Identification of Clay Microporosity in the Reservoir Characterization of the Cypress Sandstone: Implications for Petrophysical Analysis, Reservoir Quality, and Depositional Environment

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Outline

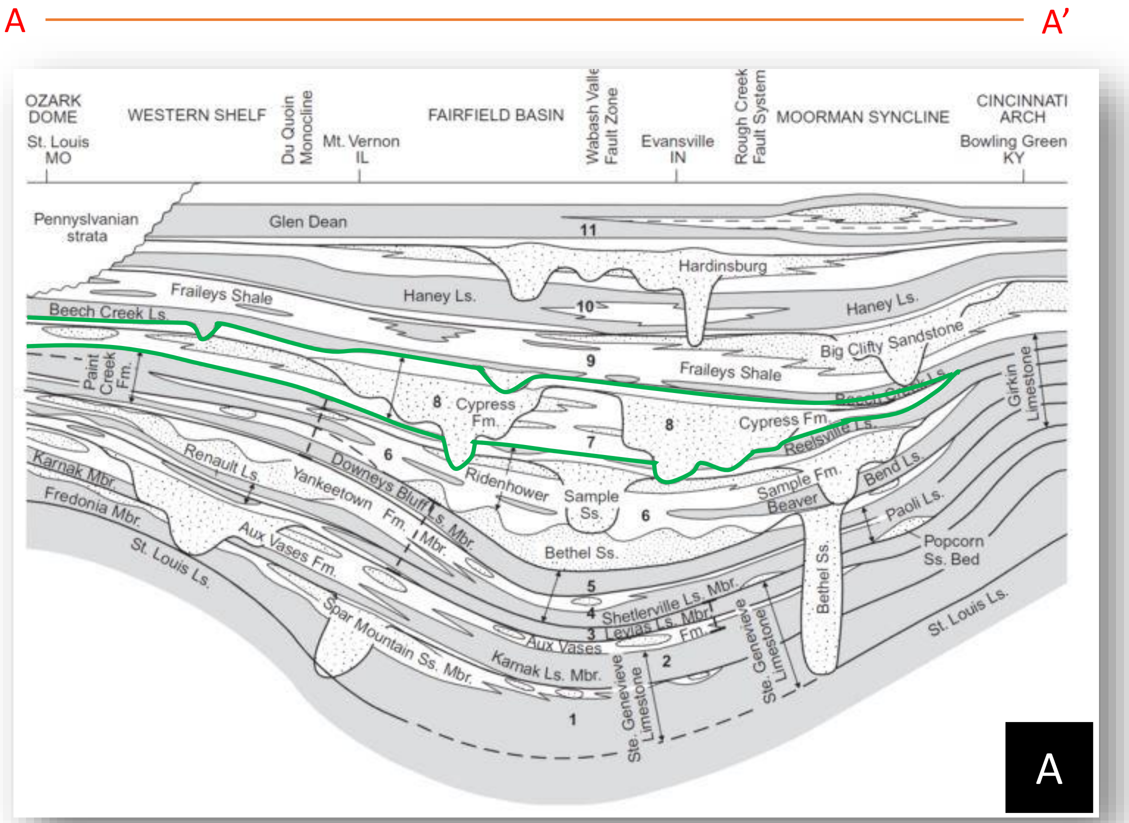
- Background
  - Cypress Sandstone, microporosity defined
- Methods
  - Petrography, scanning electron microscopy (SEM), image analysis
- Results
  - Clay types and their microporosity
- Implications
  - Petrophysical, reservoir quality
- Conclusions

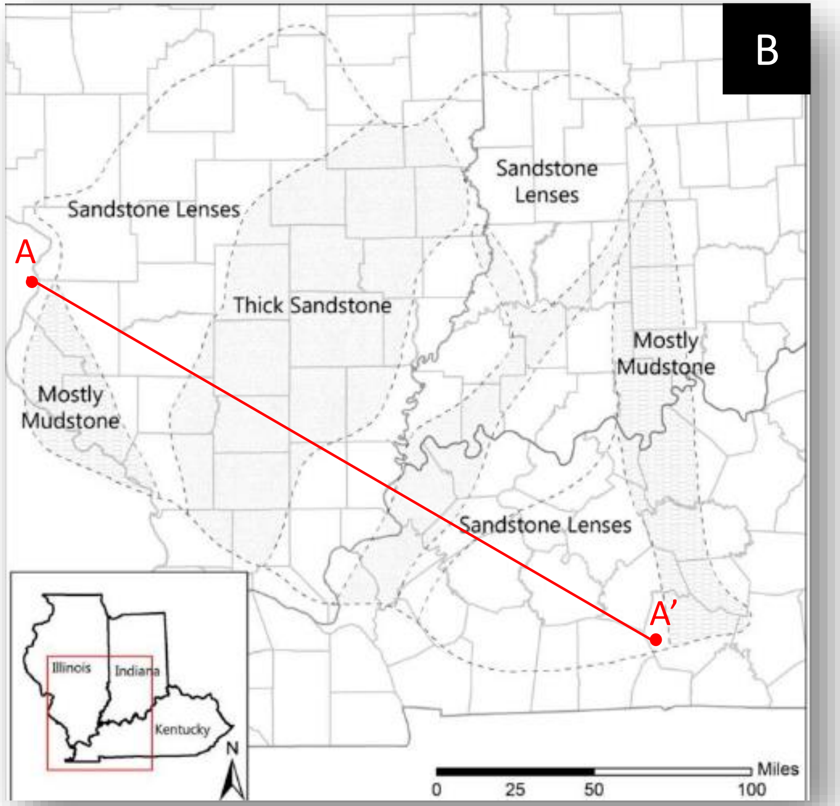
Background

Cypress Sandstone

Microporosity

Geology of the IVF Cypress Sandstone



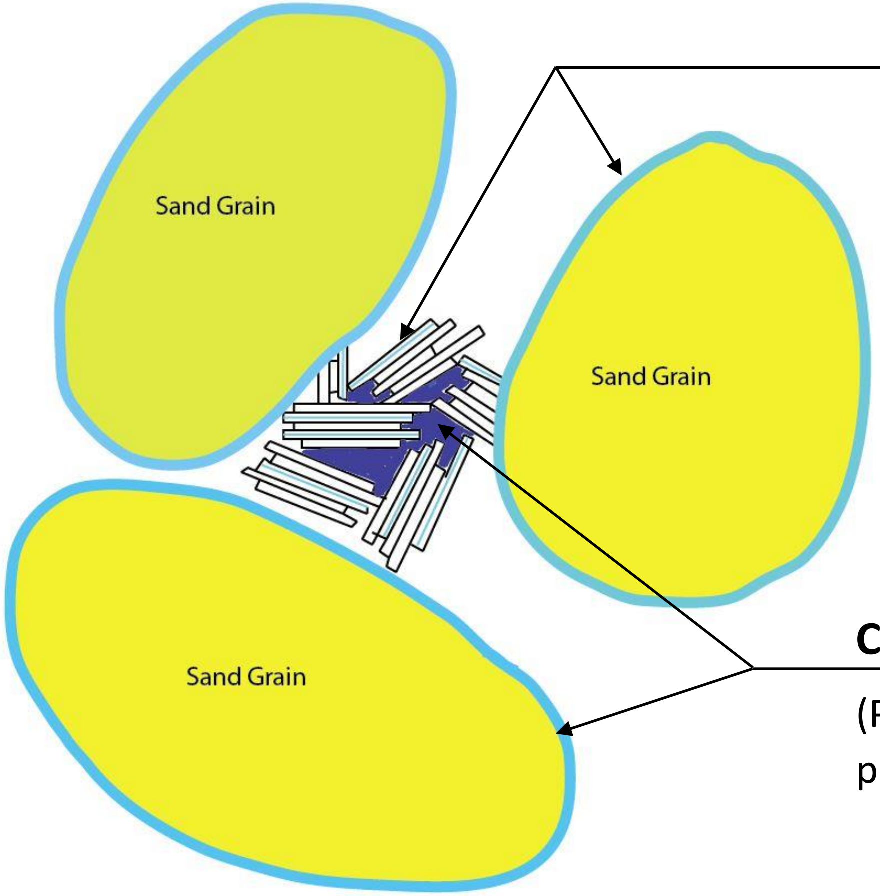


A. Generalized cross section of lower Chesterian Series
B. Generalized facies map displaying the relative location of the IVF (thick) Cypress Sandstone

Nelson et al., 2002

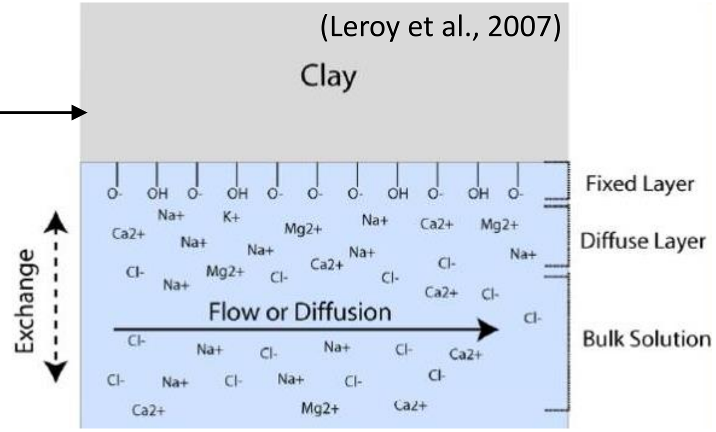
Microporosity in Clay Minerals

- Defined as the part of pore space with characteristic dimension less than 1 μ (Schlumberger)
- This study examines microporosity as it occurs in clay minerals, or "clay microporosity"



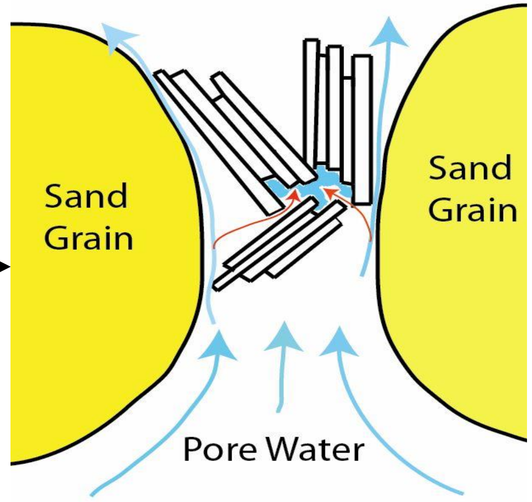
Clay-Bound Water

(Electrochemically adsorbed to negatively charged surfaces)



Capillary-Bound Water

(Physically adsorbed into small pores by capillary action)



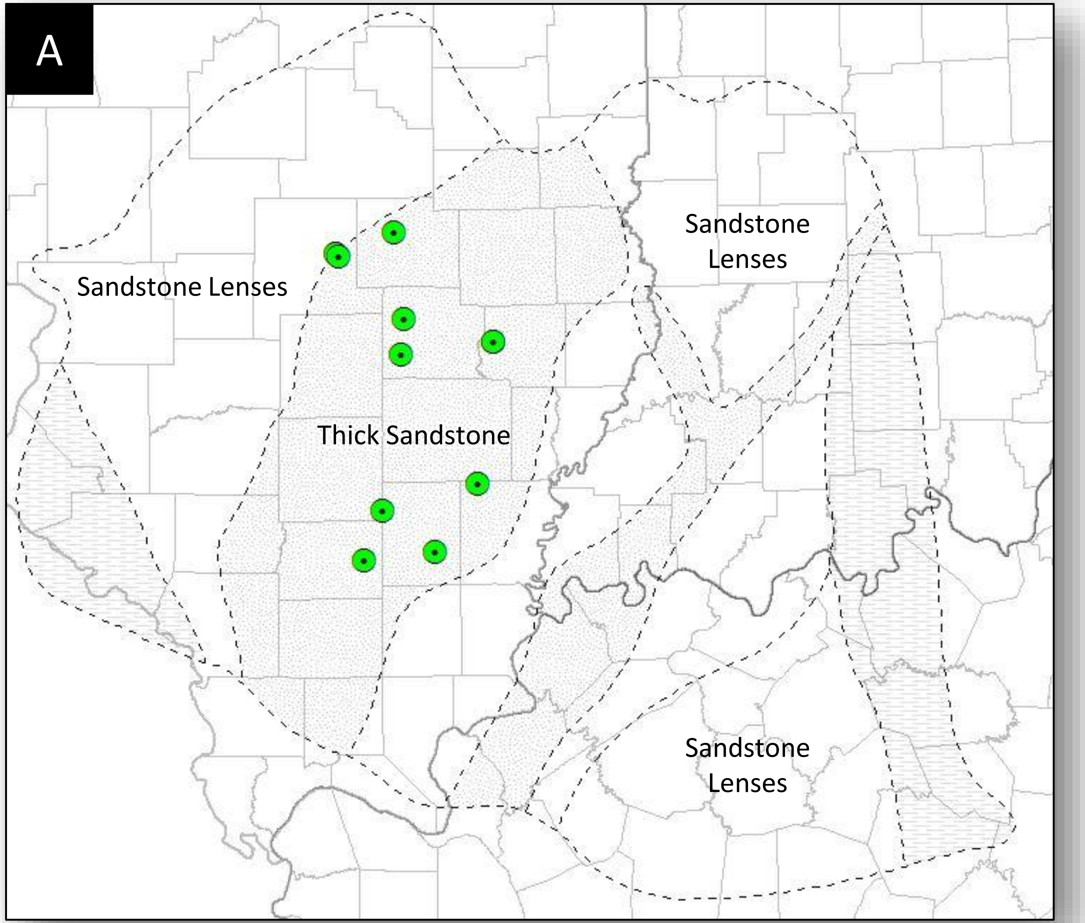
Methods

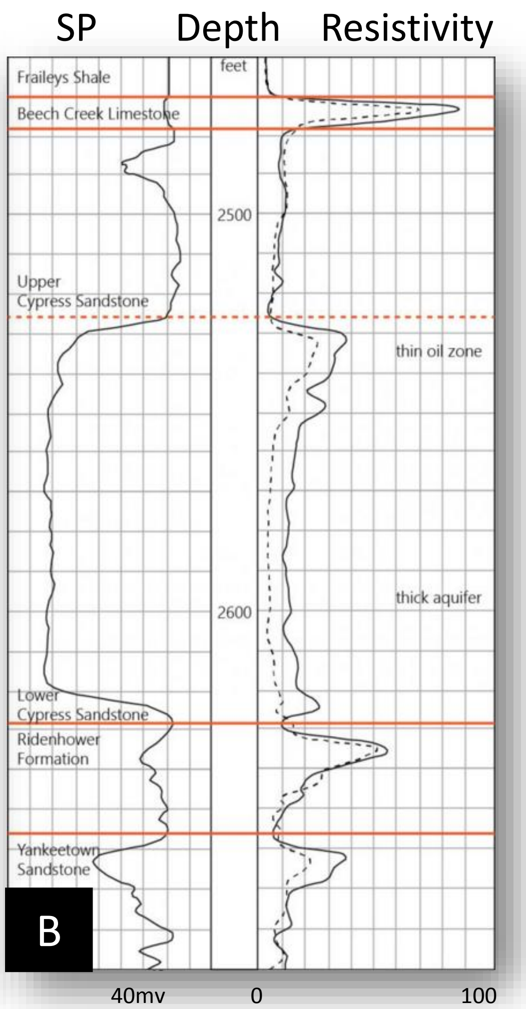
Samples

Petrography

SEM

Sample Selection



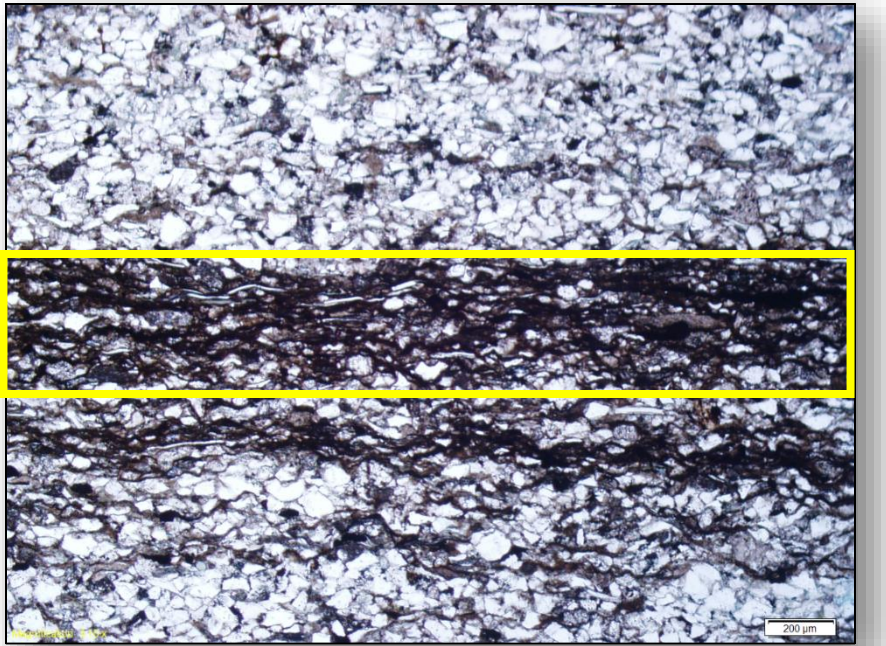


- Samples from the **IVF Cypress Sandstone**
  - 35 sample depths
  - 13 wells
- Large lateral and vertical distribution
  - Ensures microporosity "typical" of the thick Cypress Sandstone

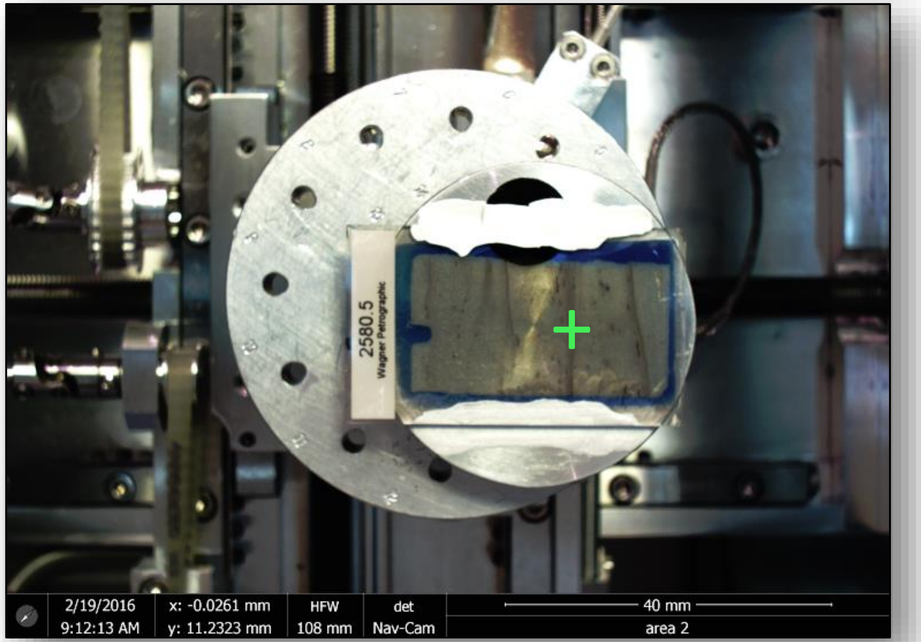
Fig. A. Location of sampled wells
Fig. B. Typical spontaneous potential (SP) and resistivity log responses of thick Cypress intervals

Petrographic Thin Sections prepared for Scanning Electron Microscopy (SEM)

Photo of clay texture in plain polarized light



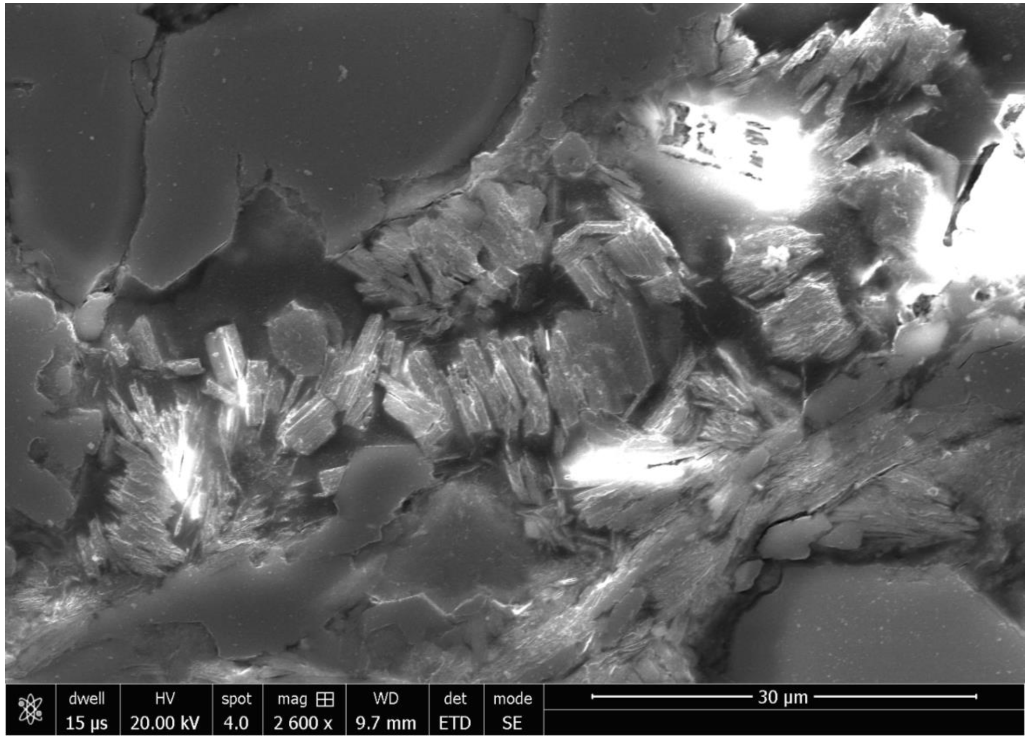
“NavCam” photo of slide in SEM chamber



- Identify clay texture with petrographic microscope; Image area with SEM
- Sample Preparation: Epoxy impregnated, polished, carbon coated, attached with carbon tape and silver paint

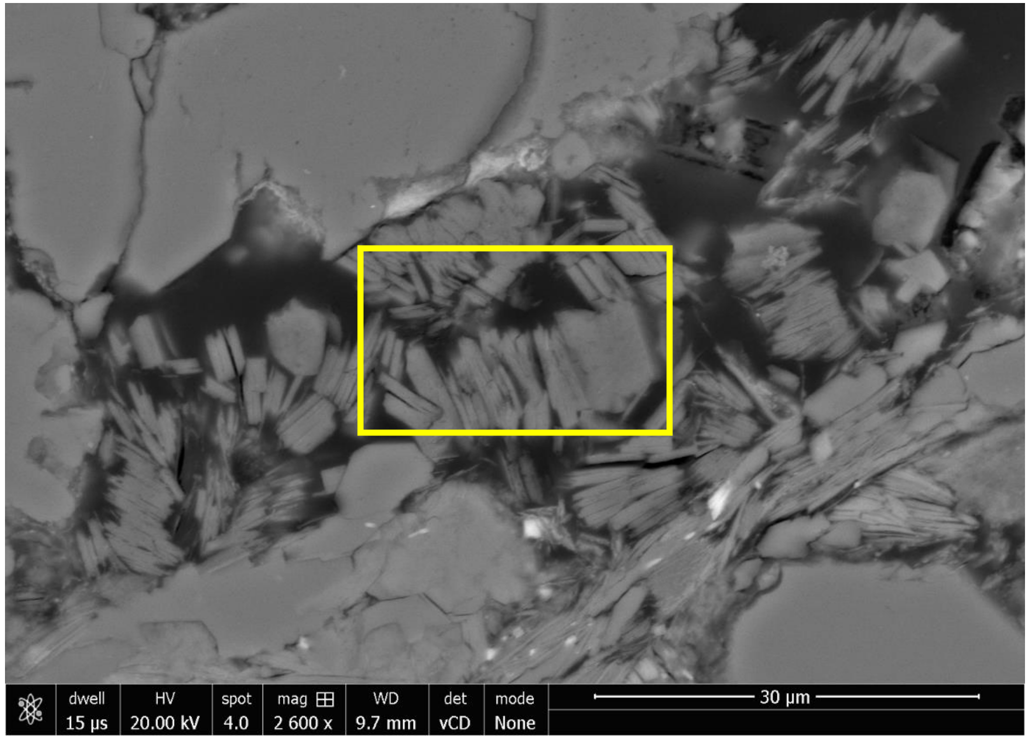
SEM Imaging Techniques

Secondary Electron (SE) Image



Information on mineral morphology, topography

Back-Scattered Electron (BSE) Image



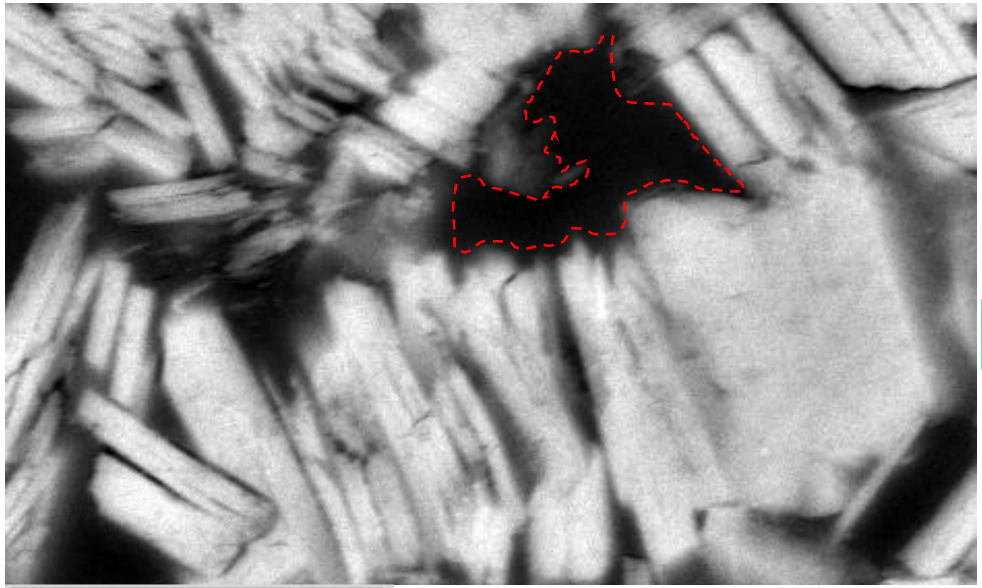
Better for determining phases present

Images of **pore-filling kaolinite booklets** (occurrence, mineral, morphology)

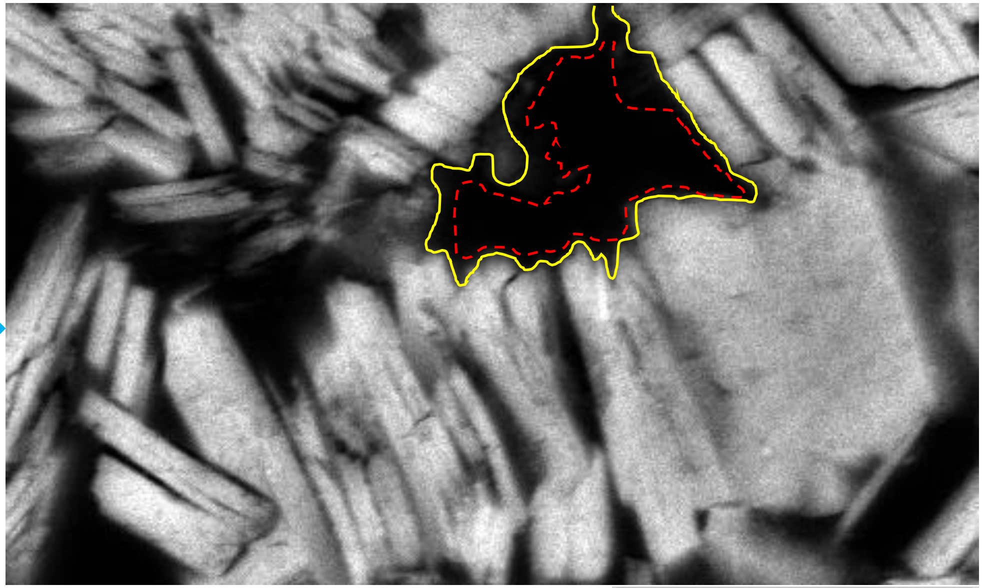
Quantifying Clay Microporosity

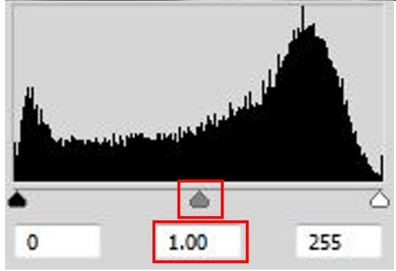
- Contrast in BSE images is determined by the atomic number (Z) of the phase
- Silicates with high Z elements (Si, Al, O) appear **LIGHT**; Epoxy (C, H, etc) appear **DARK**

Before Deletion of Grey Tones

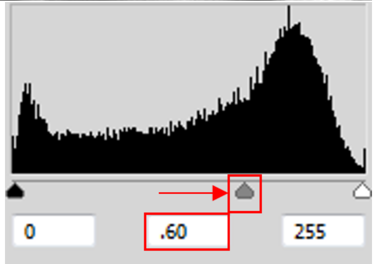


After Deletion of Grey Tones





- Deletion of grey tones until only mineral surfaces remain
- **Percentage grey tones deleted = microporosity of the area** (Hurst & Nadeau, 1995)
- Example: 40% grey tones deleted = 40% microporosity in kaolinite



Results

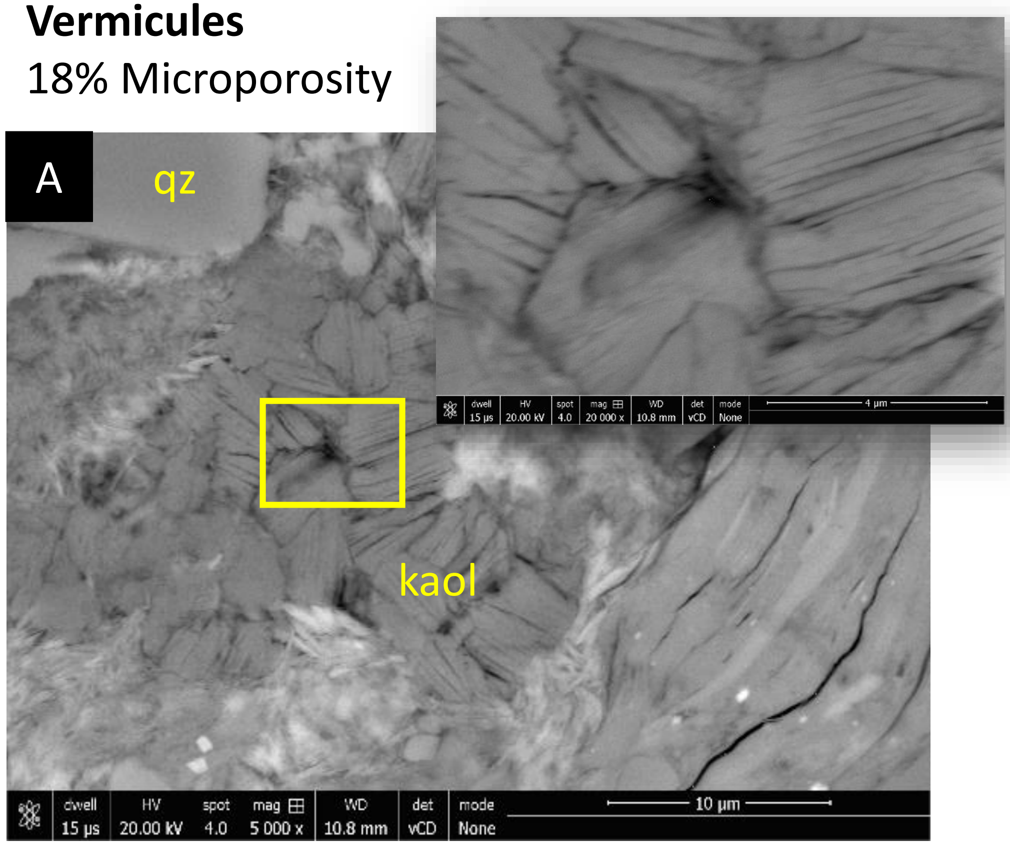
Kaolinite
Chlorite
Illite
Illite-Smectite

Kaolinite

- Most abundant clay mineral in the Cypress Sandstone; 50% of all clay
- Two morphologies, both occur as pore-filling, both are diagenetic

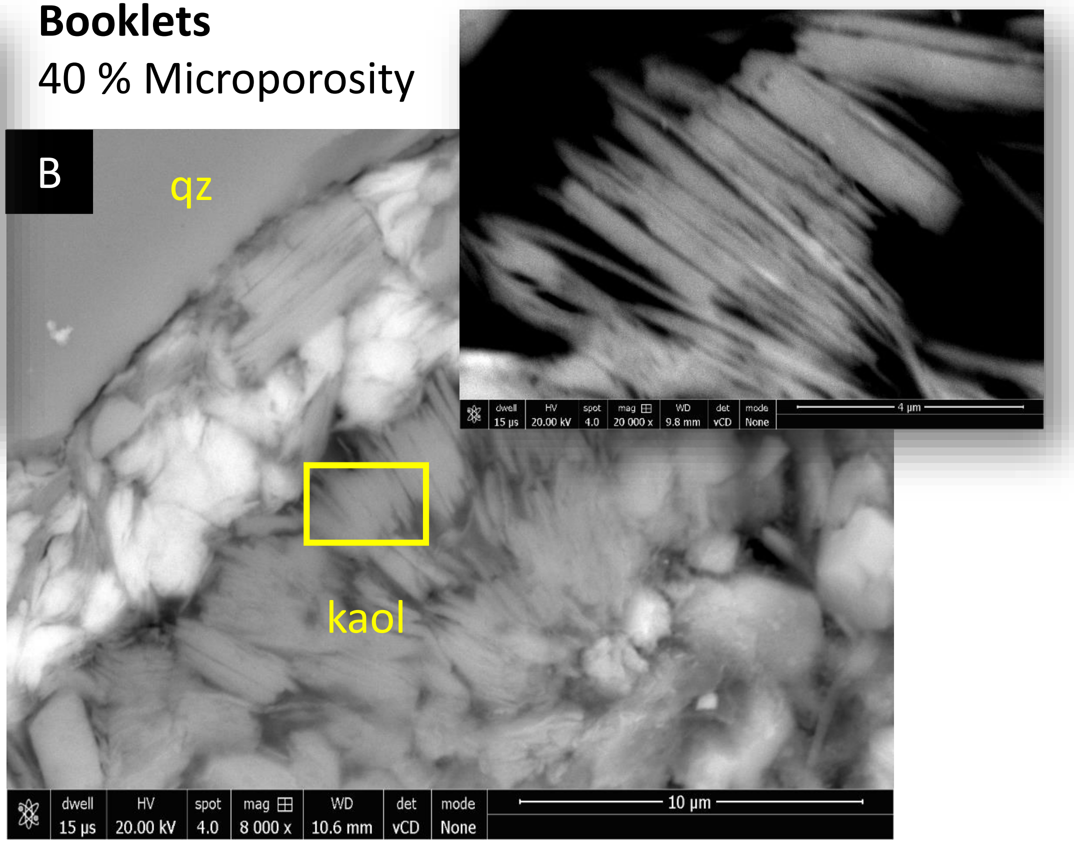
Vermicules

18% Microporosity



Booklets

40 % Microporosity

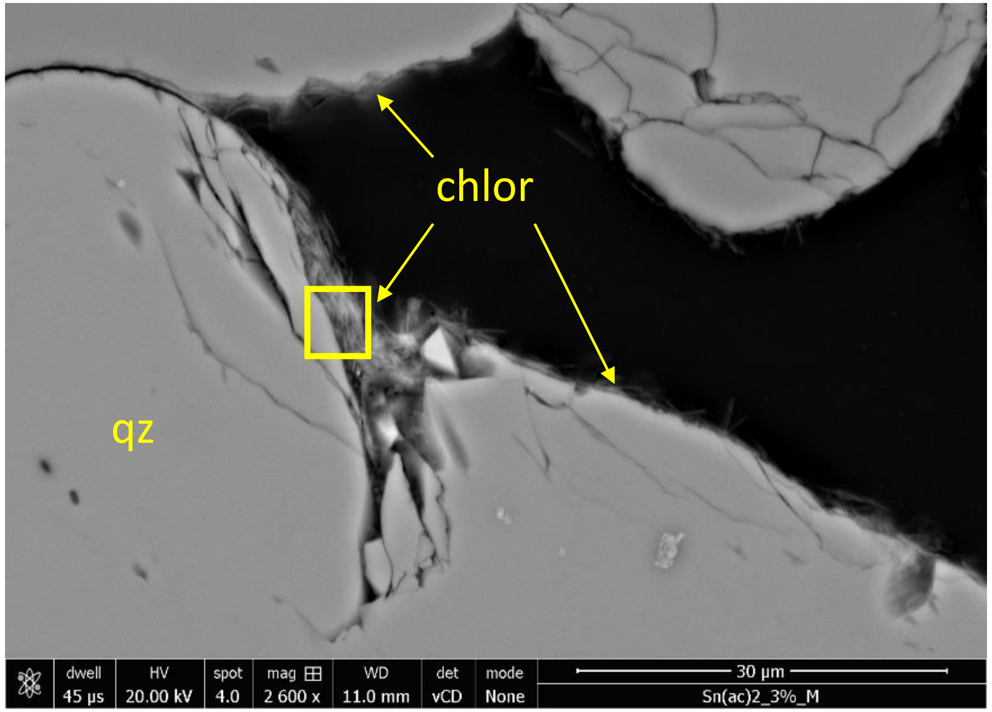


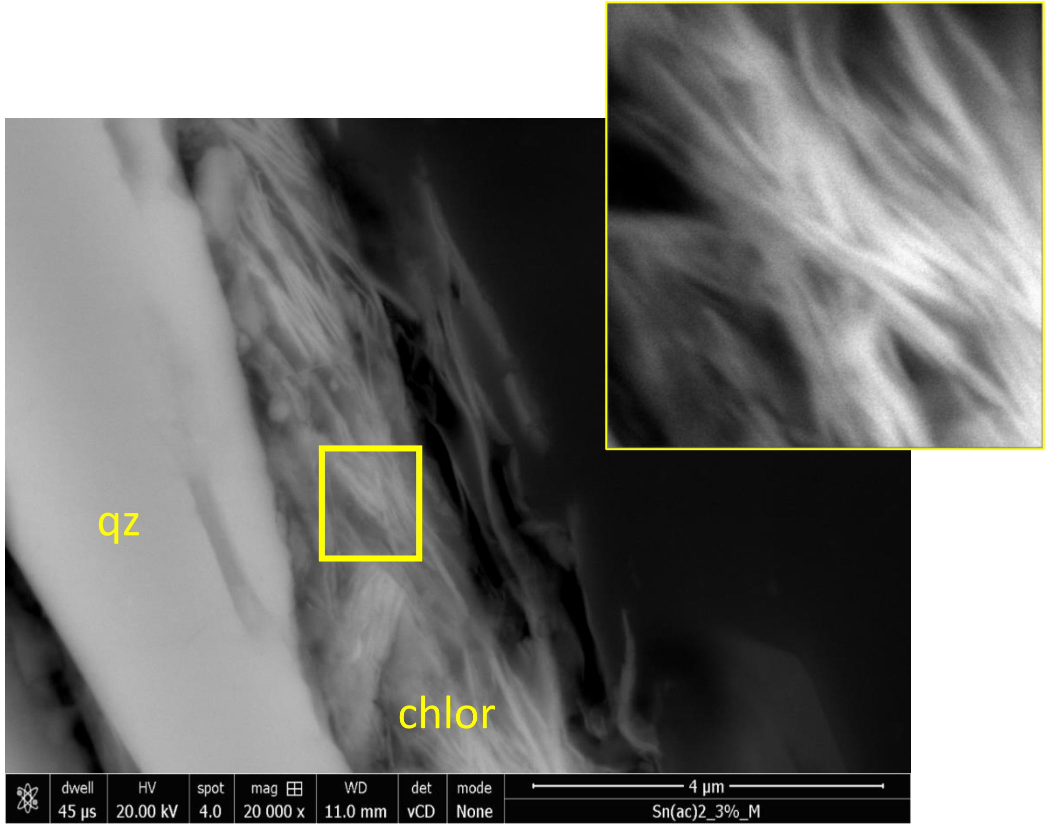
Photos A & B. BSE Images pore-filling kaolinite. Different morphologies create different volumes of microporosity

Chlorite

- Abundant clay mineral in the Cypress; 23% of all clay (Rehak, 2014)
- One morphology, occurs exclusively as grain-coating, diagenetic

Stacked Rosettes: 46% Microporosity



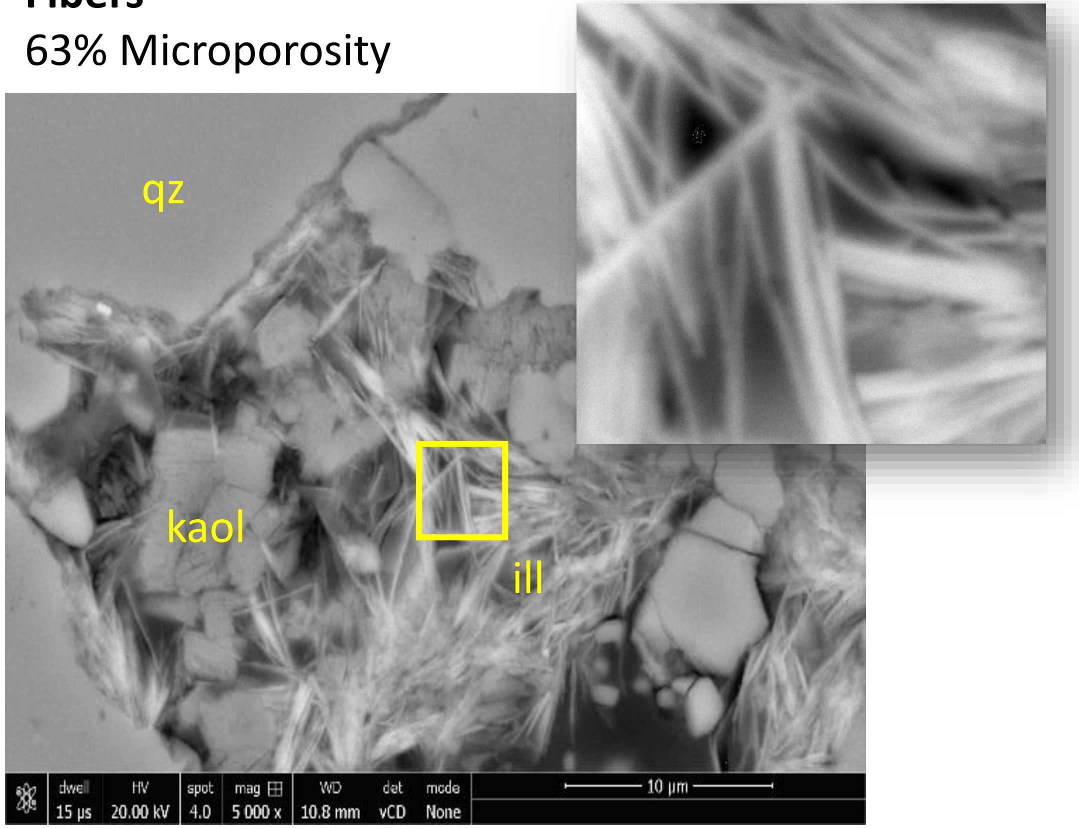


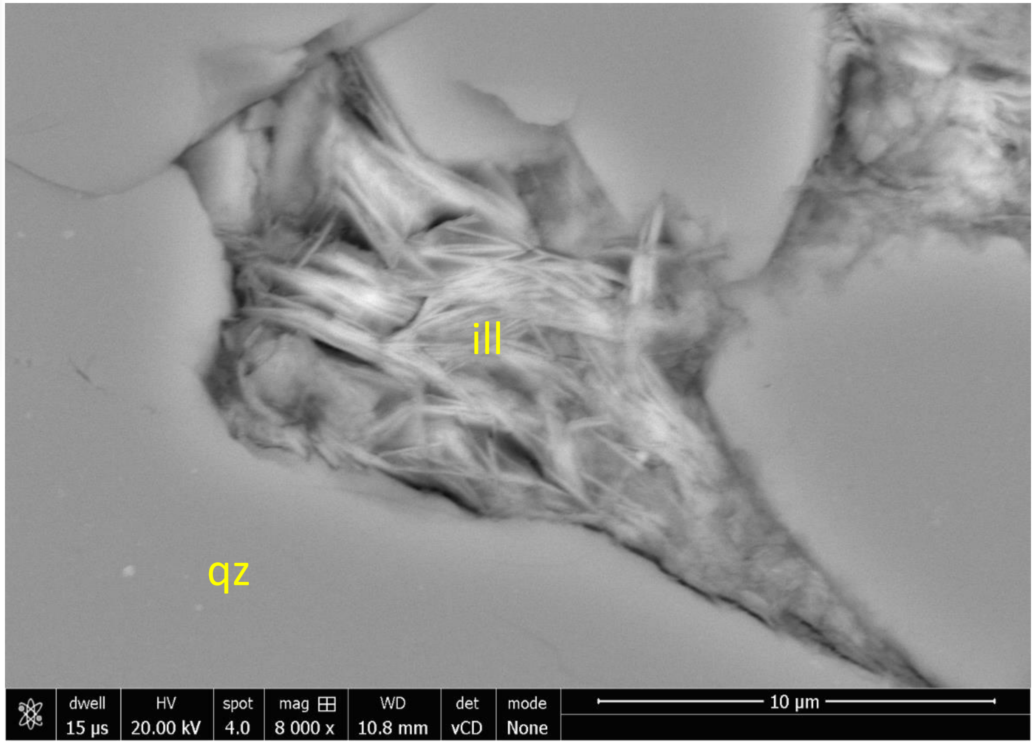
*All BSE Images

Illite

- Abundant clay mineral in the Cypress; 15% of all clay (Rehak 2014)
- One morphology, occurs as pore-filling and pore-bridging, both are diagenetic

Fibers
63% Microporosity





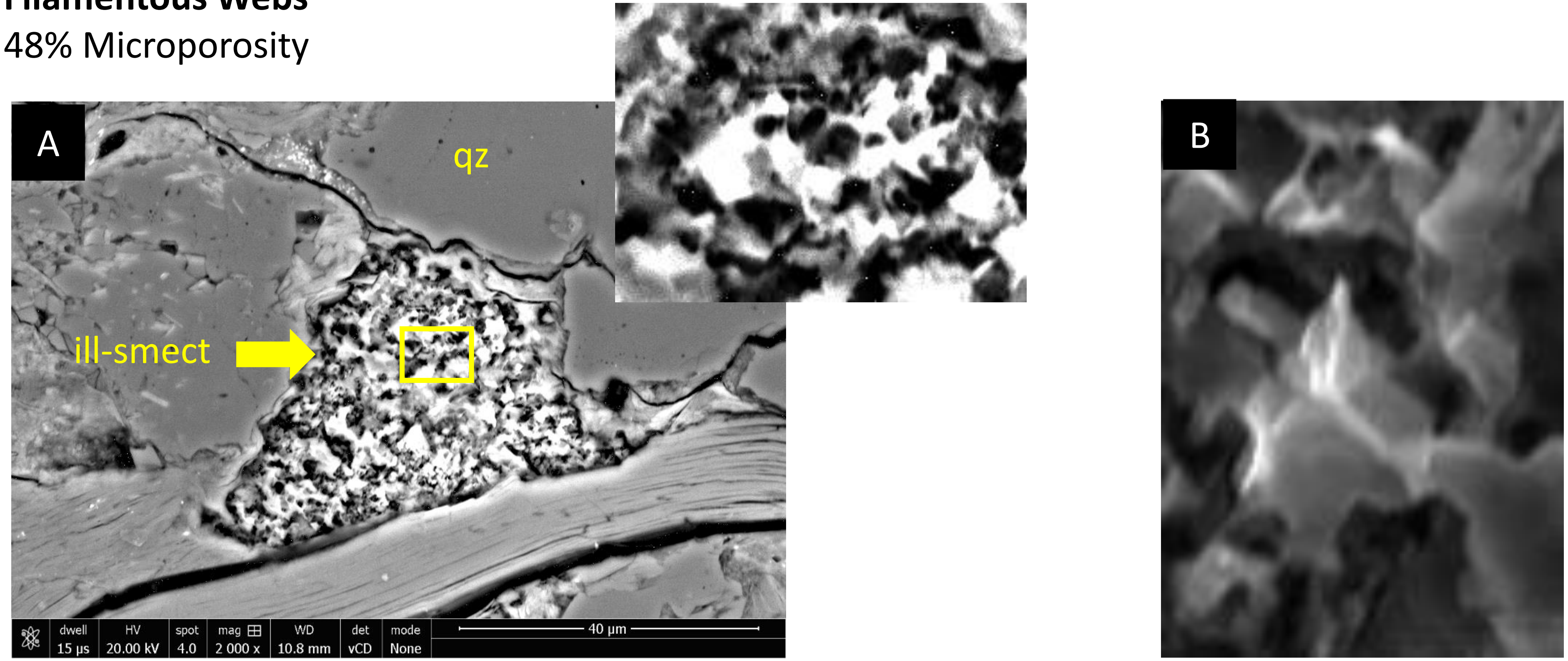
*All BSE Images

Mixed Layered Illite-Smectite

- Least abundant clay mineral in the Cypress; 10% of all clay (Rehak, 2014)
- One morphology, occurs as grain coating and pore-filling, diagenetic

Filamentous Webs

48% Microporosity



SEM Photos**. (A) BSE** photo of pore-filling illite-smectite **(B) SE** image of filamentous webs of illite-smectite

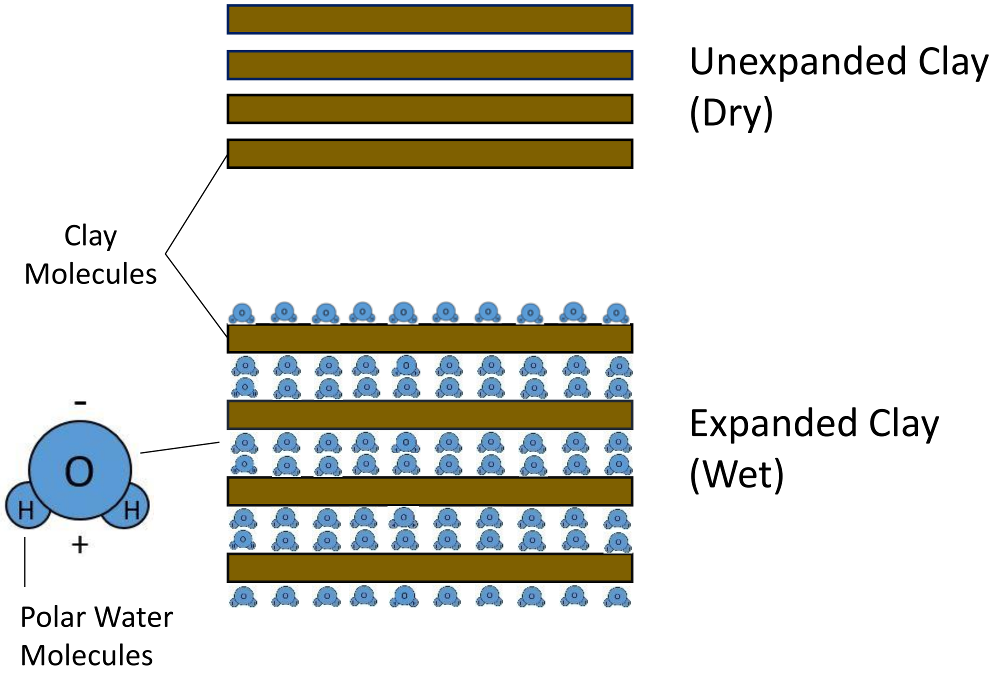
Implications

Petrophysical Analysis

Reservoir Quality

Petrophysical Implication: Clay Mineral Volume

- Well log evaluation requires accurate measurements of clay mineral volume
- Clay weight percentages from XRD represent the dry clay only. **DO NOT** include water-filled micropores
- Values of Effective clay mineral **volume** can be calculated using microporosity in clay minerals



Volume of solid clay mineral (V_m)

m_a= weight percent of mineral m
ρ_a = density of mineral m
φ_t = total porosity
$\sum(m_i/\rho_i)$ = sum of weight % of each mineral over its respective density

$$V_m = \frac{(m_a/\rho_a)}{\sum(m_i/\rho_i)}(1\text{-}\varphi_t)$$

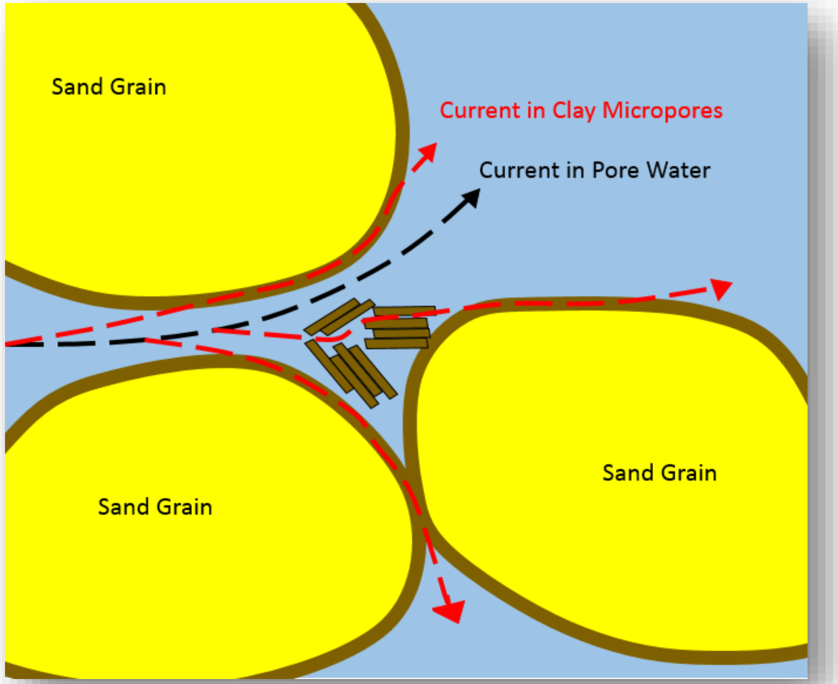
Effective clay volume (V_e)

φ_m = clay mineral microporosity
V_m = volume of solid clay mineral

$$V_e = \frac{V_m}{(1-\varphi_m)}$$

Petrophysical Implication: Water Saturation

- Microporosity in clay minerals creates a continuously conducting path of water-filled pores
- Extra source of conductance ➔ low resistivity log response
- Leads to overestimation of water saturation; underestimation of oil saturation



The volume of clay-bound water + capillary-bound water (immobile water) held within a given clay type can be calculated using values of clay microporosity:

$$V_{immob\ water} = V_e - V_m$$

V_e = Effective Clay Volume

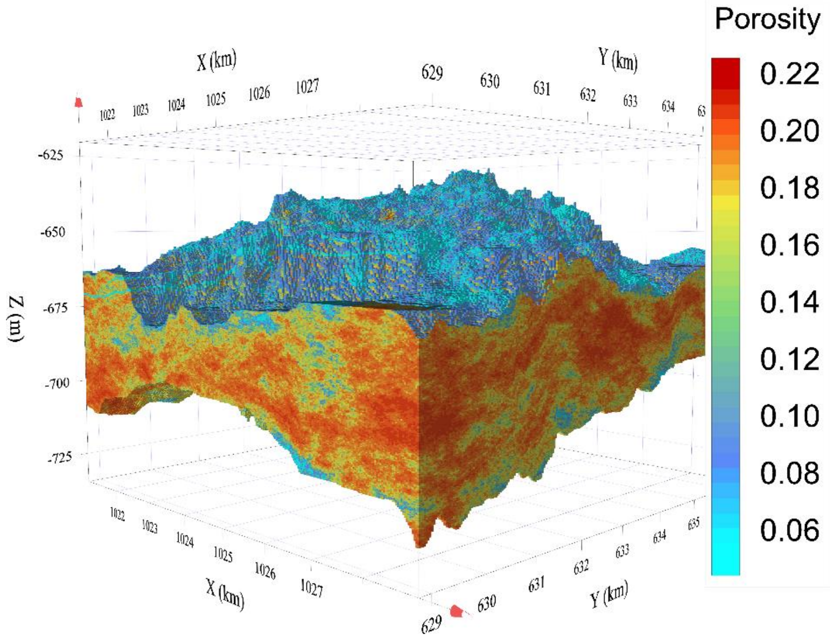
V_m= Volume of Solid Clay Mineral

(equations from previous slide)

Correct water saturation values to exclude immobile water

Reservoir Quality Implication: Effective Porosity

- Effective porosity (φ_e) is the pore space that contributes to fluid flow
- Water in clay microporosity is immobile (does not flow) during production
- This can lead to significant overestimations of porosity, and therefore recoverable oil
- For accurate resource assessment, microporosity (φ_m) must be excluded from total porosity (φ_t)



Effective Porosity (φ_e)

$$\varphi_e = \varphi_t - \varphi_m$$

φ_t = total porosity (evaluated from wireline logs)

φ_m = microporosity

Fig. Geocellular porosity model at Noble Field. Created from SP and ND logs. Roughly 0.5 x 0.5 mi., 50x vertical exaggeration

Model by Nate Grigsby, ISGS

Conclusions

- Scanning Electron Microscopy (SEM) of petrographic thin sections is amenable to identifying microporosity in clay minerals
- Clay minerals in the Cypress Sandstone contain microporosity specific to their morphology
    - Kaolinite (18-40%), Chlorite (46%), illite (63%), illite-smectite (48%)
- Clay minerals identified are diagenetic in origin
- Accounting for microporosity improves calculations of clay mineral volume, water saturation, and effective porosity

Future Work

- Apply corrections of formation evaluation throughout thick Cypress Sandstone
- Use SEM images to create a paragenetic sequence of clay minerals
- Develop statistical relationship between clay minerals and gray-scale BSE Images
- Determine effect of Cypress clay minerals on CO_2 – EOR

Acknowledgements

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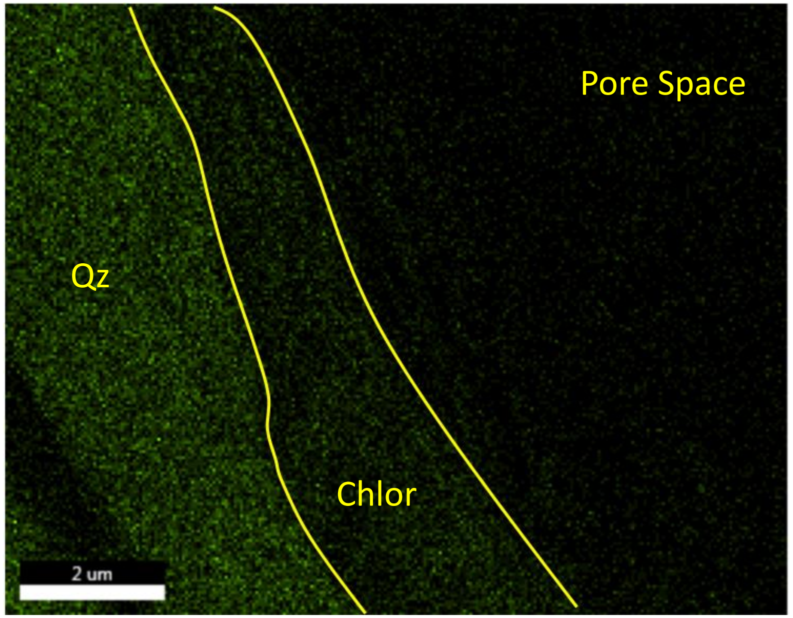
- Imaging Technology Group (ITG), Beckman Institute
  - FEI Quanta FEG 450 ESEM was used for imaging, TEAM software by EDAX was used for EDS

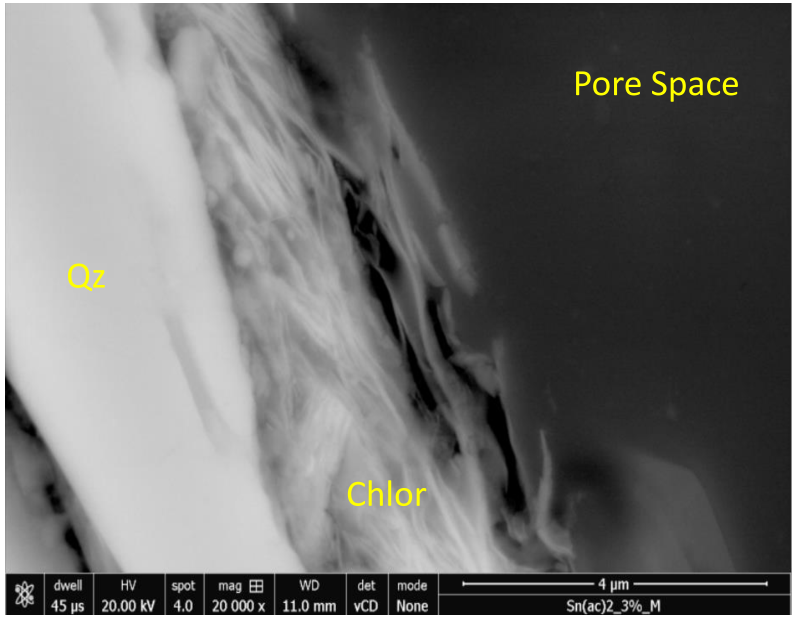
- Shane Butler and Nathan Webb (research advisors)

EDS Element Mapping against BSE Images

Oxygen Distribution Map



BSE Image **Before** Grey Tone Deletion

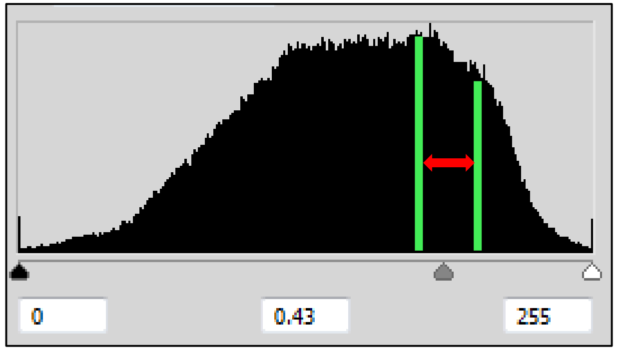


BSE Image **After** Grey Tone Deletion

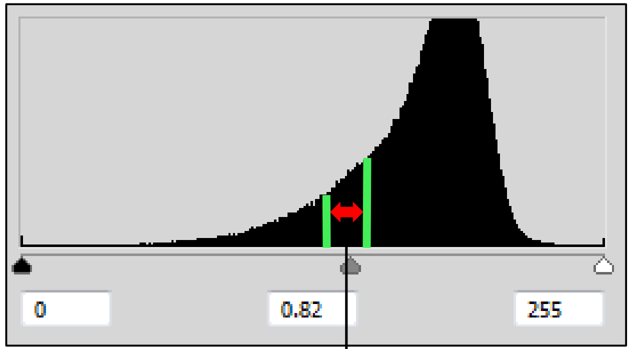
Grain-coating stacked chlorite rosettes

Gray Level Histograms Specific to Clay Minerals

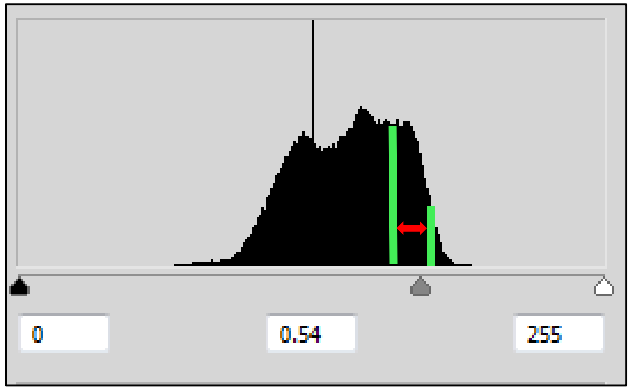
Illite



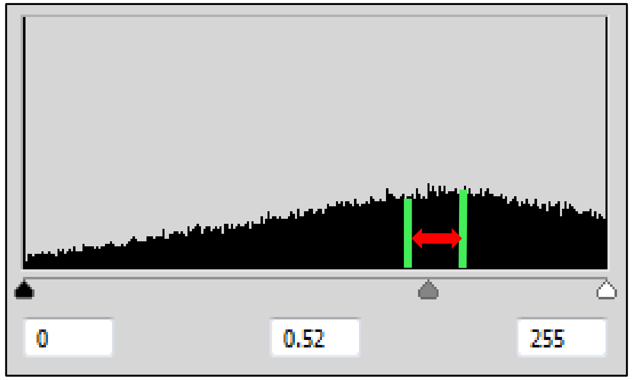
Kaolinite (vermicules)



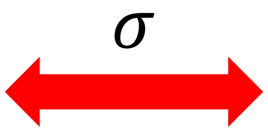
Chlorite



Illite-Smectite



Standard Deviation of clay mineral microporosity



17 images of kaolinite analyzed:

$$\textbf{mean and } \boldsymbol{\sigma}\ \varphi_m(vermicular\ kaolinite)$$

= 18% $\pm$ 4.2%