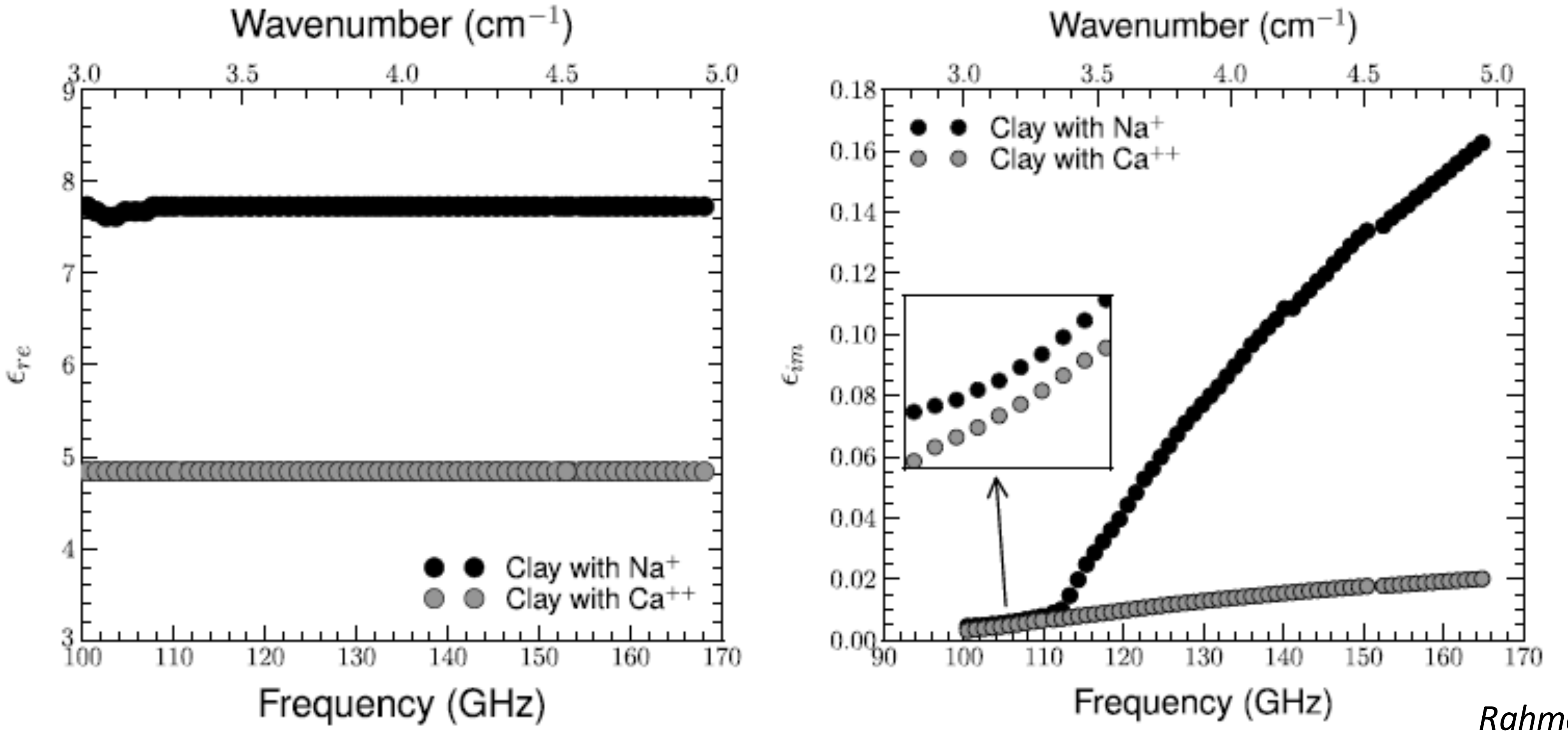
April 2016

SPECIFIC SURFACE AREA CONTROLS ON SIP



Niu et al., submitted

DIELECTRIC CONSTANT OF HOMOIONIC SMECTITES

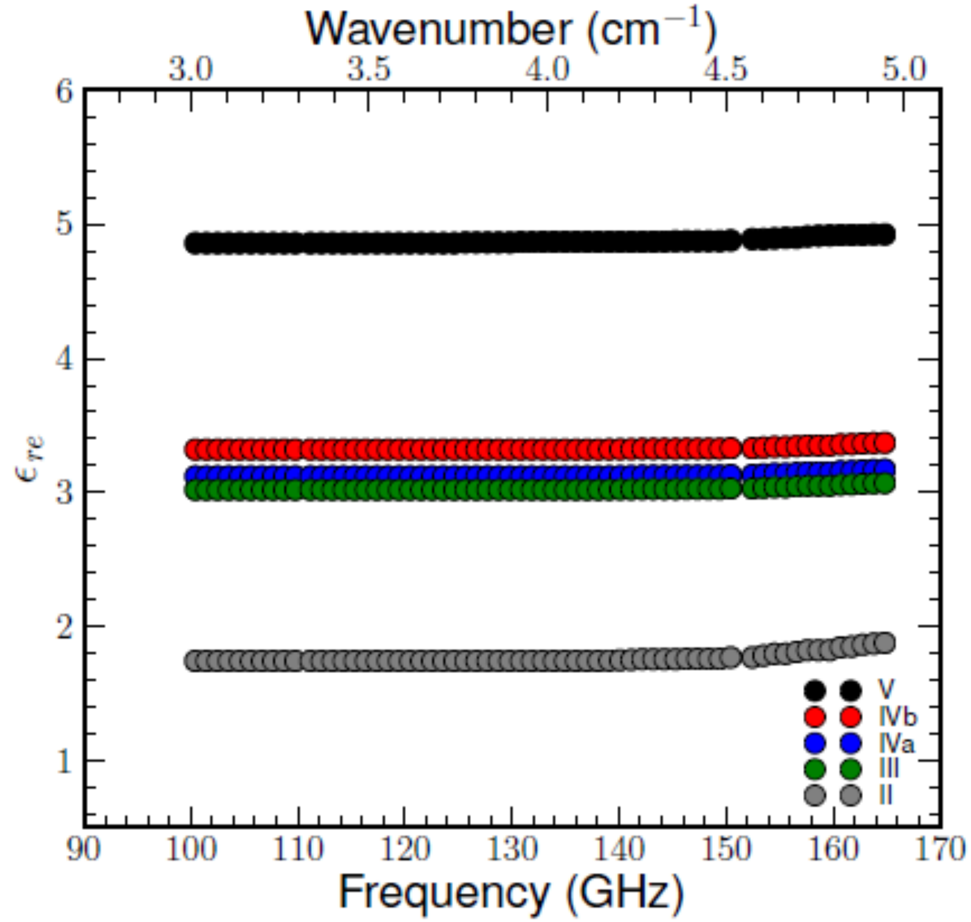


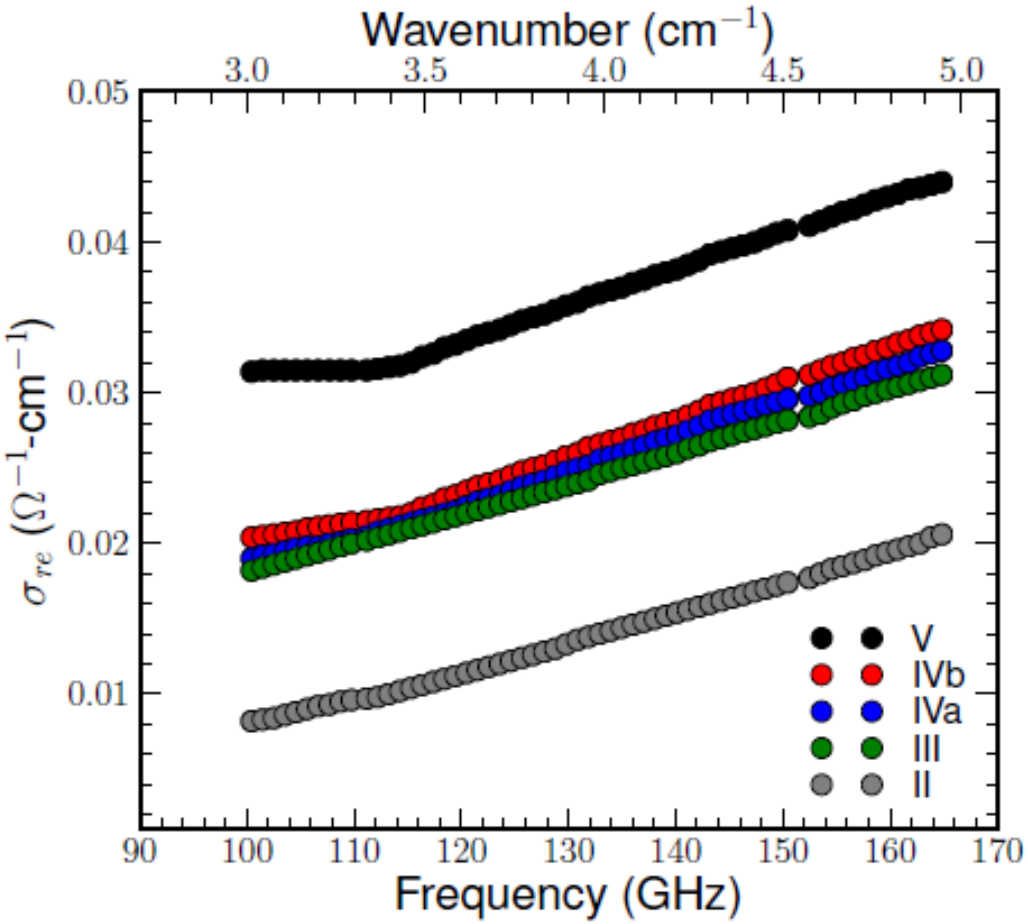
Rahman et al., 2015

Na+ smectite: higher specific surface area (SSA) and dominant 1–3 nm pores

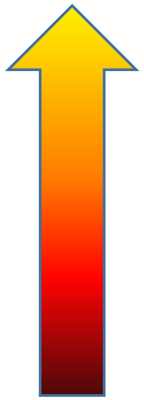
Ca++ smectite: has predominantly larger pores between 50 and 100 nm

DIELECTRIC CONSTANT OF ORGANIC MATTER



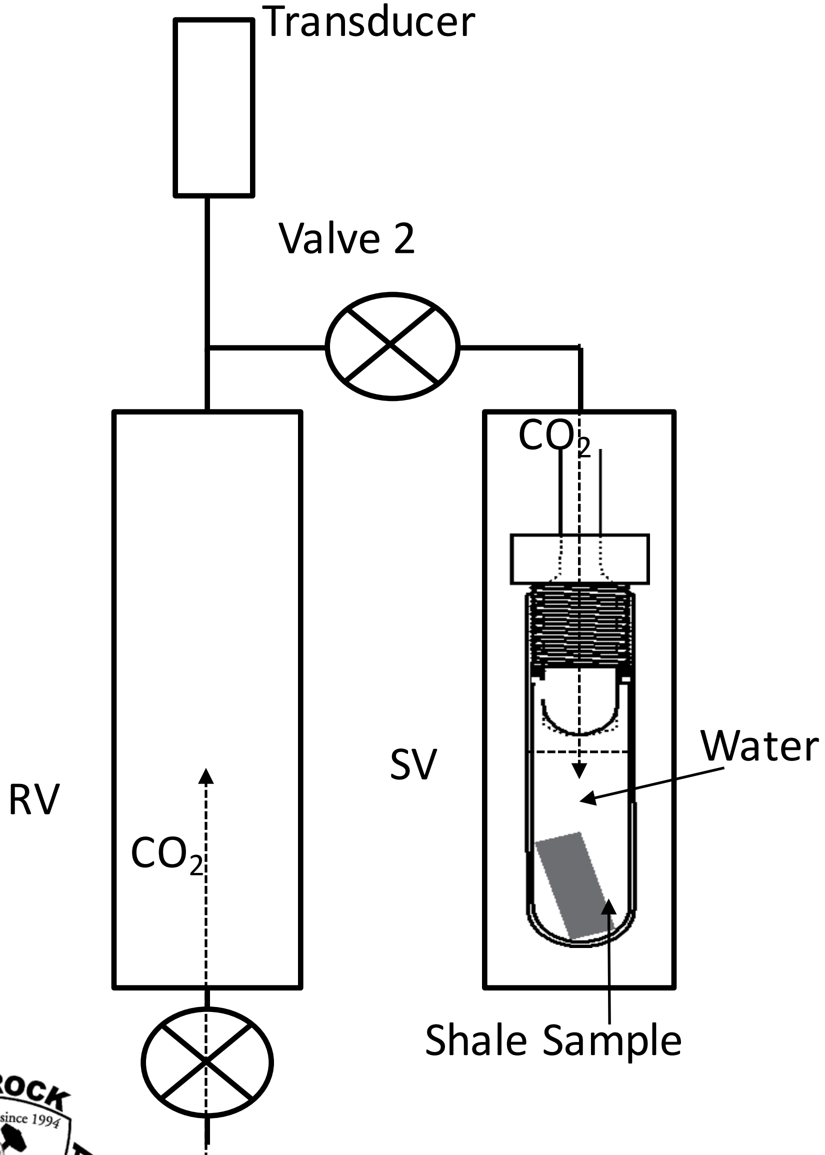


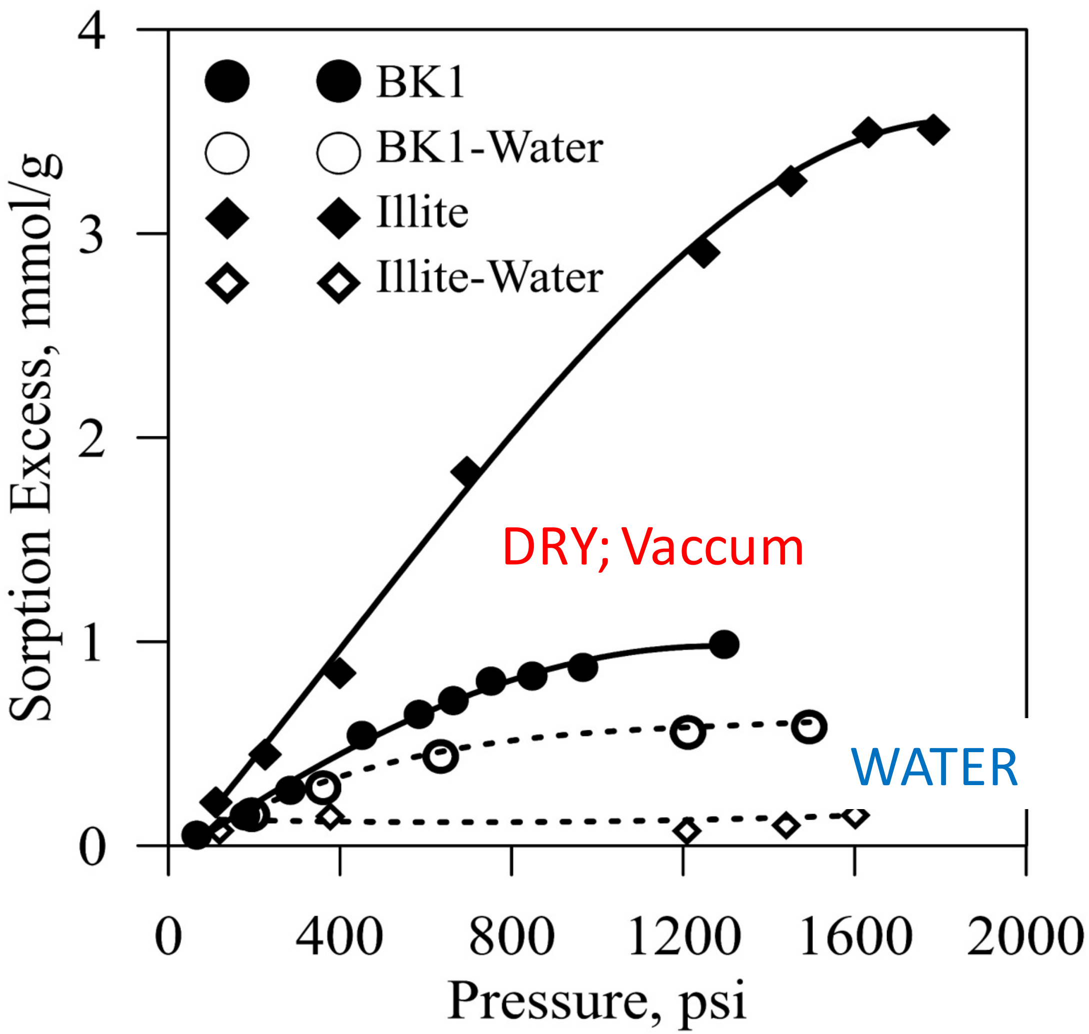
Maturity



Rahman et al., submitted

SUPER-CRITICAL CO_2 IN WATER IMMERSED ORGANIC SHALE





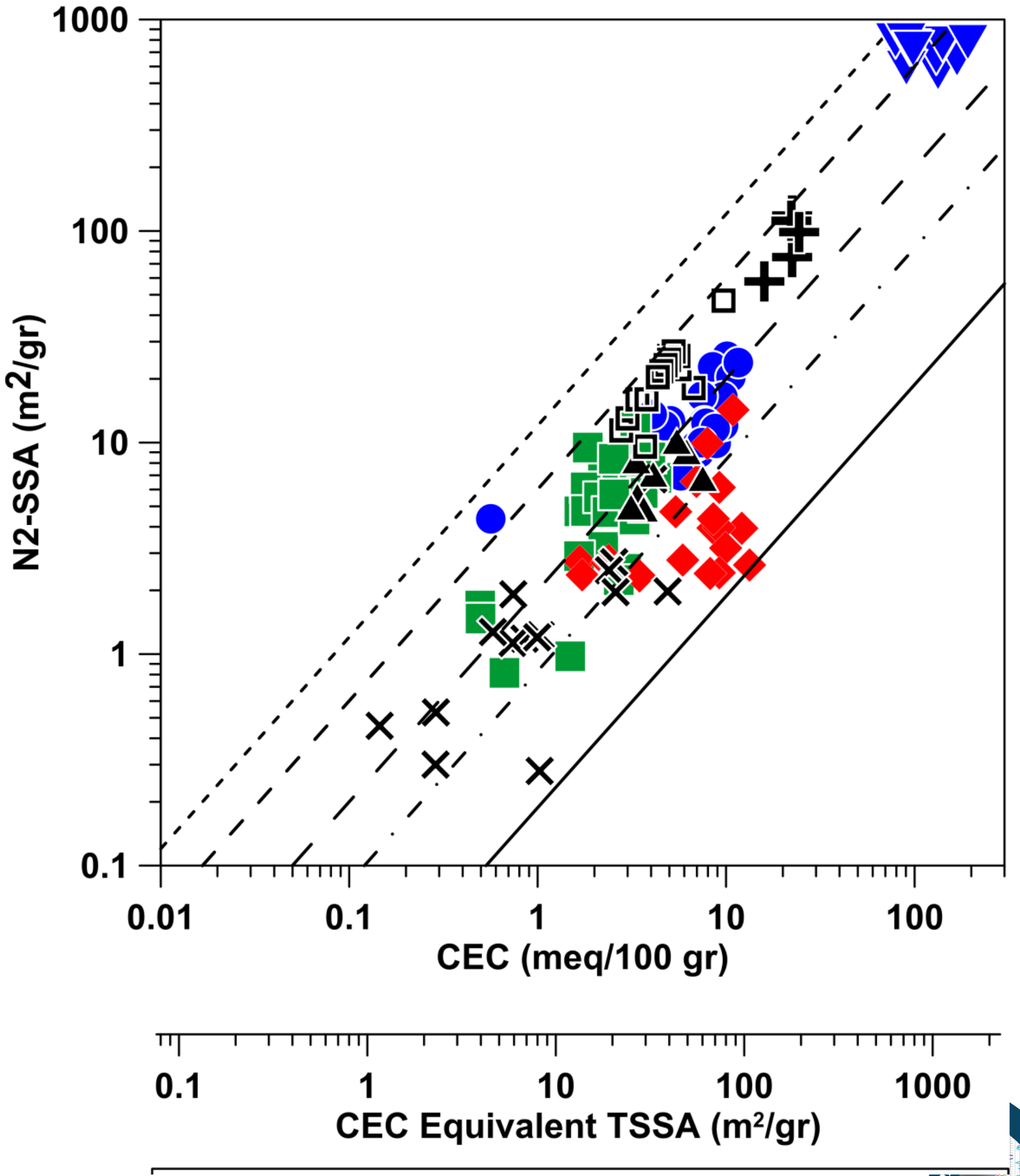
BK1 Maturity: Oil Window; TOC-12%, Illite-25%

CONCLUSIONS

- Fluid coverage in poly-mineratic rocks is controlled by:
  - Mineralogy
  - Surface Area
  - Surface Chemistry
- Fluids compete for inorganic and organic constituents
- Preferential fluid coverage depends on mineralogy and fluids polararity
- Fluid coverage affects elastic and electrical properties

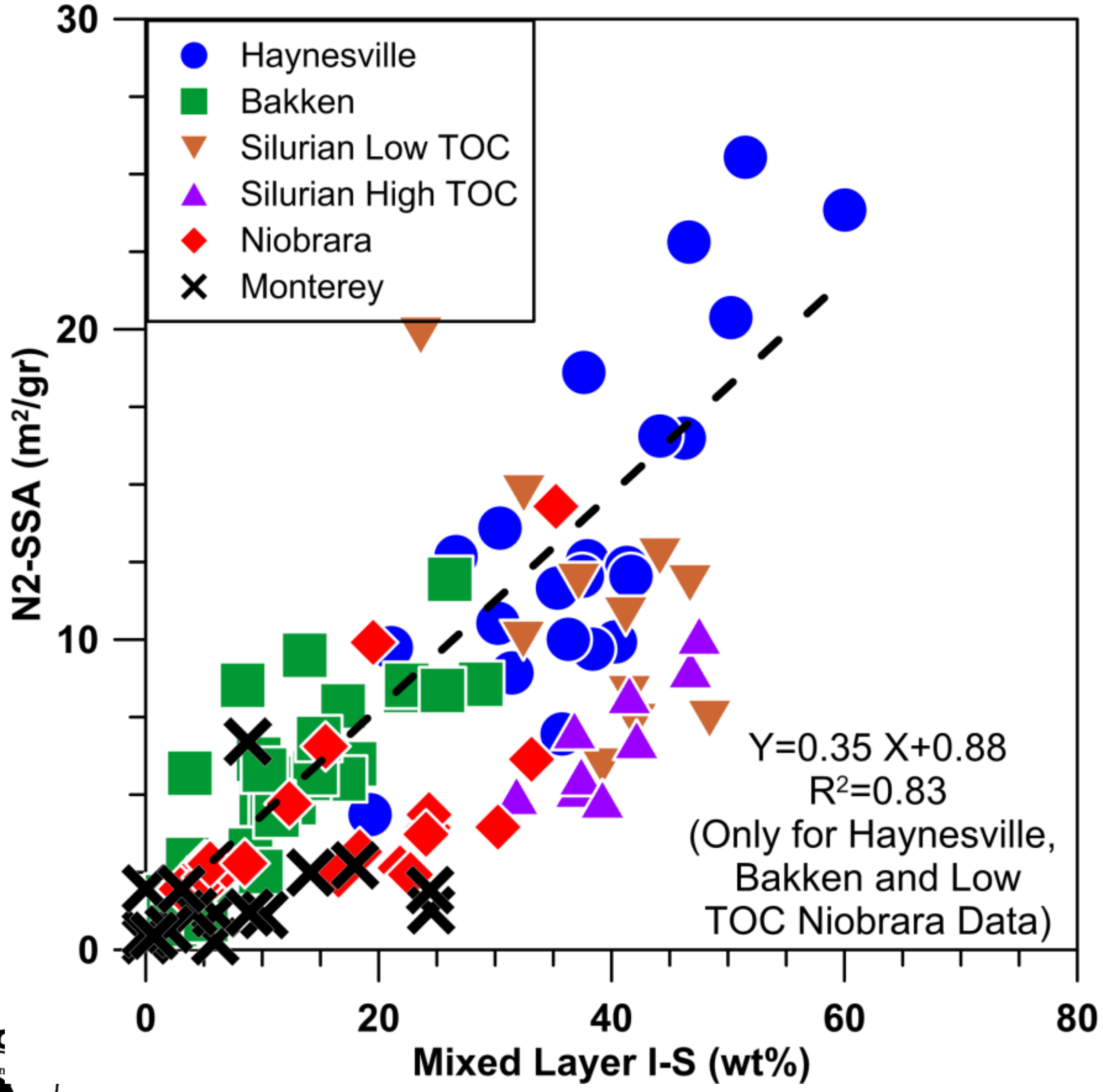
CEC TSSA-N2 SSA CORRELATION

CEC is linearly correlated with smectite content



Saidian et al., 2015

CLAY & ORGANIC MATTER EFFECTS ON SURFACE AREA

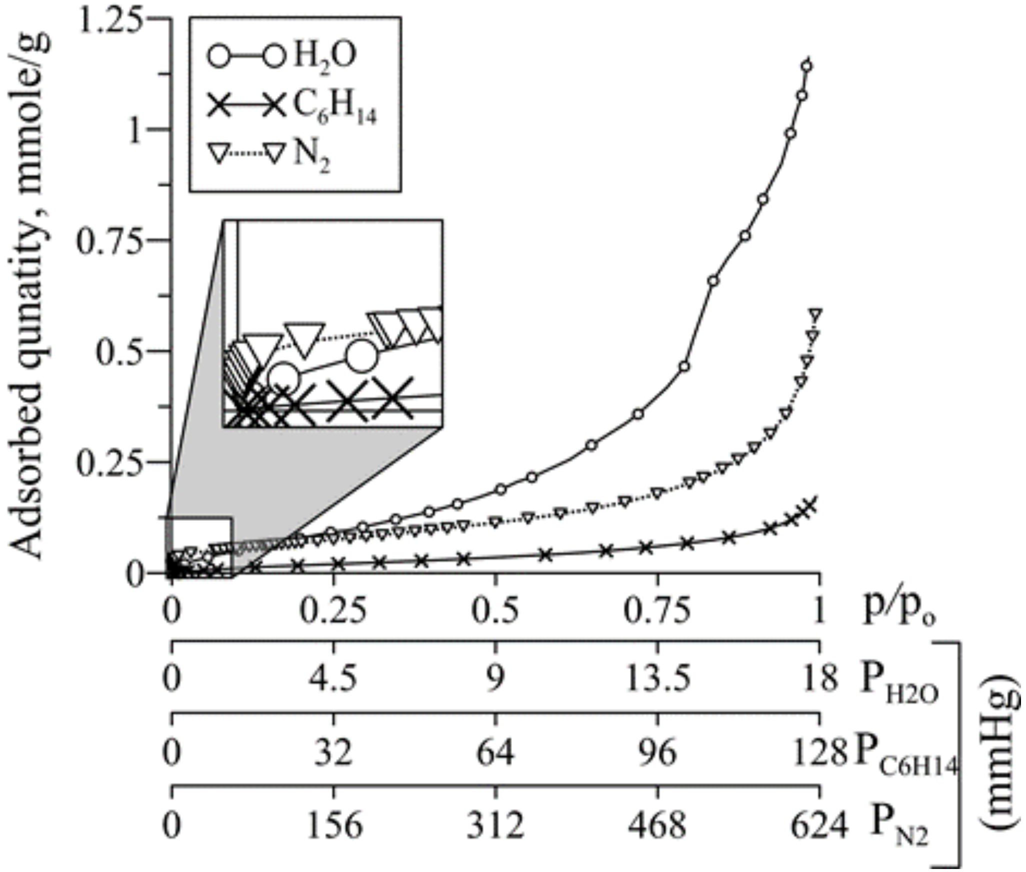


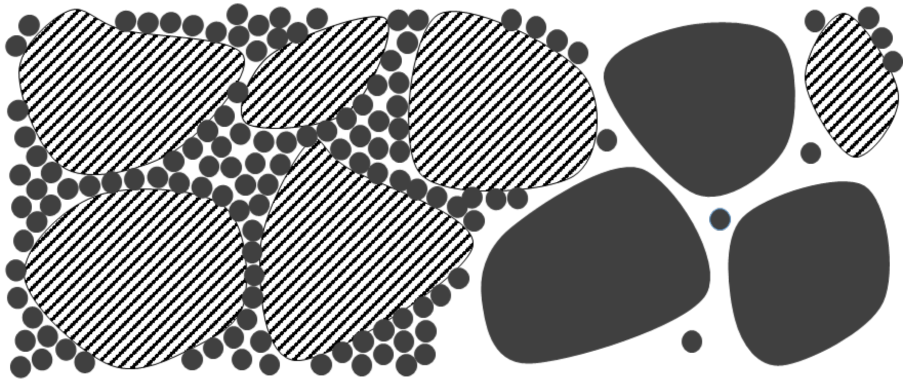
CEC is linearly correlated with smectite content

Saidian et al., 2015

PREFERENTIAL SORPTION OF FLUIDS

Preferential sorption of fluids depends on polarity of surfaces

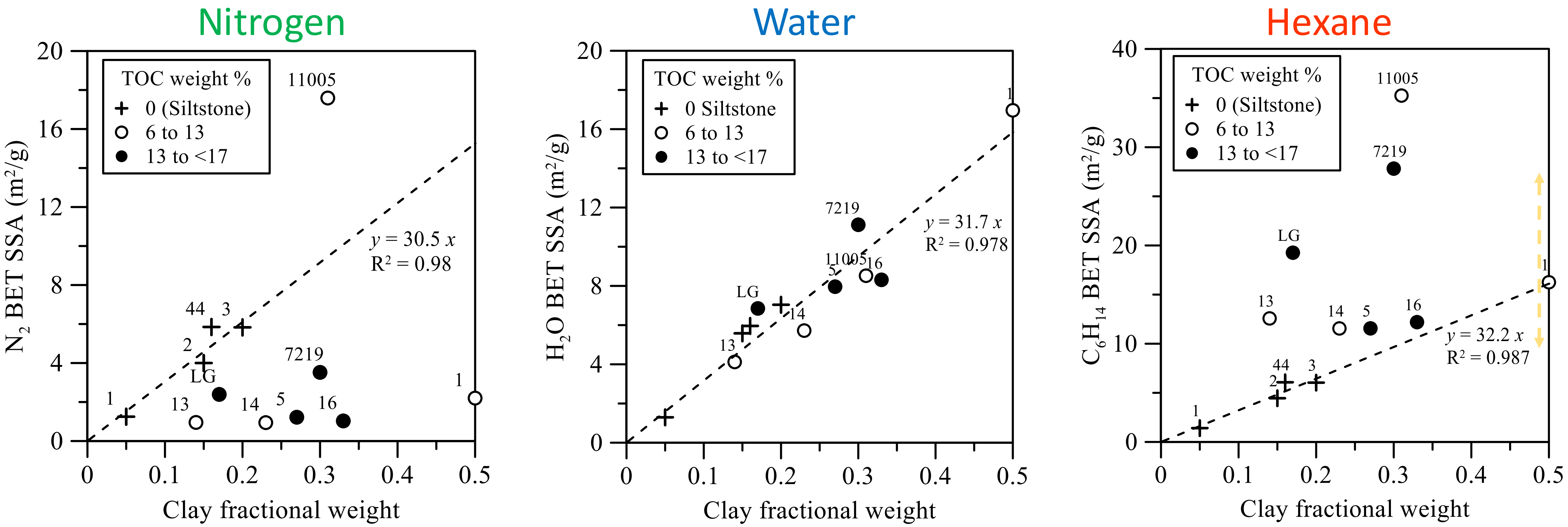




- Quantification of hydrophilic and hydrophobic pores of shales

Kumar et al., submitted

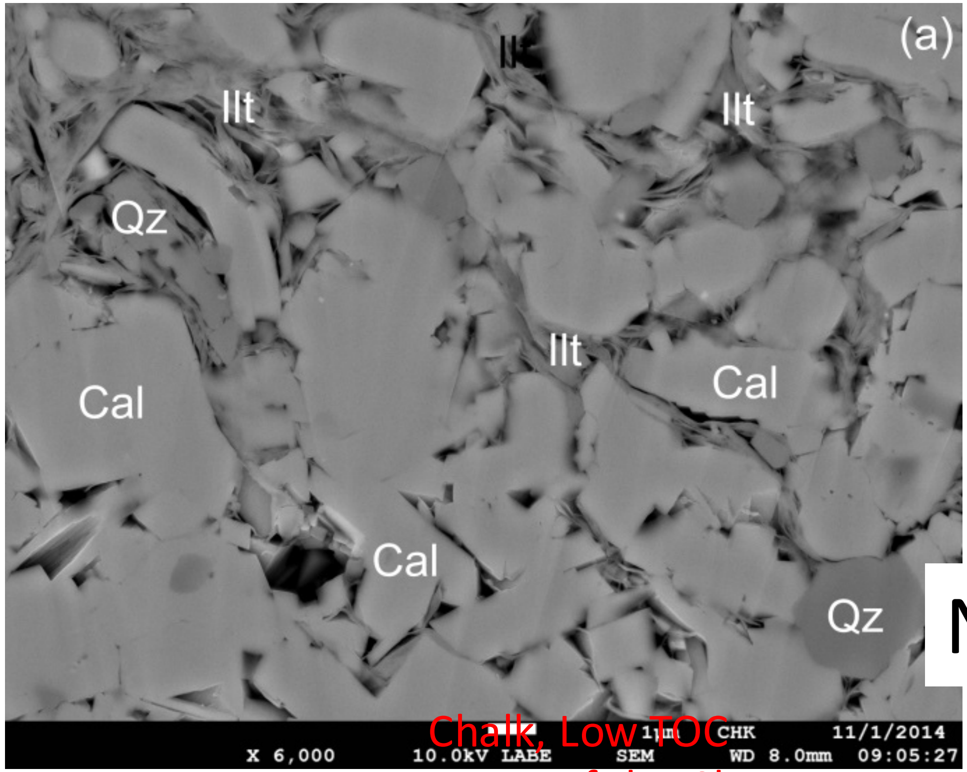
SURFACE AREA AND CLAY CONTENT



- OM pores are hydrophobic
- OM pore development starts at the onset of oil window
- Presence of **bitumen free OM pores**
- Cryogenic N_2 blocked by nano-sized pores in organic matter

Kumar et al., submitted

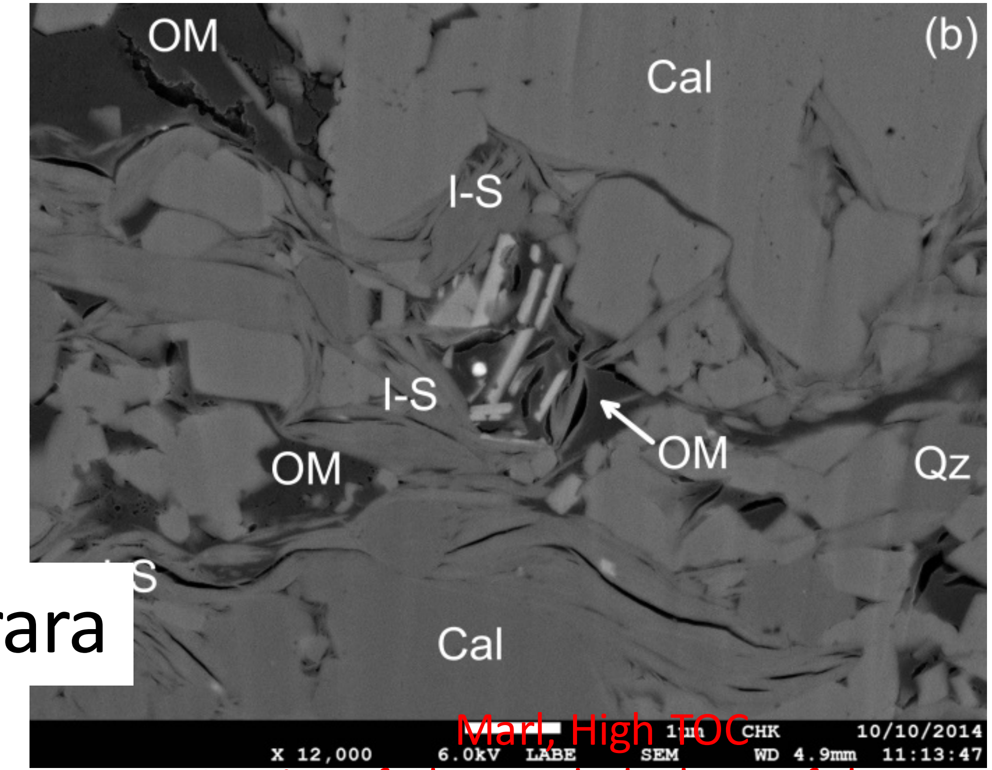
WHICH SURFACES ARE EXPOSED



Chalk, Low TOC

Exposure of the Clays

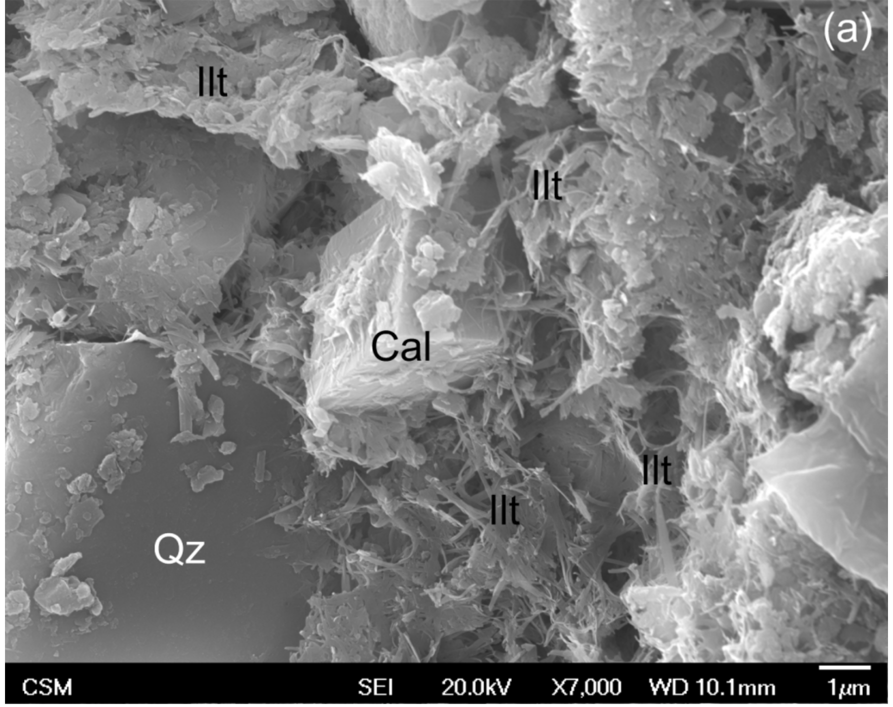
Niobrara



Marl, High TOC

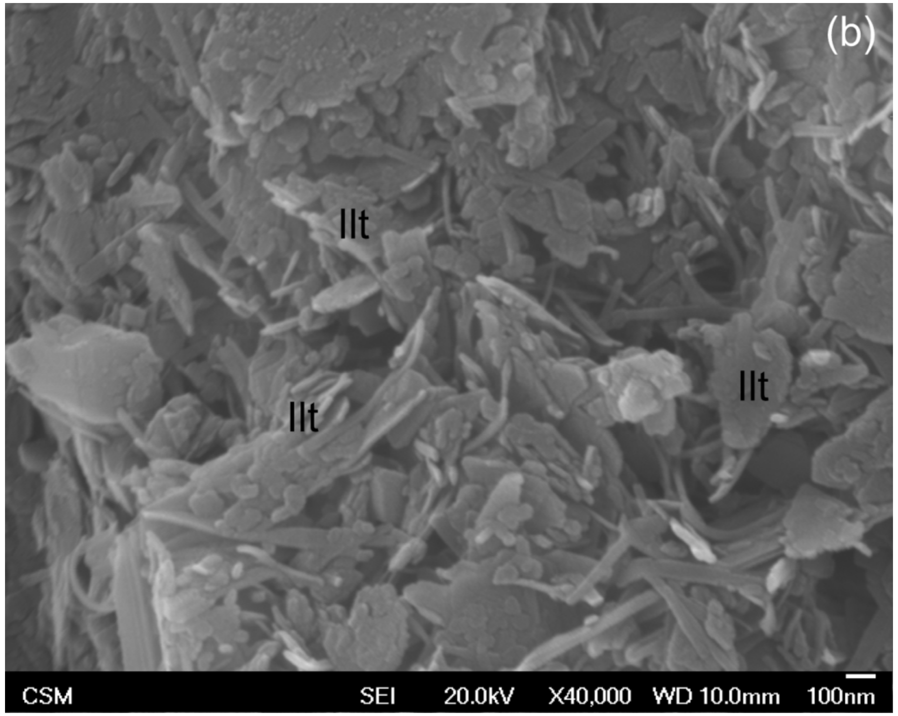
Coating of Clays and Blockage of the Pores

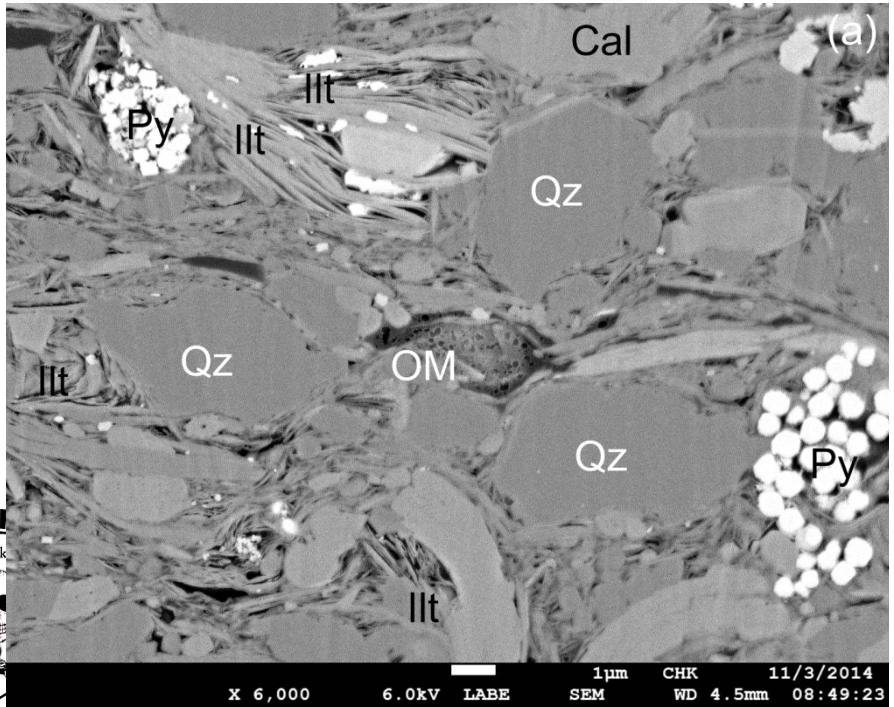
Kuila, 2013; Saidian et al., 2015



Bakken

Exposed illite flakes

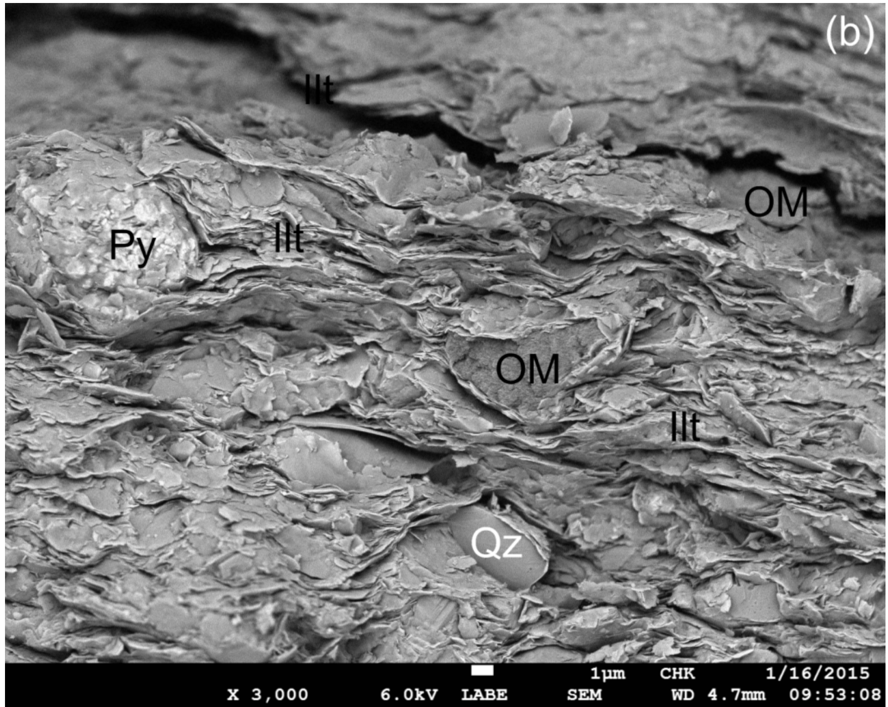




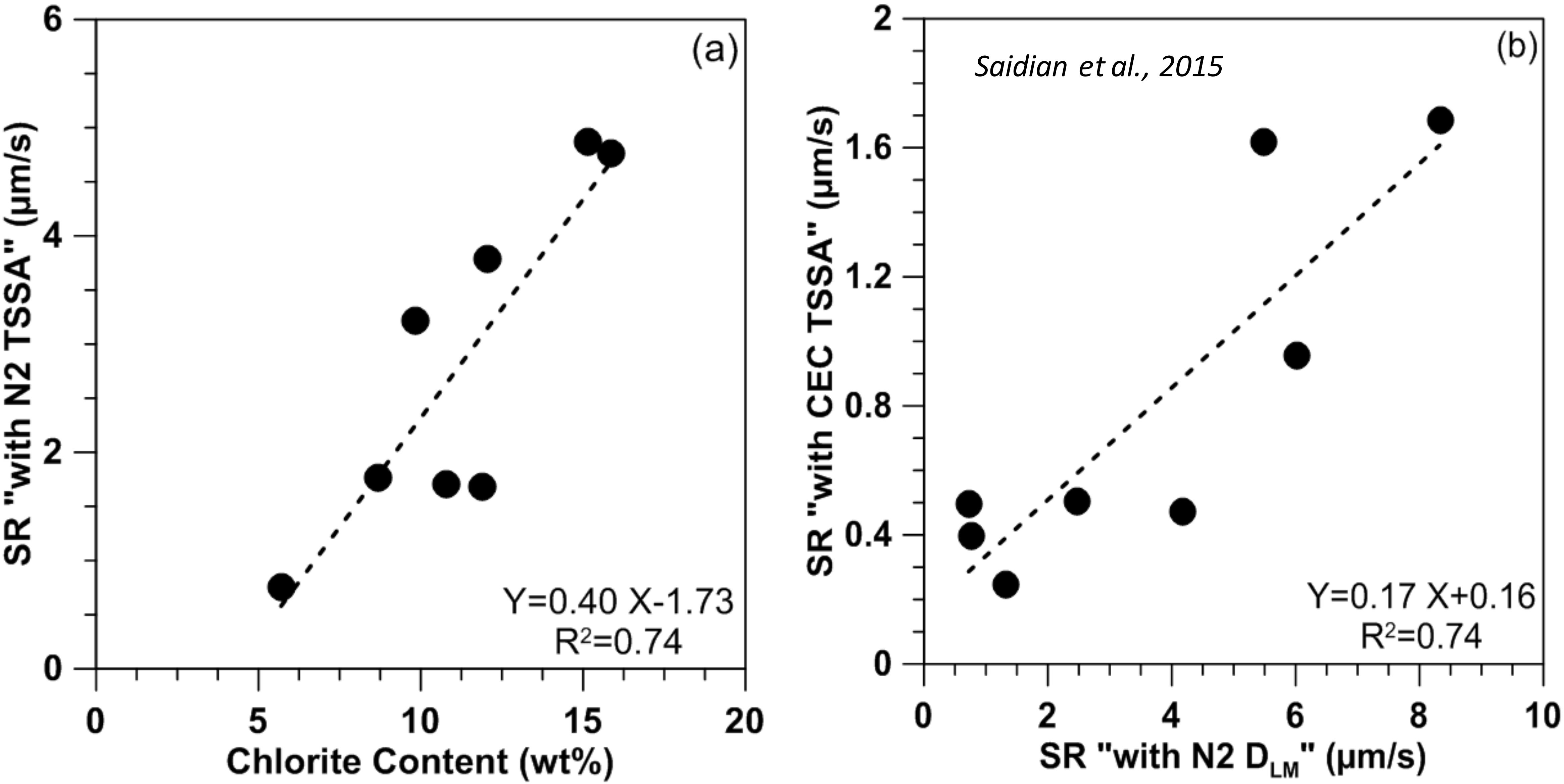
Haynesville

Exposed illite flakes

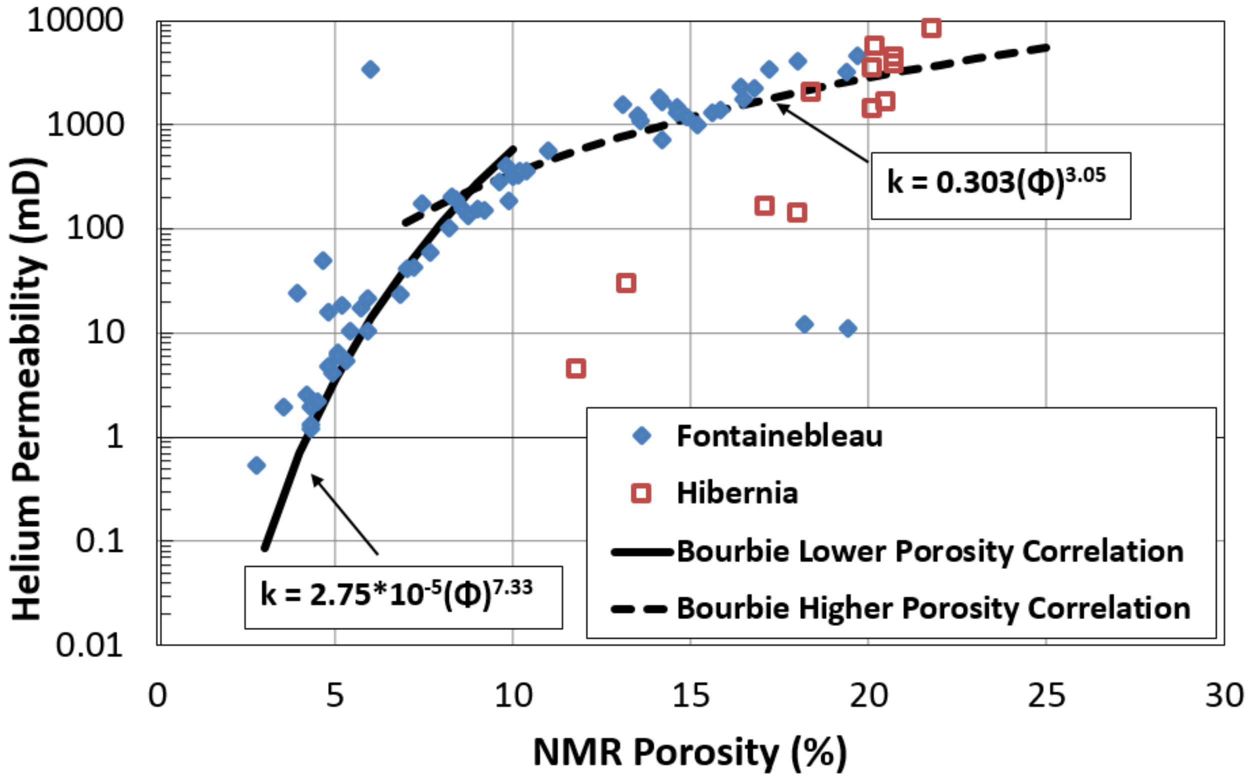
Kuila, 2013; Saidian et al., 2015

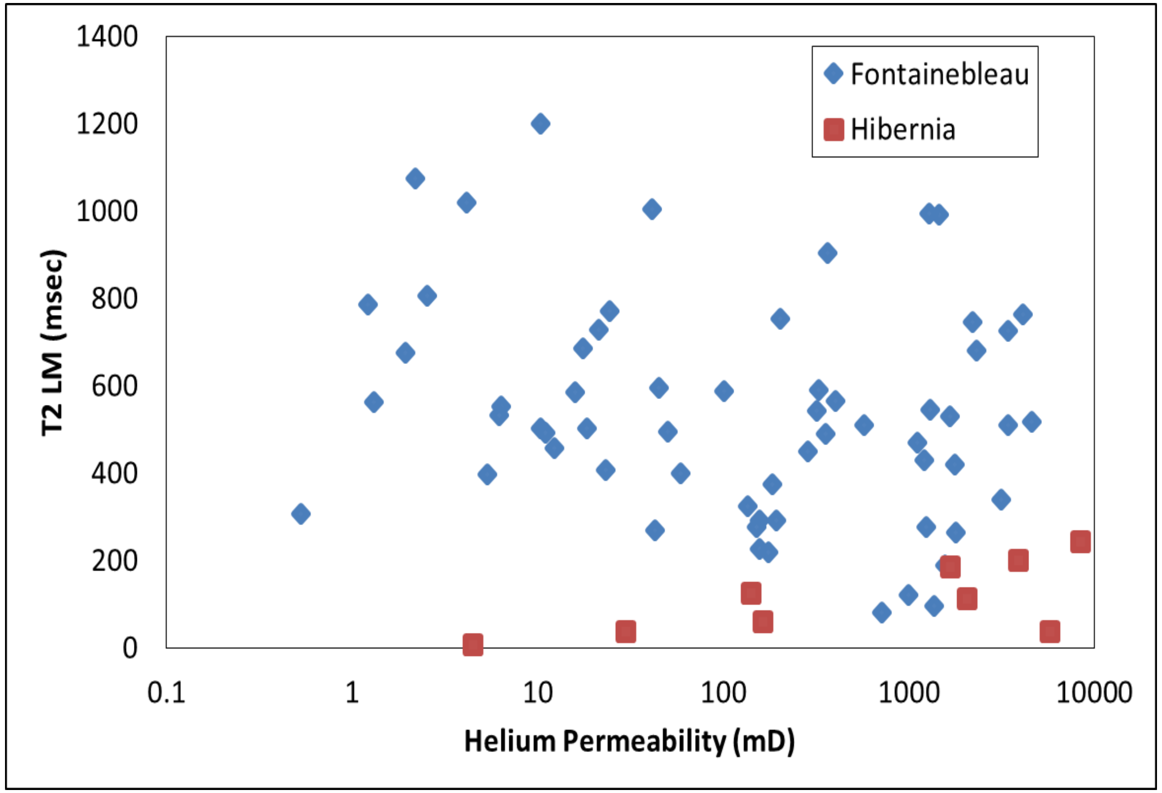


SURFACE RELAXIVITY AND SURFACE AREA



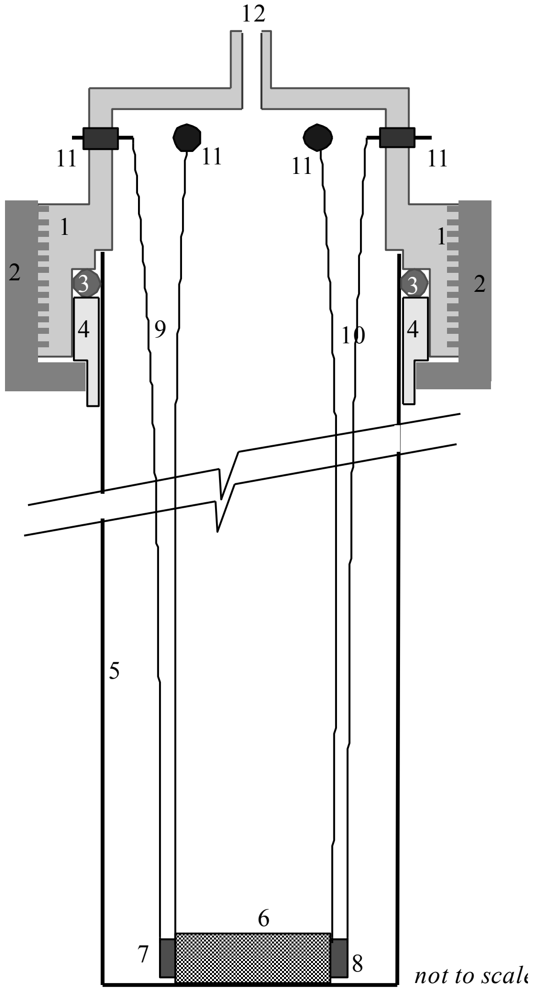
PERMEABILITY MODELS





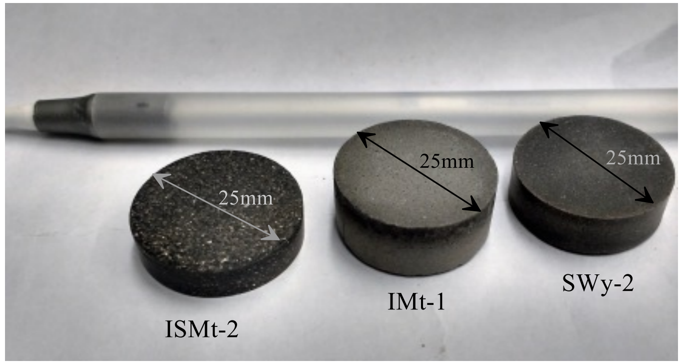
Livo et al., submitted

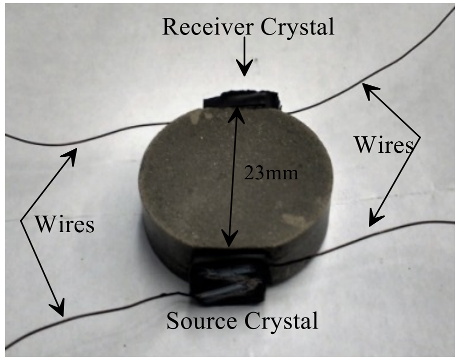
ACOUSTIC SIGNATURES

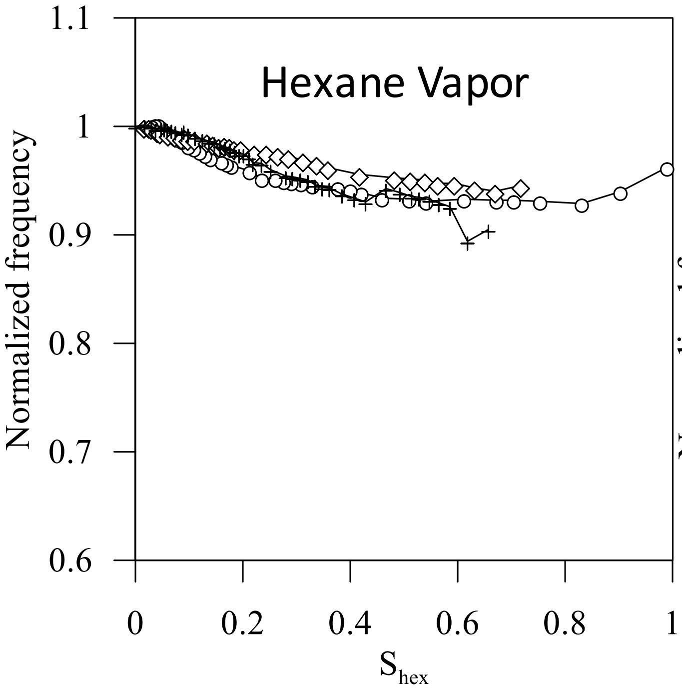


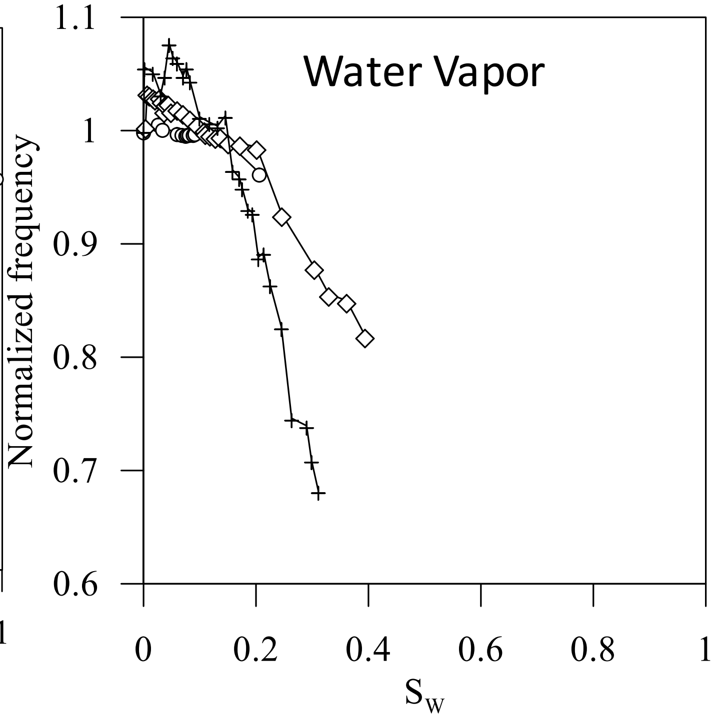
Sample Tube

Confined Undersaturated Condensates





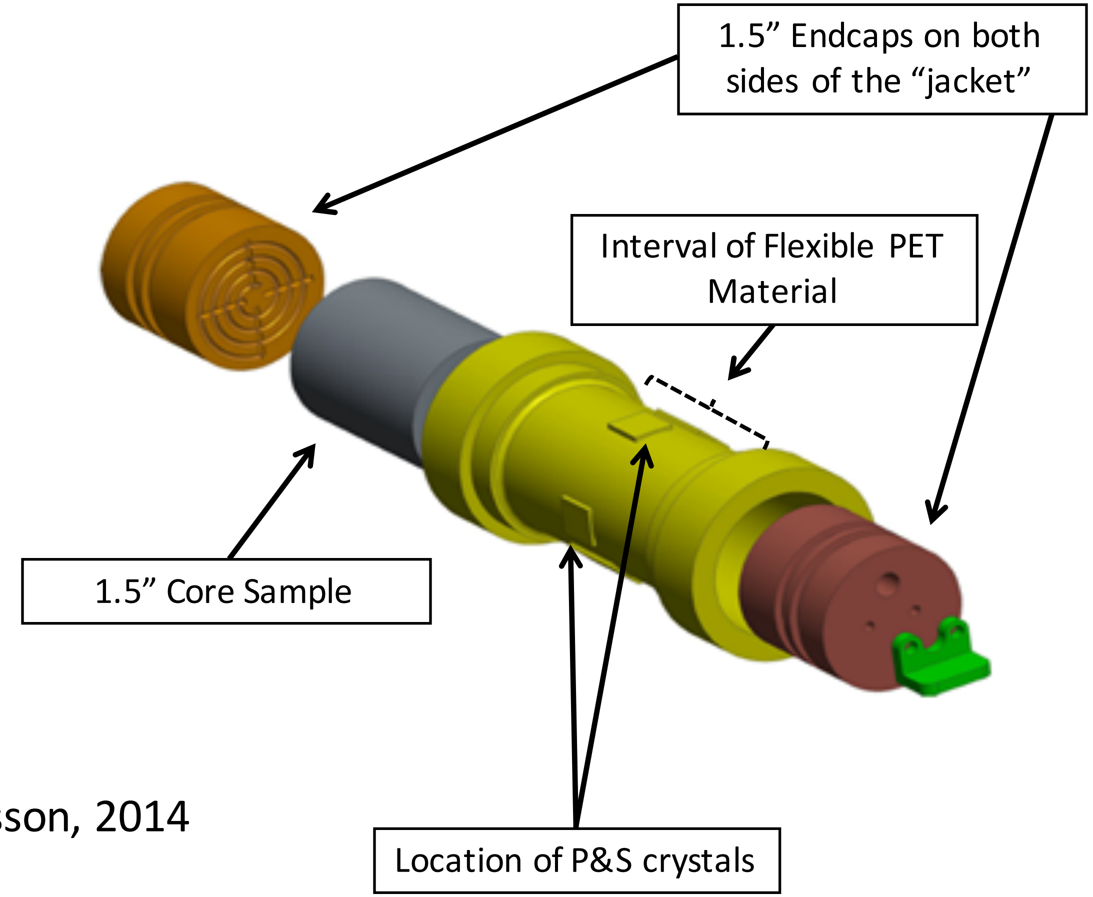




SIMULTANEOUS ELASTIC AND ELECTRICAL PROPERTY MEASUREMENTS

Jacket Design:

- Flexible PET jacket
- End pieces for pore fluid lines
- P-wave and S-wave measurements in 0° 45° and 90° degrees direction under pressure
- Core sample is **reusable**
- Simultaneous elastic and electrical property measurements



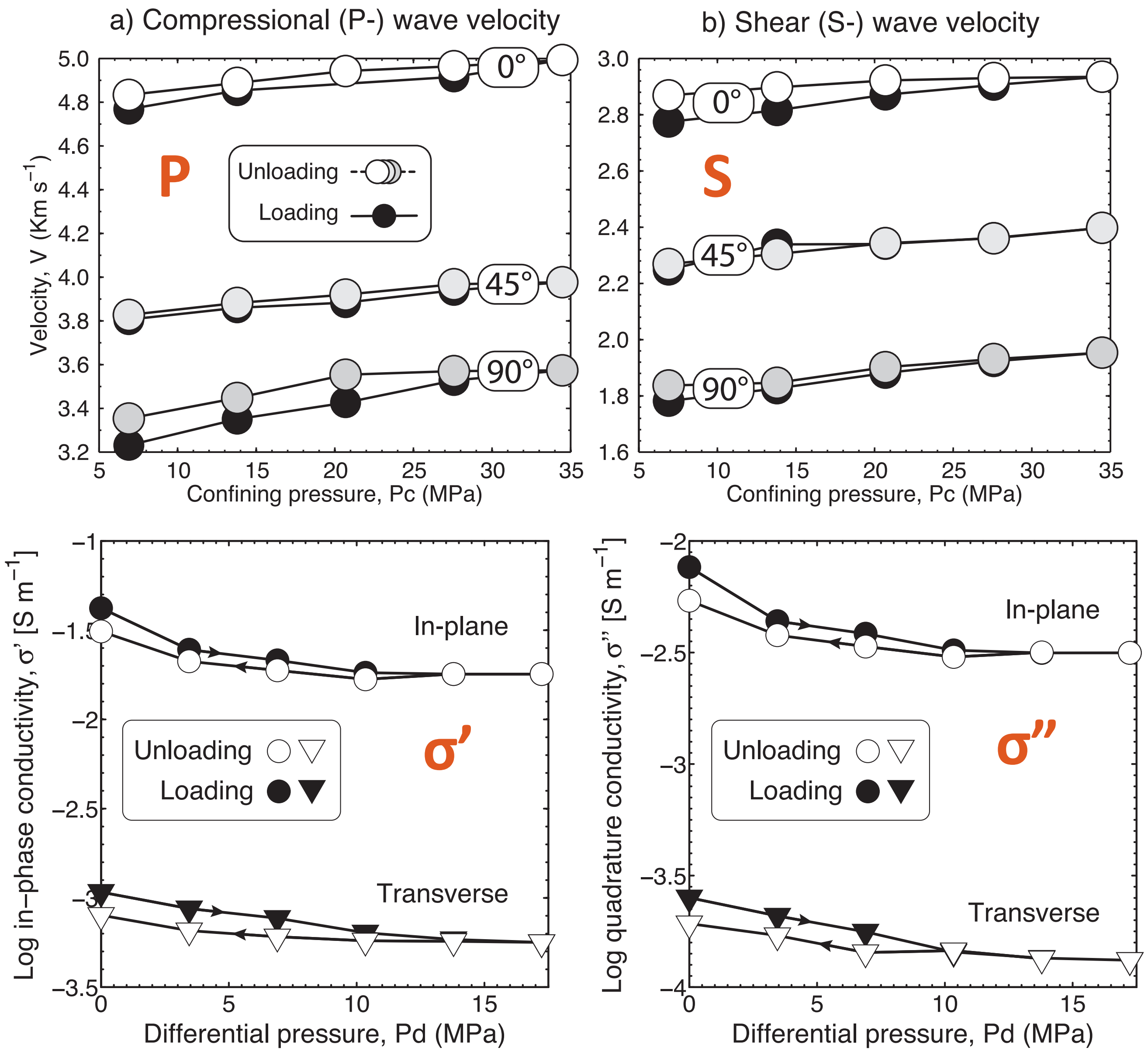
Designed by Prasad, Panfiloff and Larsson, 2014

Panfiloff, 2015

JOINT ULTRASONIC AND SIP MEASUREMENTS

Ultrasonics

Complex conductivity

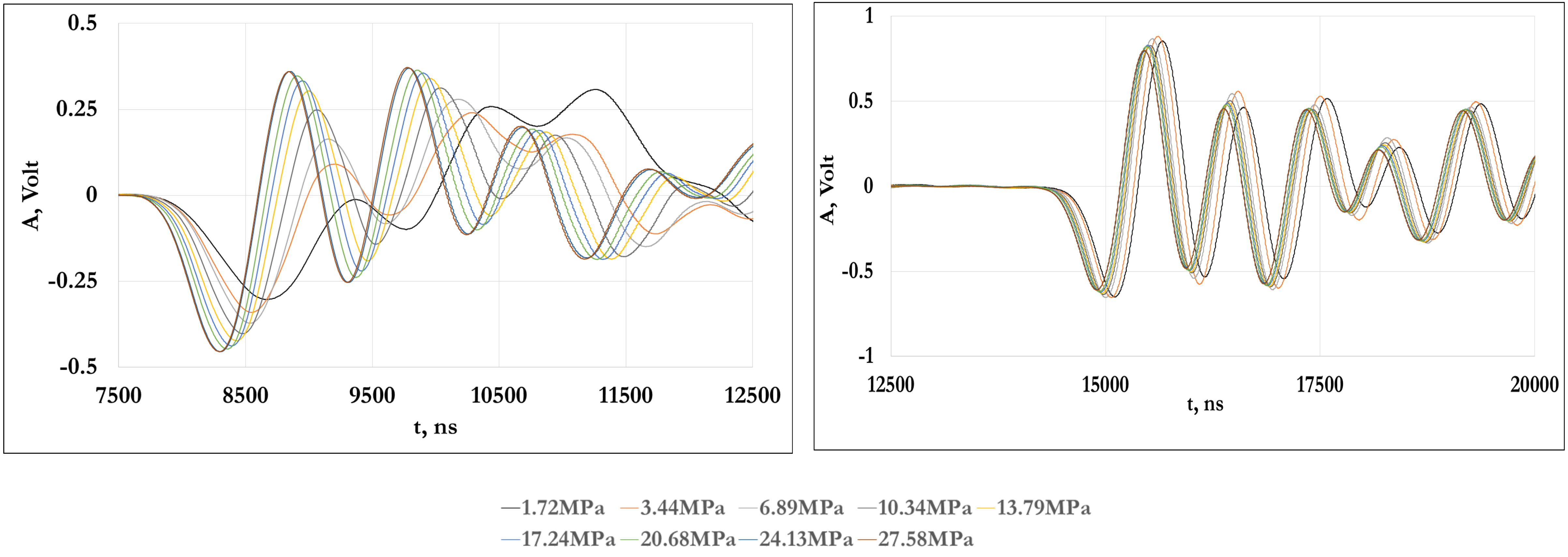


Woodruff et al., 2014

TYPICAL ACOUSTIC WAVE SIGNALS

Compressional Waves

Shear Waves



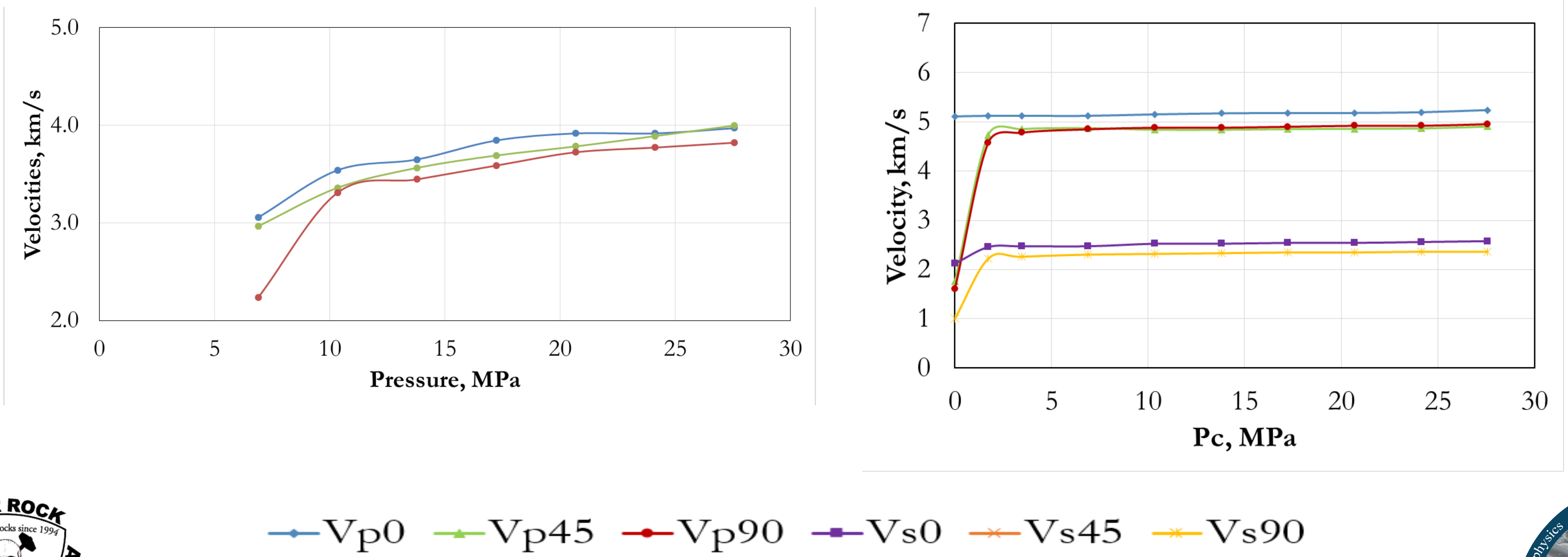
Panfiloff (MS cand.); Ou (PhD cand.); Niu (posdoc)

ACOUSTICS – VELOCITIES

- Pressurized measurement from 0 to 28 MPa (4000psi)
- Velocities as a function of pressure:

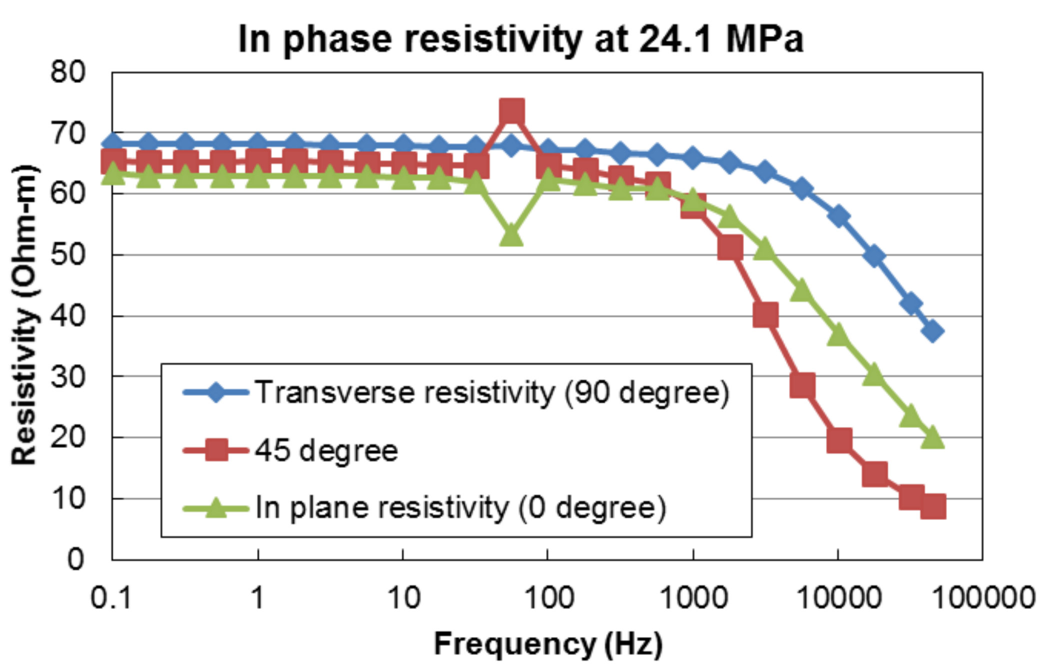
Sandstone, Dry

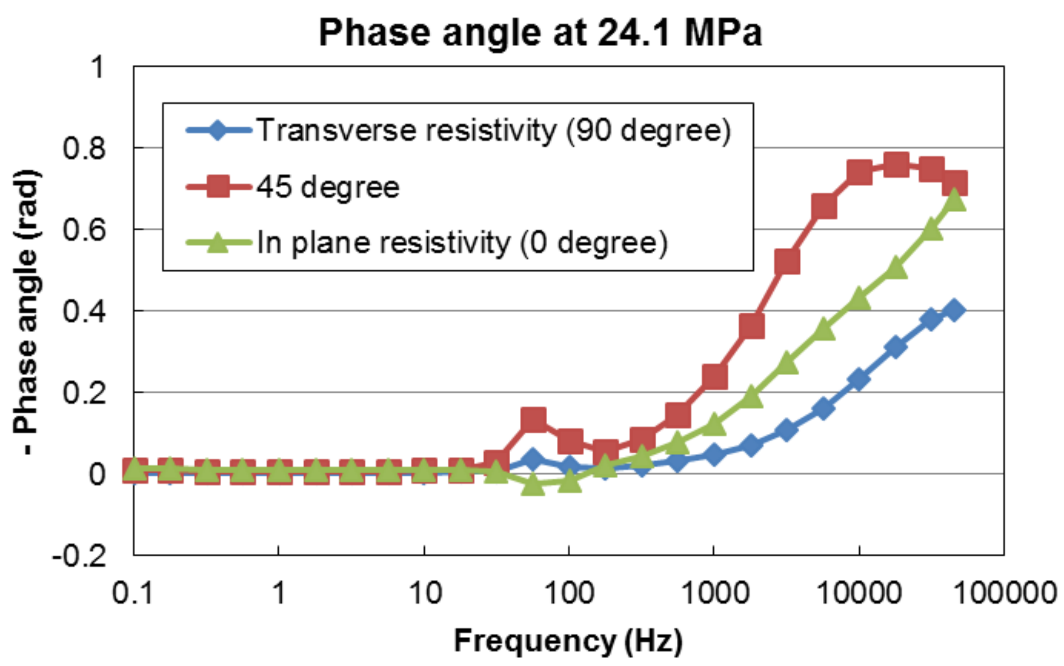
Lower Austin Chalk, Preserved



COMPLEX RESISTIVITY – FREQUENCY DOMAIN

- In phase resistivity and phase angle of **preserved lower Austin Chalk sample** as function of frequency at 24.1 MPa (3000 psi)



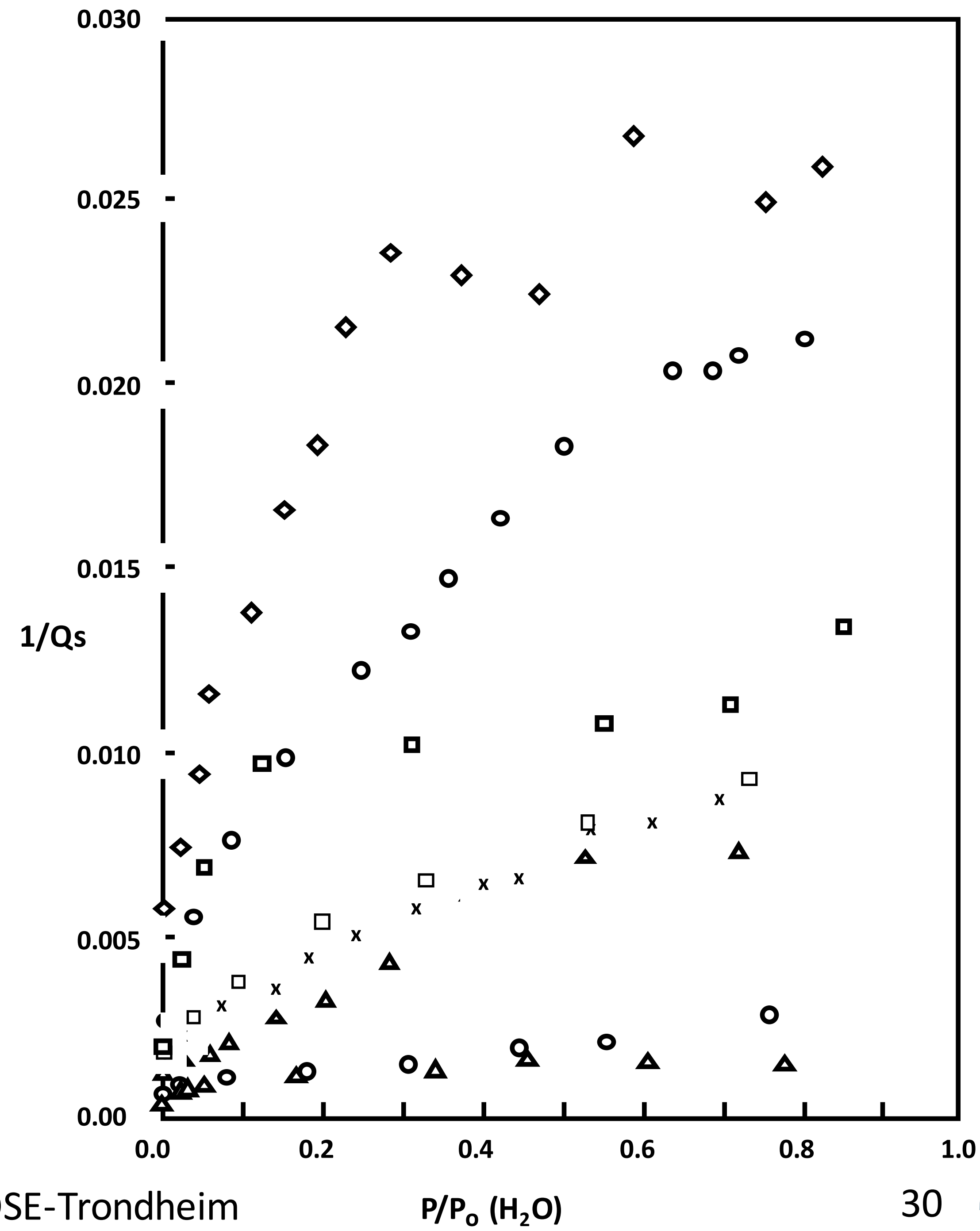


In phase resistivity anisotropy and phase angle anisotropy increase at high frequency (>1 kHz)

EFFECT OF FLUIDS

	Sioux Qtz
	Tennessee Ss
	Austin Chalk
–	Berea Ss
✧	Wingate Ss
O	Indiana Ls
	Coconino Ss
X	Boise Ss

Clark and Tittman, 1980



CSM CAPABILITIES

1. SEISMIC & ELECTRICAL PROPERTIES

- Multi-frequency anisotropic acoustic and electrical property measurements under pressure
- Multi-frequency acoustic measurements (max. 150,000 psi, 1000 °C)
- Uniaxial load frames and numerous ultrasonic equipment to measure at high P&T conditions

2. FLOW PROPERTIES

- Nano-Darcy permeability measurements
- Conventional poro-perm measurements
- Centrifuge to measure capillary pressures (in collaboration)

3. PORE SCALE MEASUREMENTS

- 2-MHz NMR system to measure cores
- Various types of porosity measurements

CSM EQUIPMENT

4. QUANTITATIVE ANALYSES (including those with other departments)

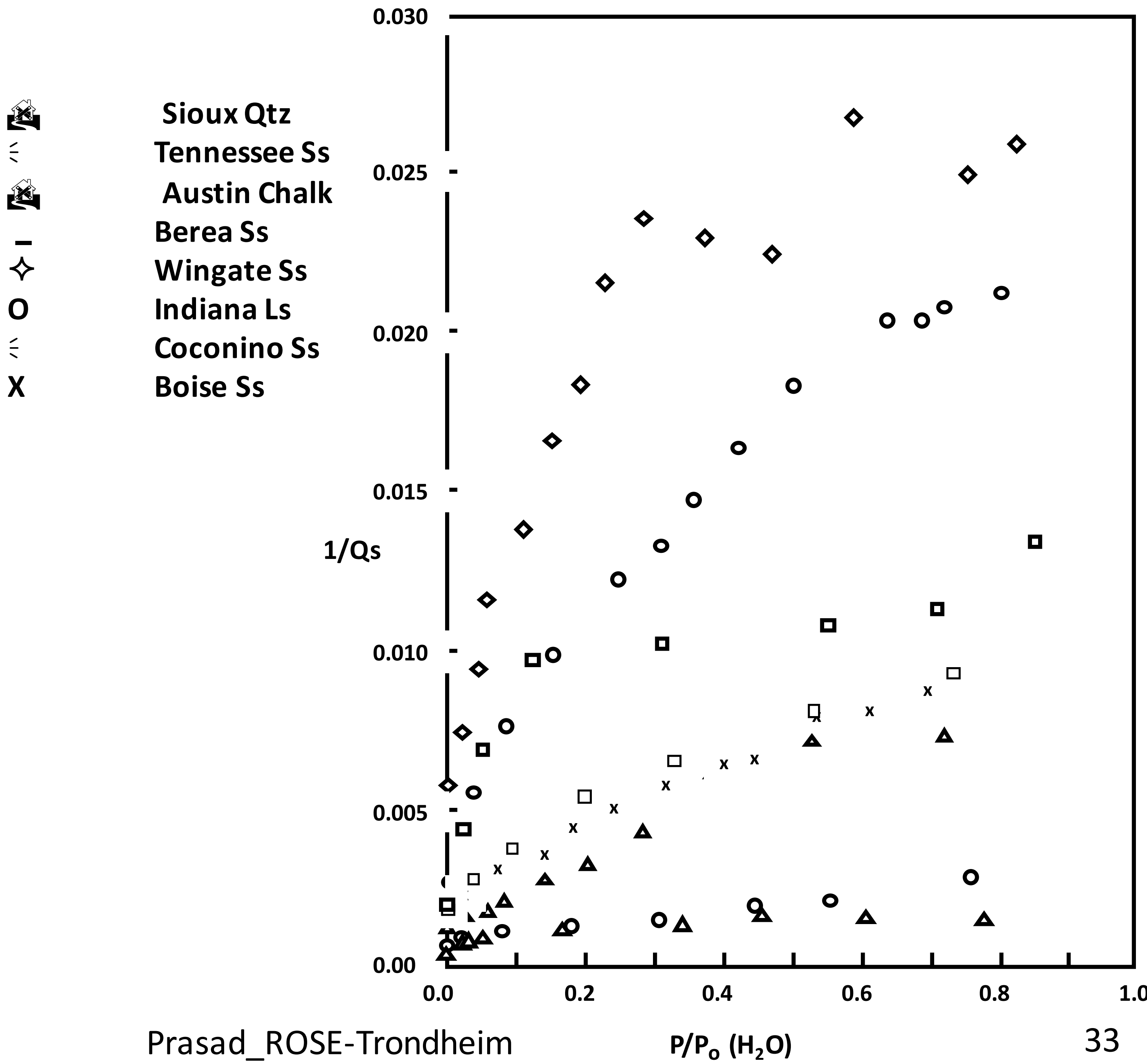
- Scanning acoustic microscope up to 250 MHz (up to 10 µm resolution)
- Micro-CT scanner (up to 10 µm resolution)
- SEM; ESEM; FE-SEM, Nano-indentation system, ion mill (Material Science)
- QEMSCAN, SEM, XRD, Rock-Eval, and optical microscopy, (Geology)
- Open Column Liquid Chromatography (Petroleum Engineering)
- NMR, FTIR, GCMS; MBMS (Chemistry and Chemical Engineering)

5. PORE SCALE MEDDLING

- Subcritical sorption equipment with various gases, including moisture
- Equipment for high pressure sorption under construction
- Equipment for high pressure sorption under construction
- Pressure pulsing system (under construction)
- CO / CO2 Flooding system

EFFECT OF FLUIDS

Clark and Tittman, 1980



BACKGROUND

- Carbon capture and storage in deep geological settings
- Caprock seals and prevents buoyant migration of CO_2
  - Permeability of caprock ~ Nanodarcy
  - Permeability of tight-gas shales ~ Nano to Microdarcy
- CO_2 injection changes the state of stress in reservoir rocks and in caprocks
- **Could faults or fractures develop in caprocks that allow CO_2 transport and escape?**

HYPOTHESIS AND OBJECTIVES

Hypothesis:

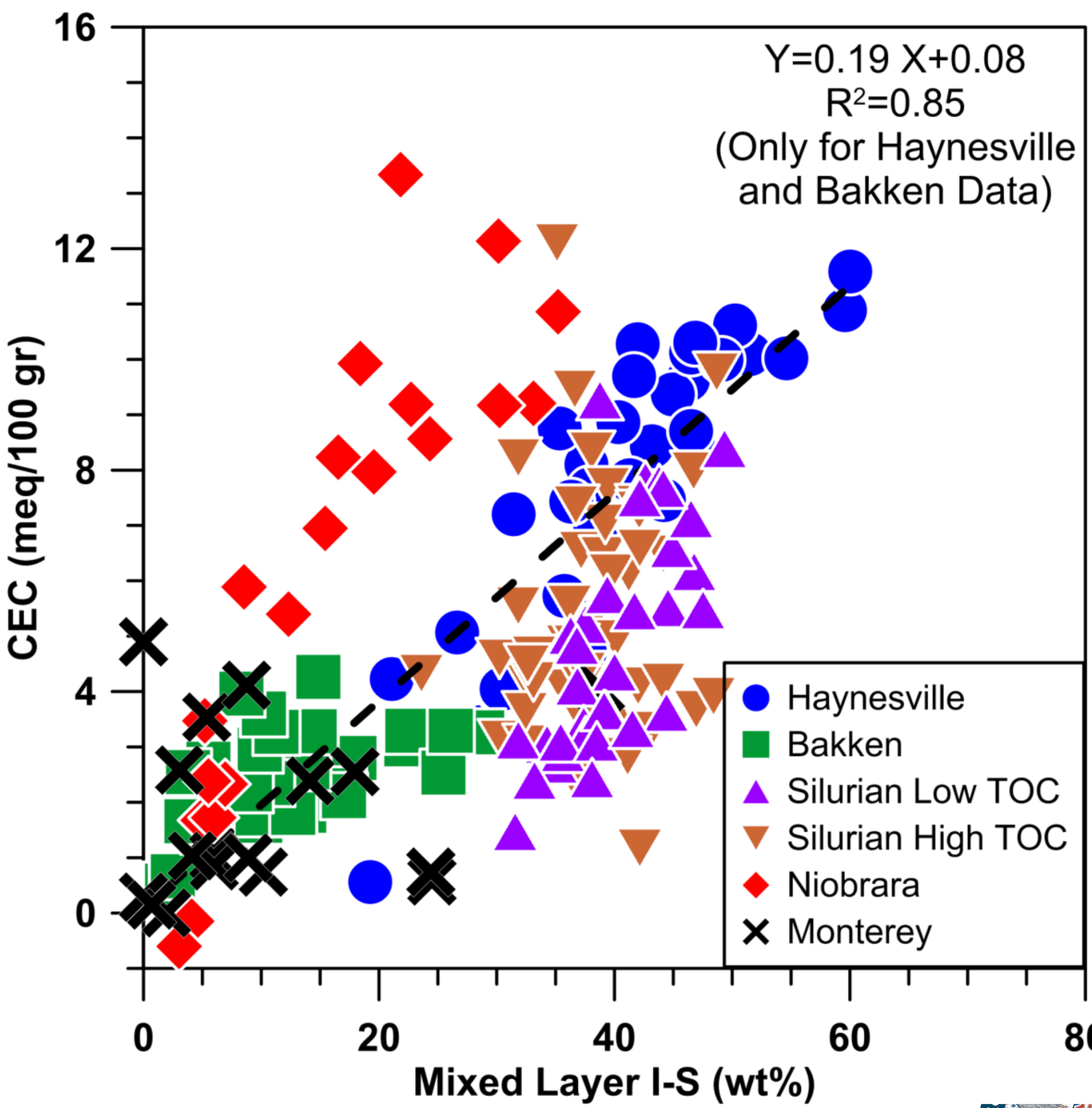
- Mechanical damage to shales not necessarily = high permeability and high leak rates

Objectives:

- Determine the behavior of intact and fractured caprocks when exposed to supercritical CO_2 at elevated pressures
- Quantify adsorption, strain and acoustic properties of shales with sorbed CO_2
- Provide framework for monitoring, verification and accounting (MVA) efforts of CO_2 sequestration and its effect on caprock

EFFECT OF CLAY AND ORGANIC MATTER

Prasad_ROSE-Trondheim



Saidian and Prasad, 2015