Using Clay Microporosity to Improve Formation Evaluation in Potential ROZs: Cypress Sandstone, Illinois Basin

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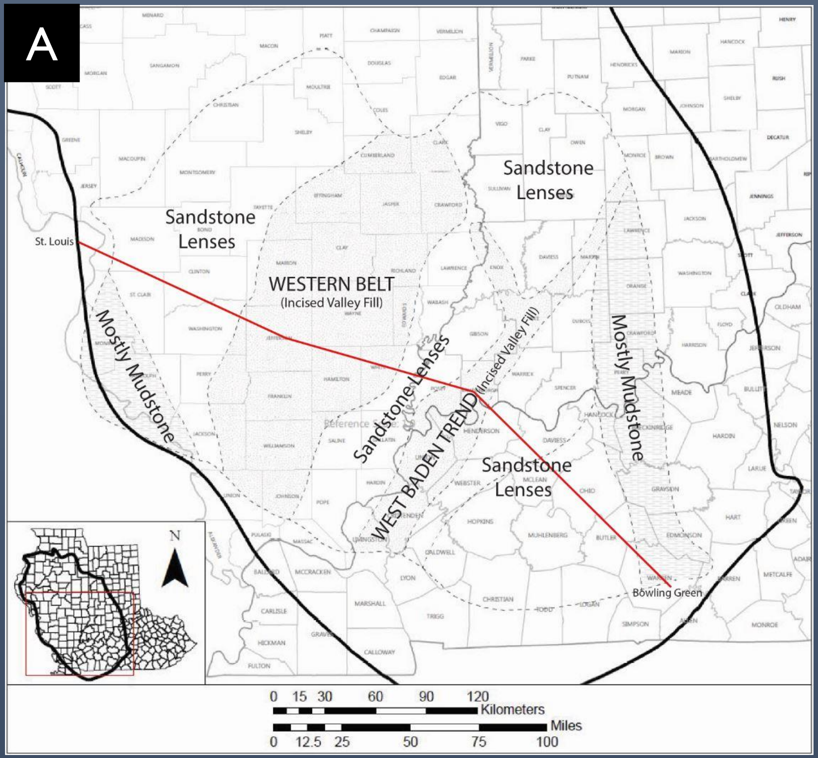
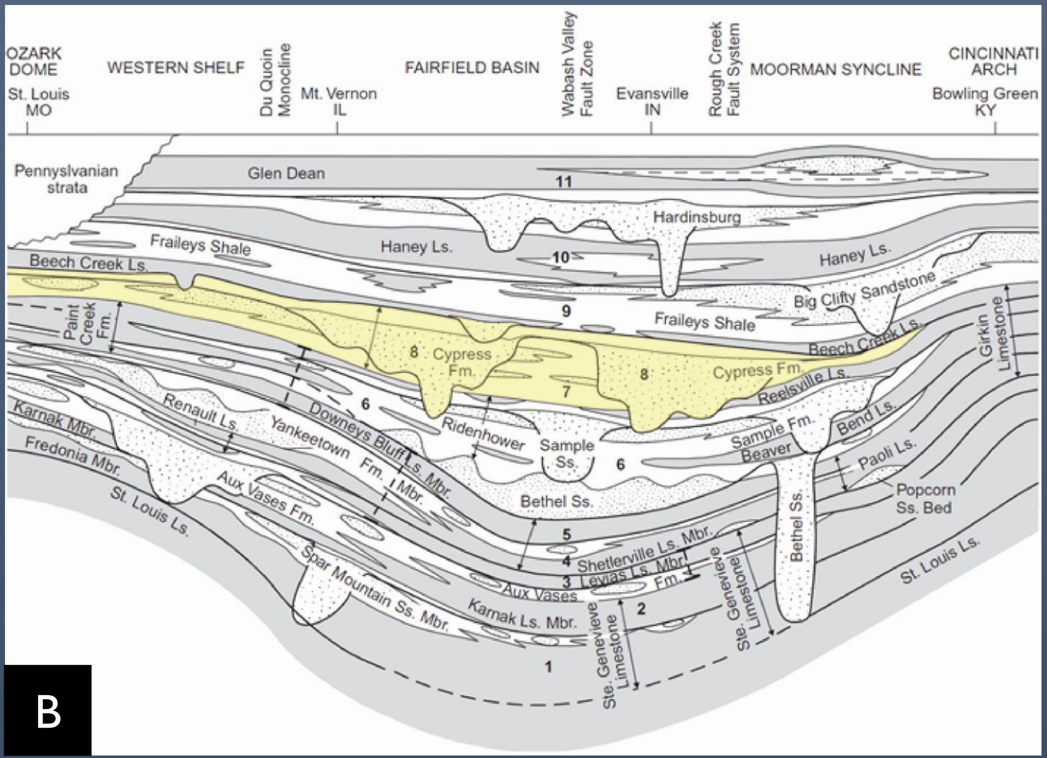
Agenda

- Background
  - Cypress Sandstone, clay microporosity
- Methods
  - Imaging techniques
- Results
  - Clay types, microporosity
- Applications
  - Clay volume, water saturation, porosity
- Conclusions

Cypress Sandstone, Illinois Basin



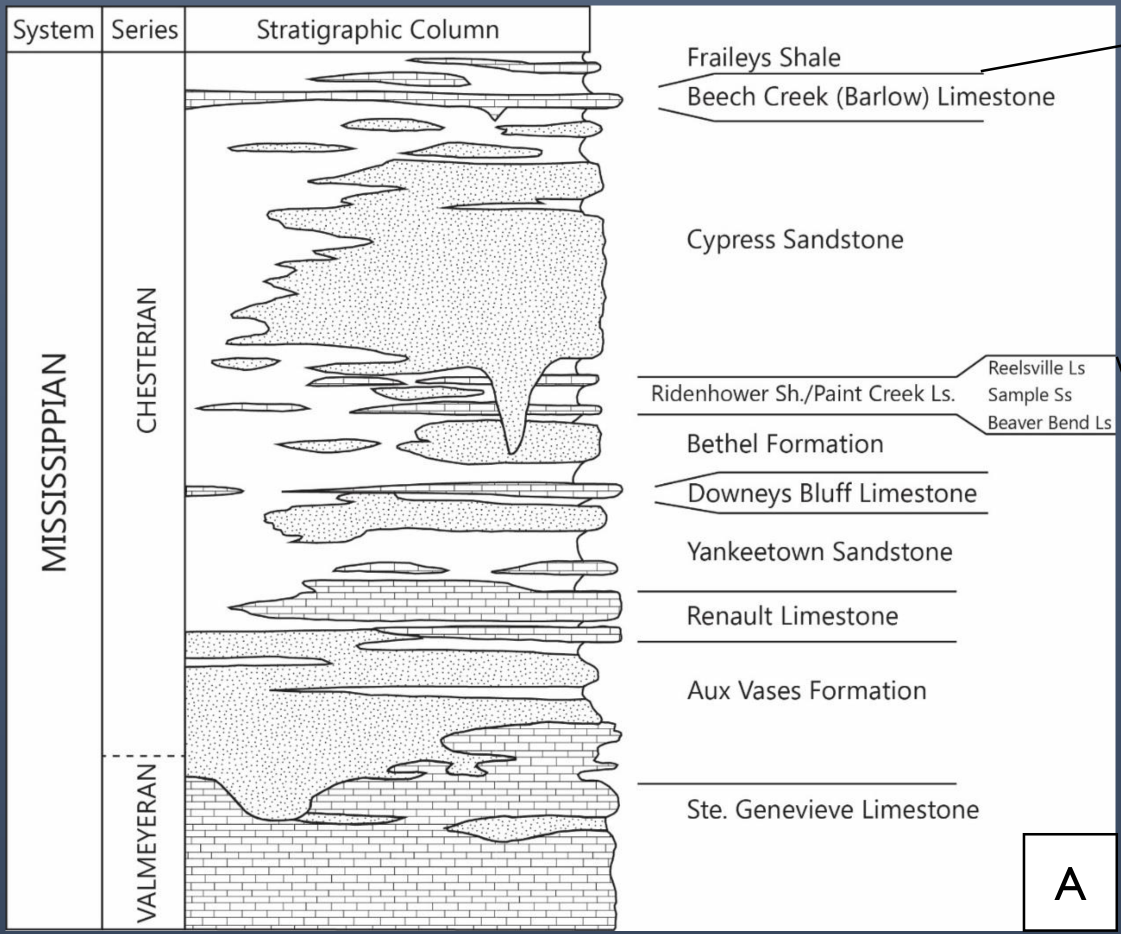


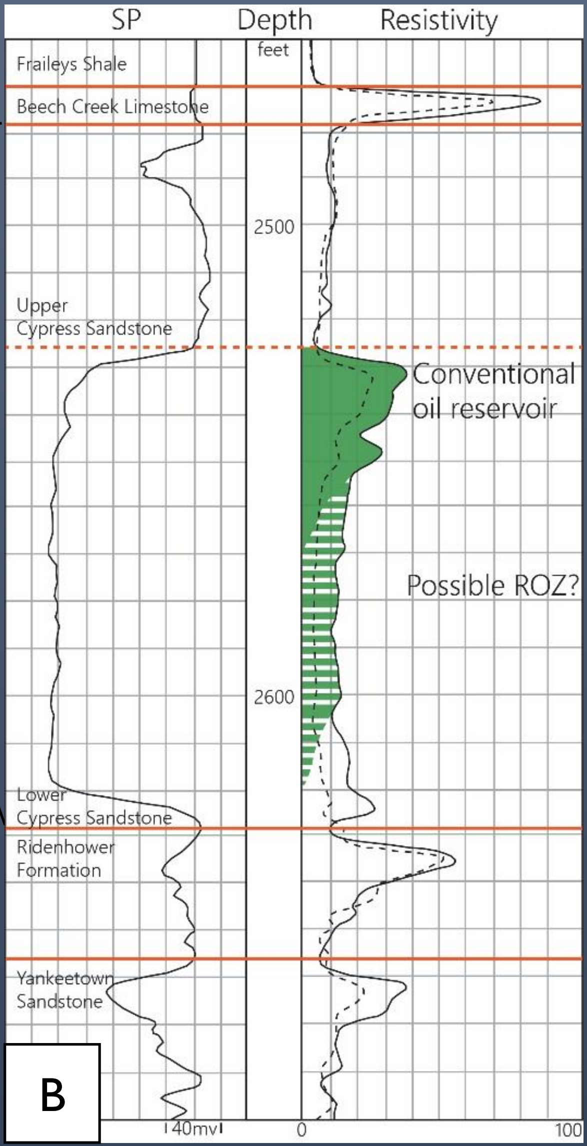
A. Generalized facies map of the Cypress Sandstone across the Illinois Basin
B. Generalized cross section of the lower Chesterian Series

Modified from Nelson et al., 2002

Thick Cypress and Possible ROZs

- Residual Oil Zones are targets for CO2-EOR and storage

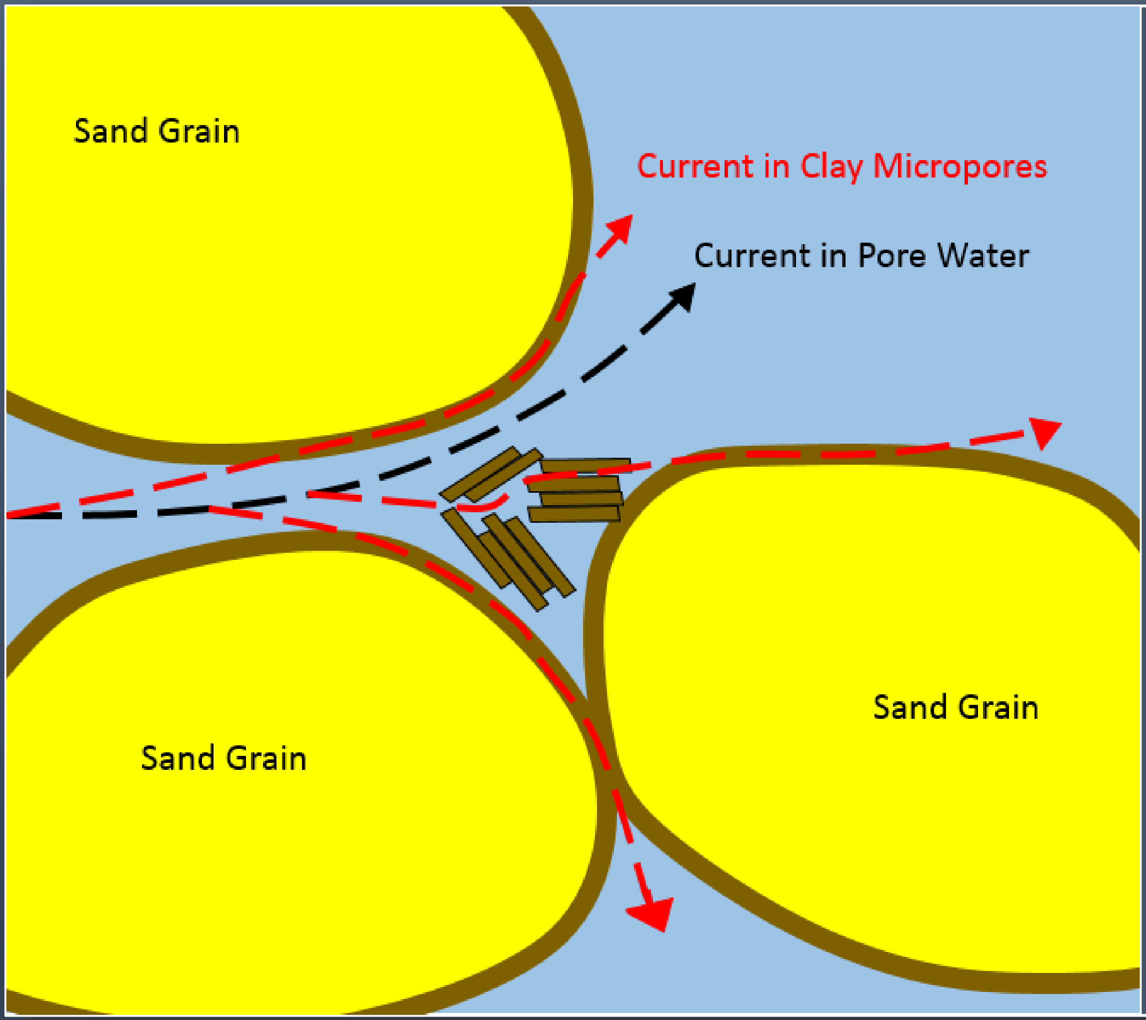




A. Generalized column of the Chesterian series containing the Cypress
B. Typical log response of the thick Cypress

Clay Microporosity

- Pore aperture radii < 5 microns (Pittman, 1979)
- Fluid saturated; immobile during hydrocarbon emplacement and production



The "clay effect":

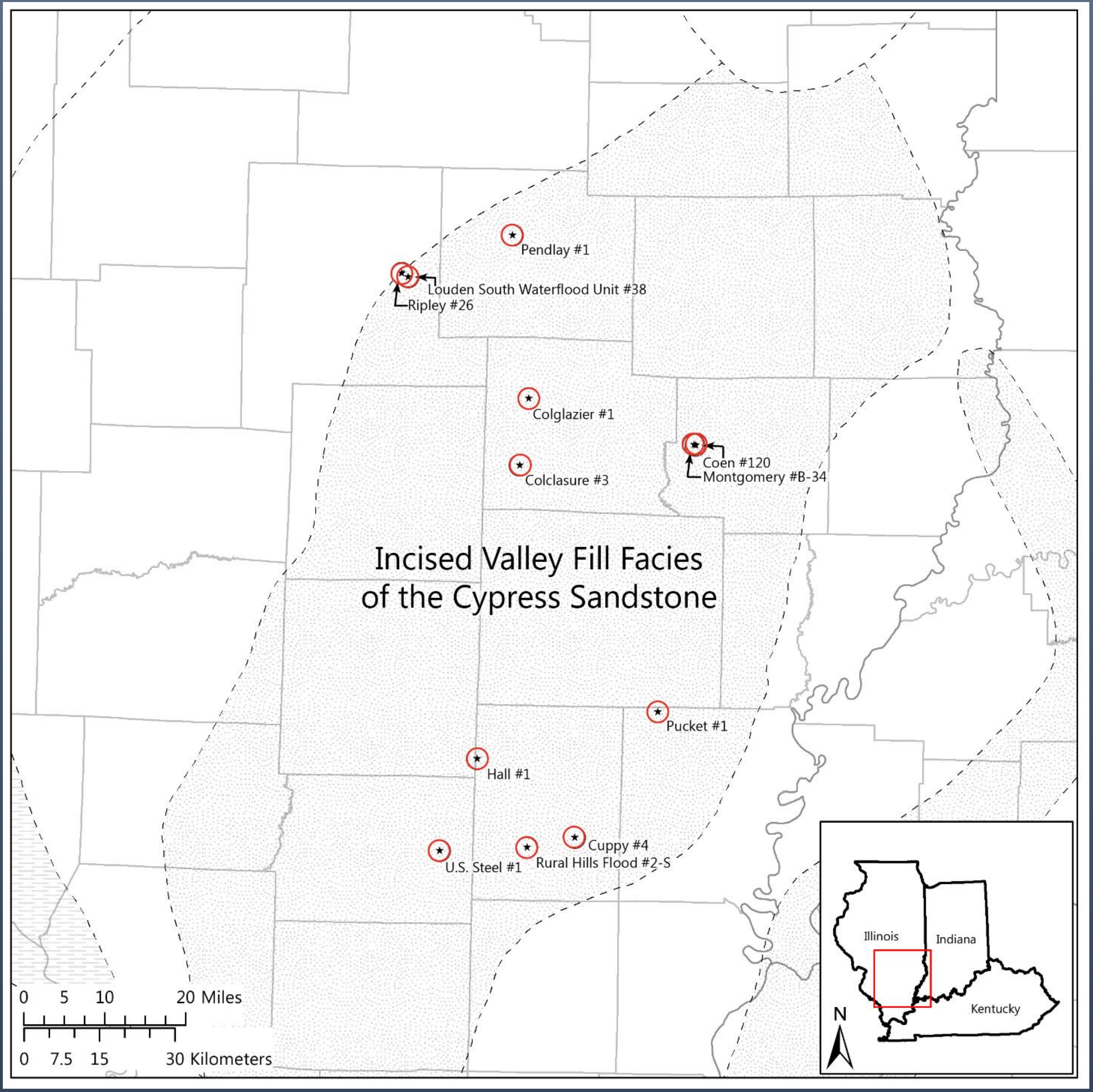
➔ Extra conductivity

➔ Low resistivity

➔ High Water Saturation

Sample Selection

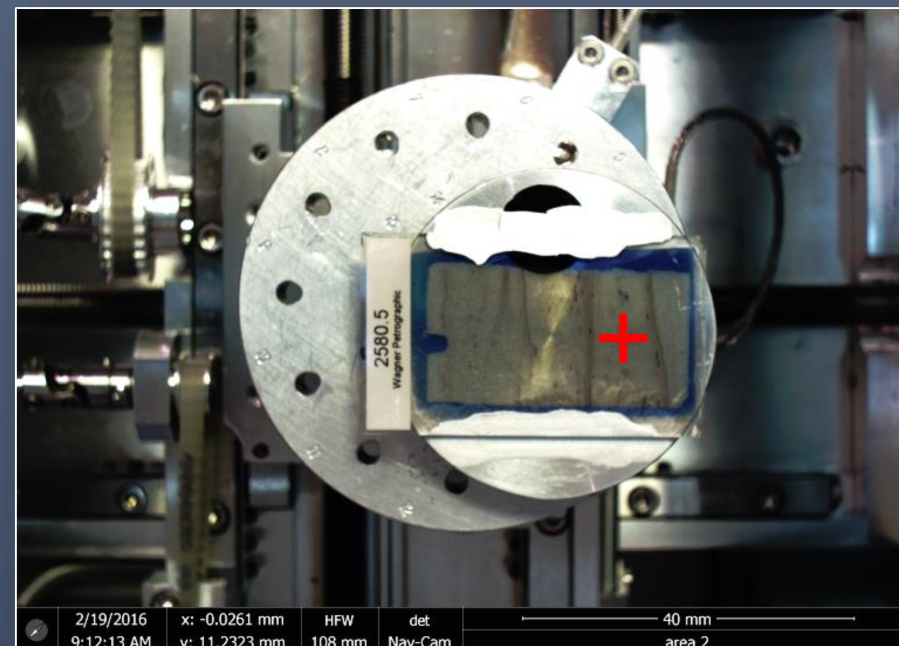
- 20 sample depths, 12 wells.
- Large vertical and lateral distribution
- All from IVF



Petrographic Analysis Using SEM

Photo with clay textures in XPL

'NavCam' photo of slide in SEM chamber

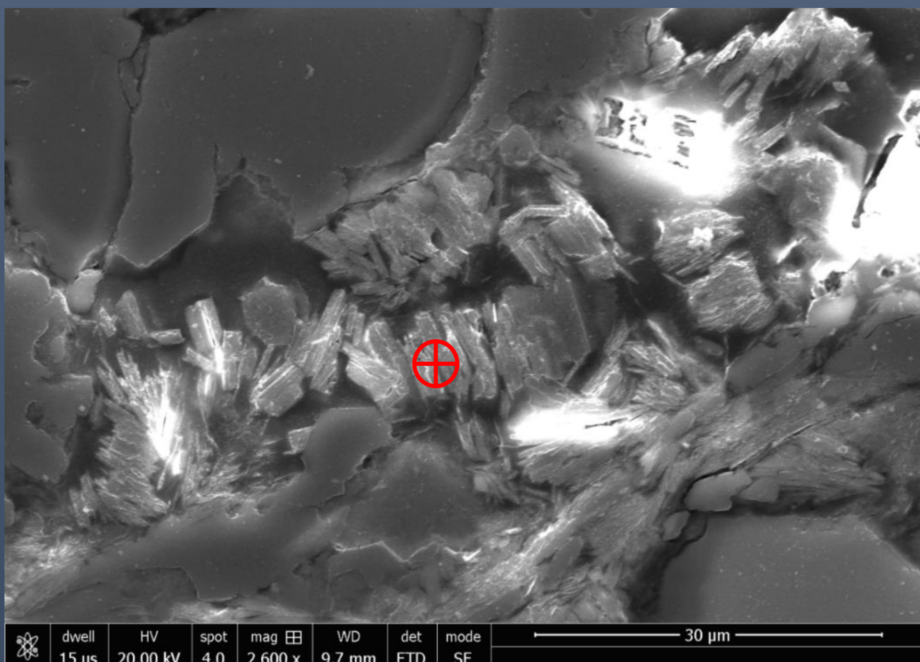


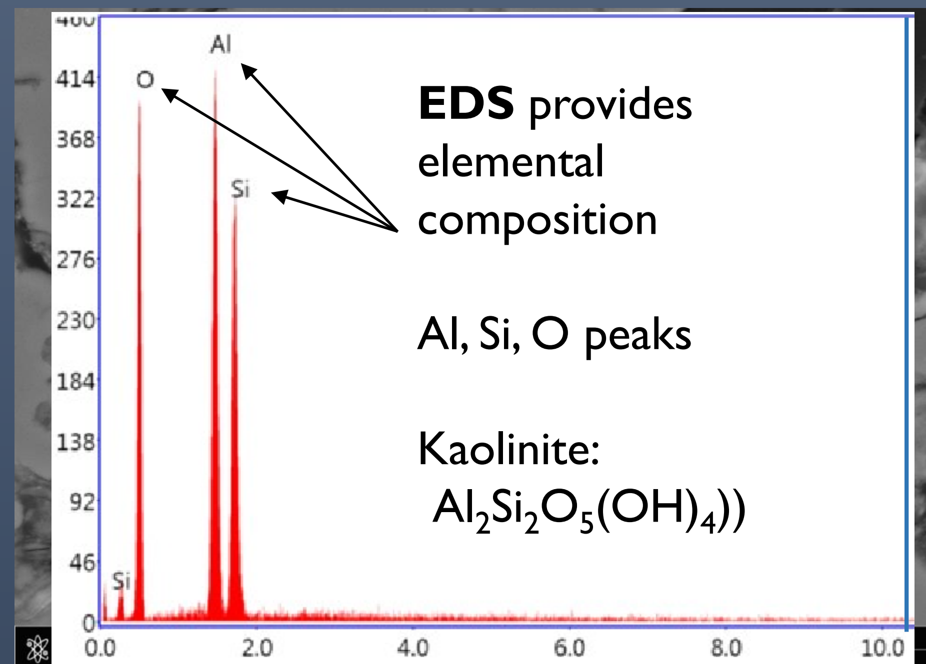
- Clay texture identified with petrography ➔ analyzed with SEM
- Epoxy impregnated, polished, carbon coated, mounted with carbon tape and silver paint

SEM Techniques

Secondary Electron (SE)
Information on morphology, topography

Backscattered Electron (BSE)
Useful for determining phases (mineral, epoxy)

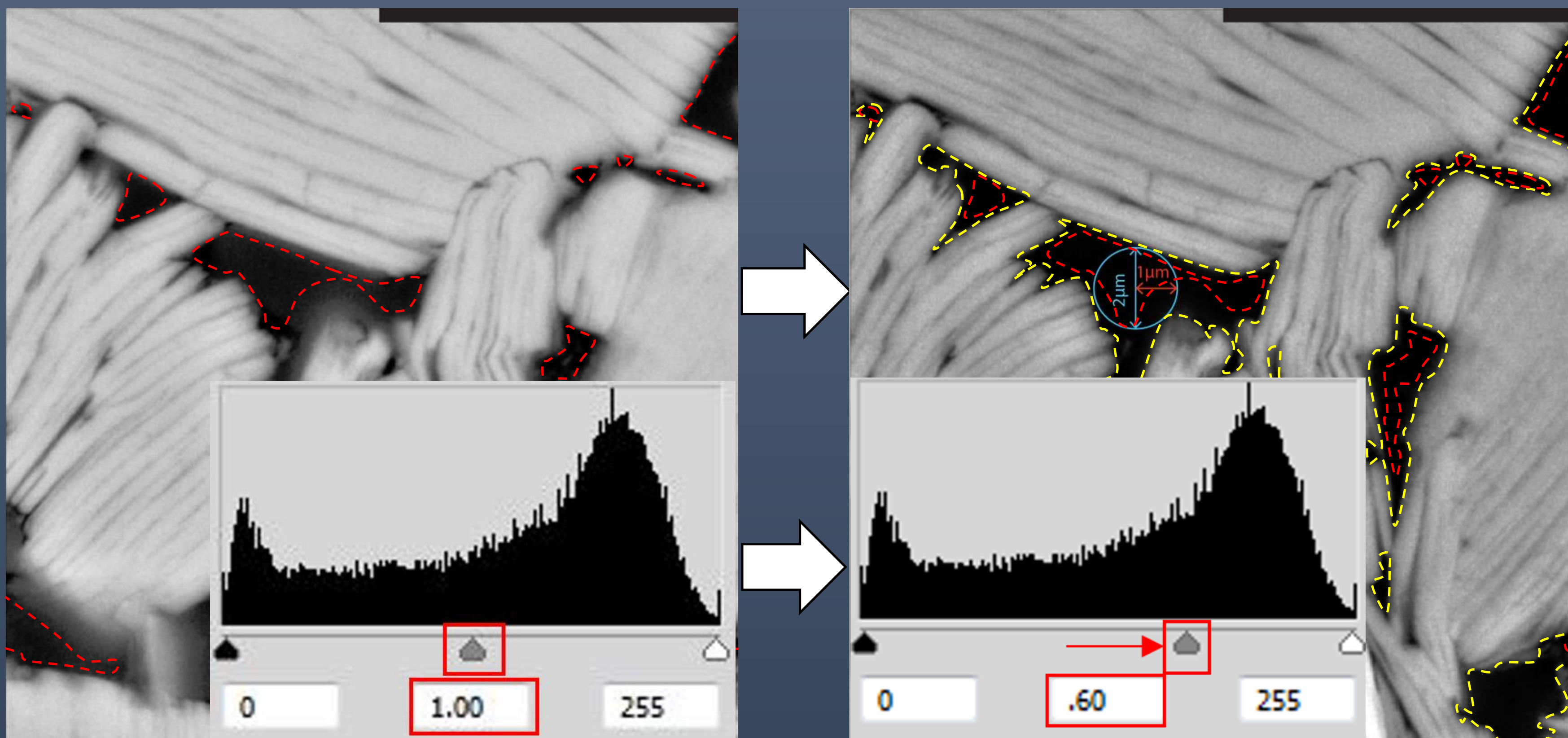




- Images of **pore-filling kaolinite booklets**

Quantifying Clay Micrporosity ($\emptyset_m$)

- BSE mage analysis. Silicates appear light, epoxy appears dark (based on Z)
- Delete grey tones until only mineral surfaces remain
- % grey tones deleted = % microporosity (Hurst & Nadeau, 1991)

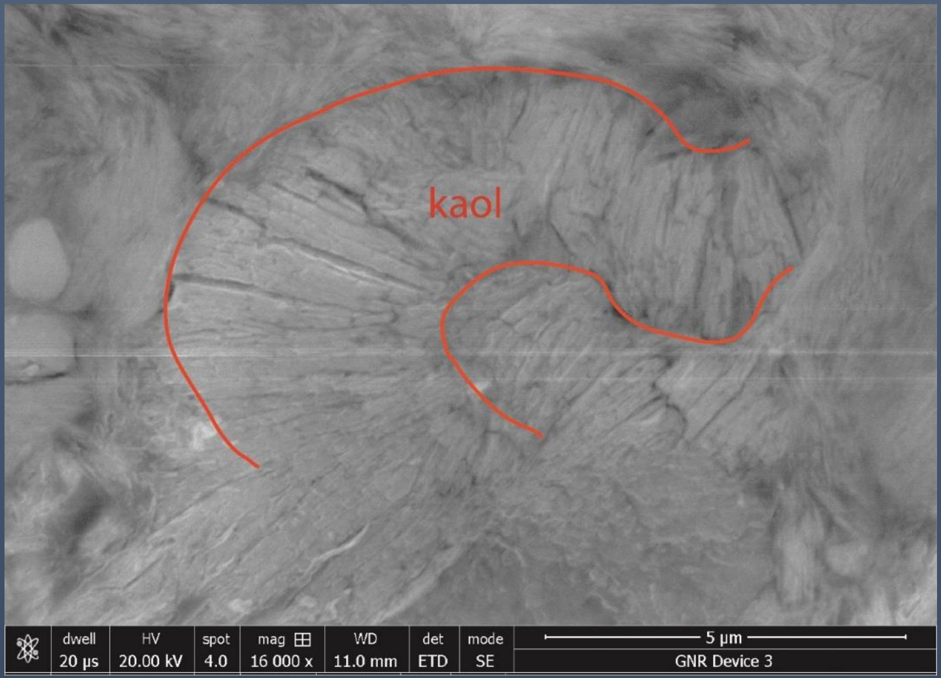


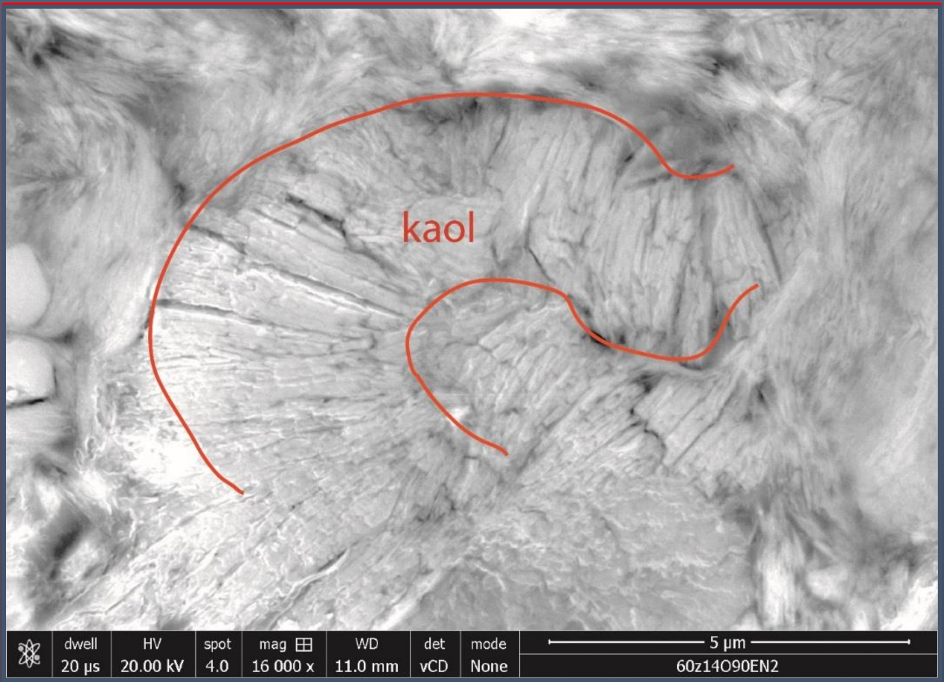
Before grey tone deletion

After grey tone deletion

Kaolinite

- Most abundant clay mineral in the Cypress (by weight %)
- Pore-filling, 3 morphologies, $\bar{X}\emptyset_m$ = **41%**

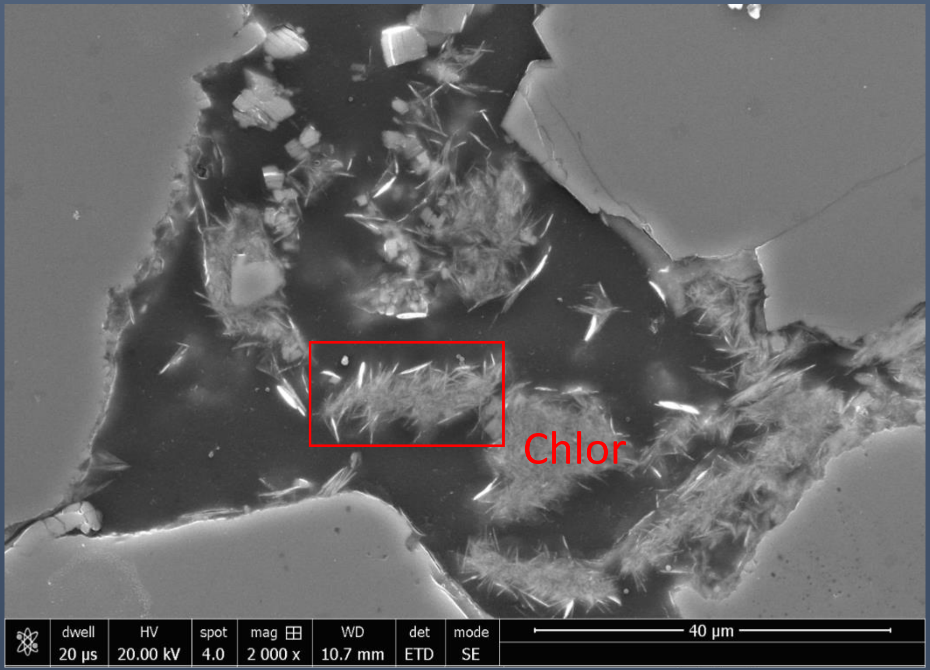


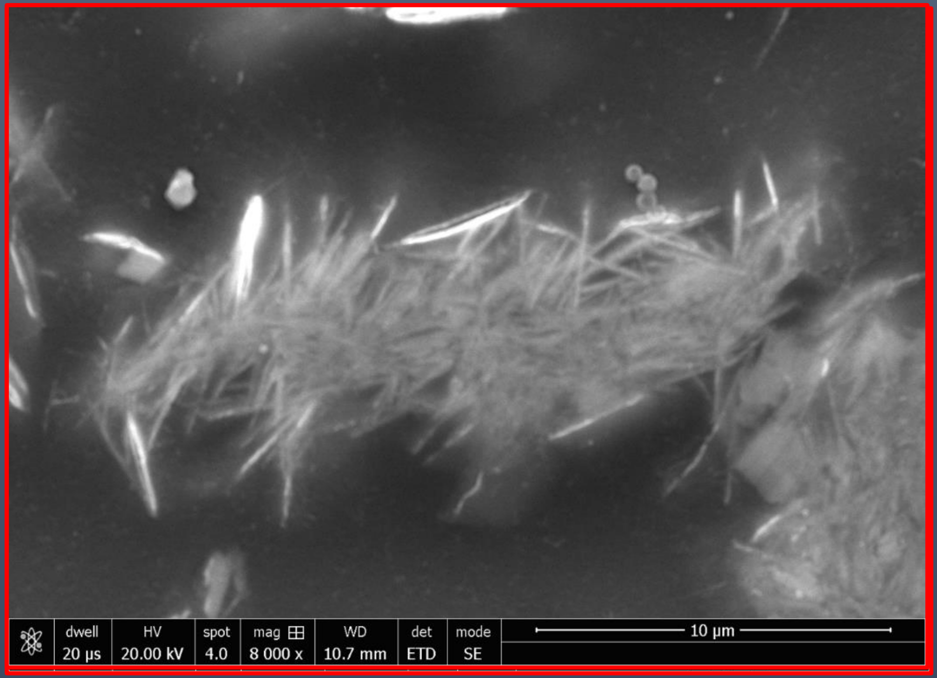


Booklets. BSE Images **Blocks.** SE Images **Vermicules.** SE & BSE Images

Chlorite

- 2nd most abundant clay mineral
- Grain coating and pore-filling, 2 morphologies, $\bar{X}\emptyset_m$ = **58%**



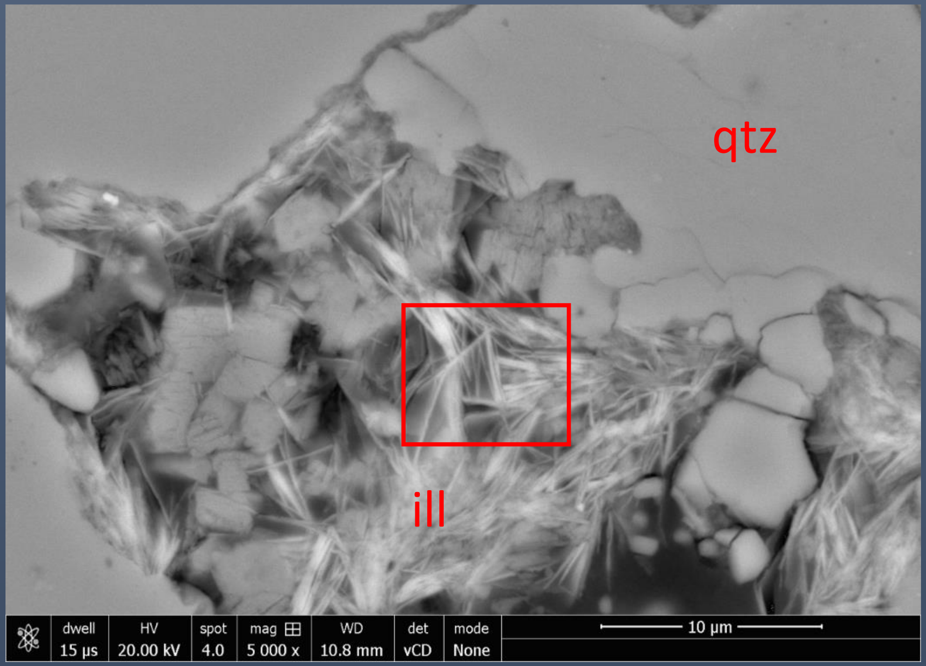


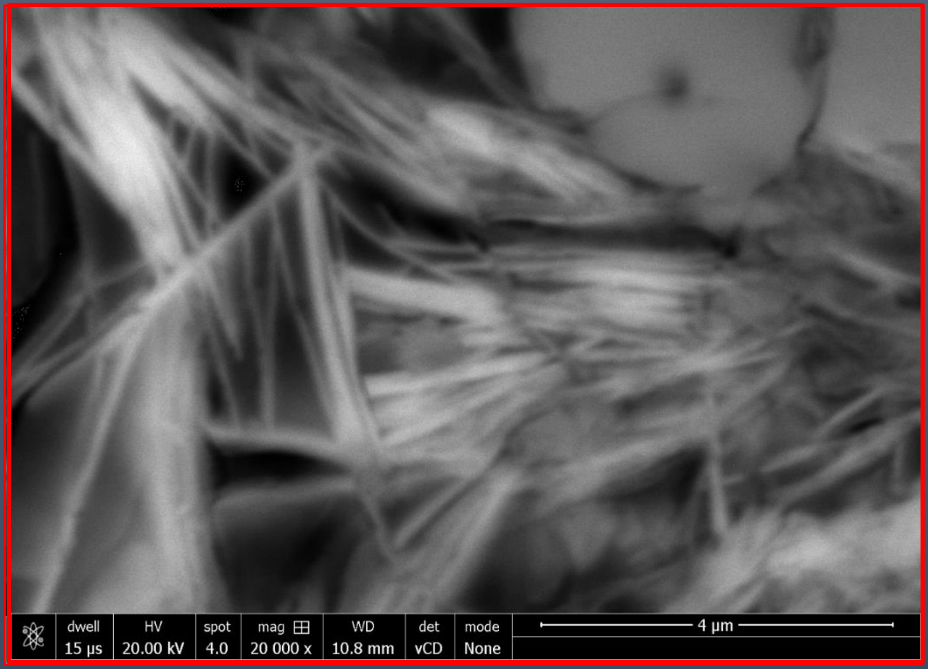
Rosettes. BSE Images

Clusters. SE Images

Illite

- 3rd most abundant clay mineral
- Pore lining and pore-filling, 2 morphologies, $\bar{X}\emptyset_m$ = 63%



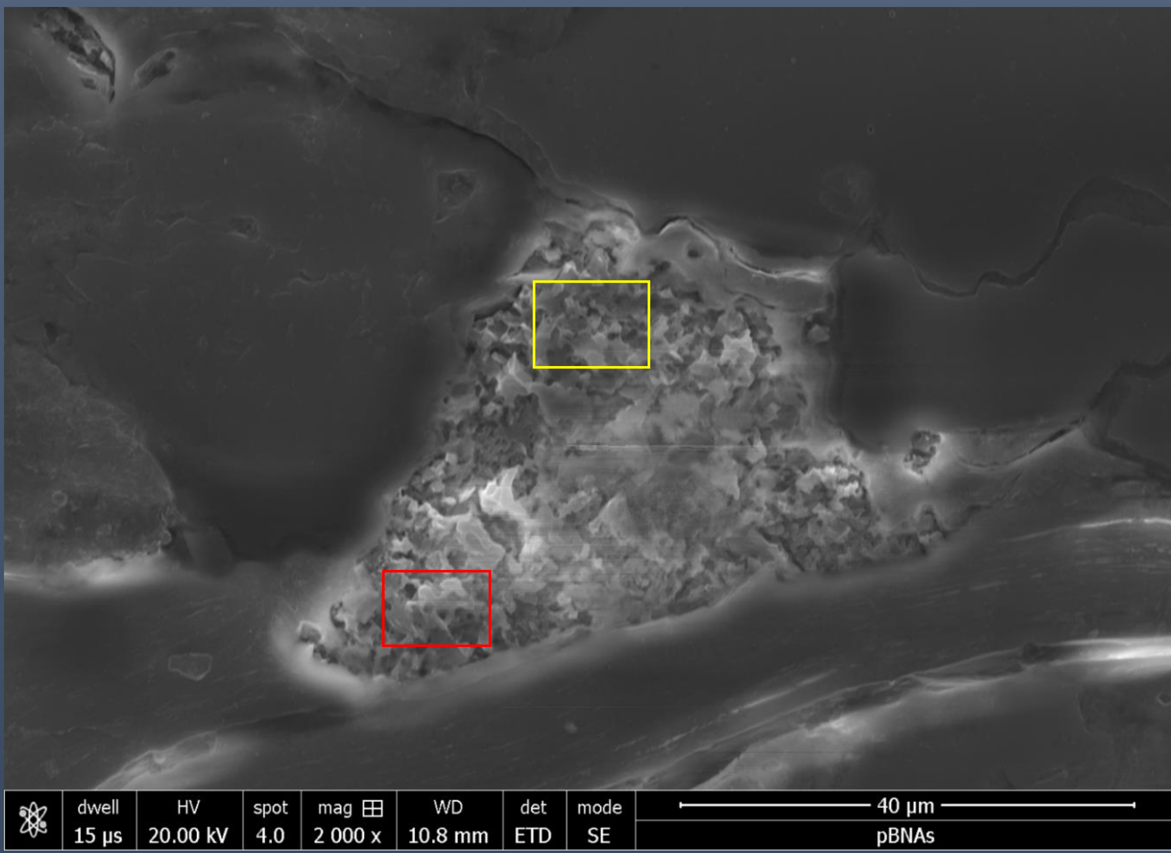


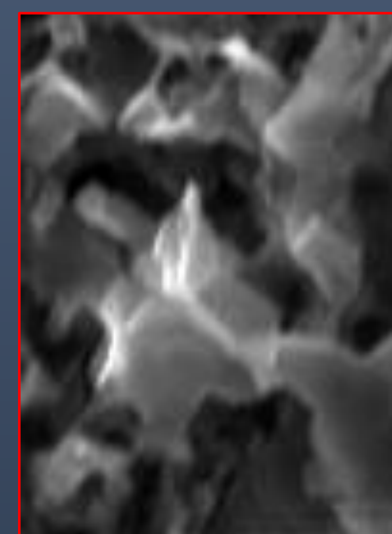
Hairy (fibrous). BSE Images

Needles. BSE Images

Mixed-Layer Illite-Smectite

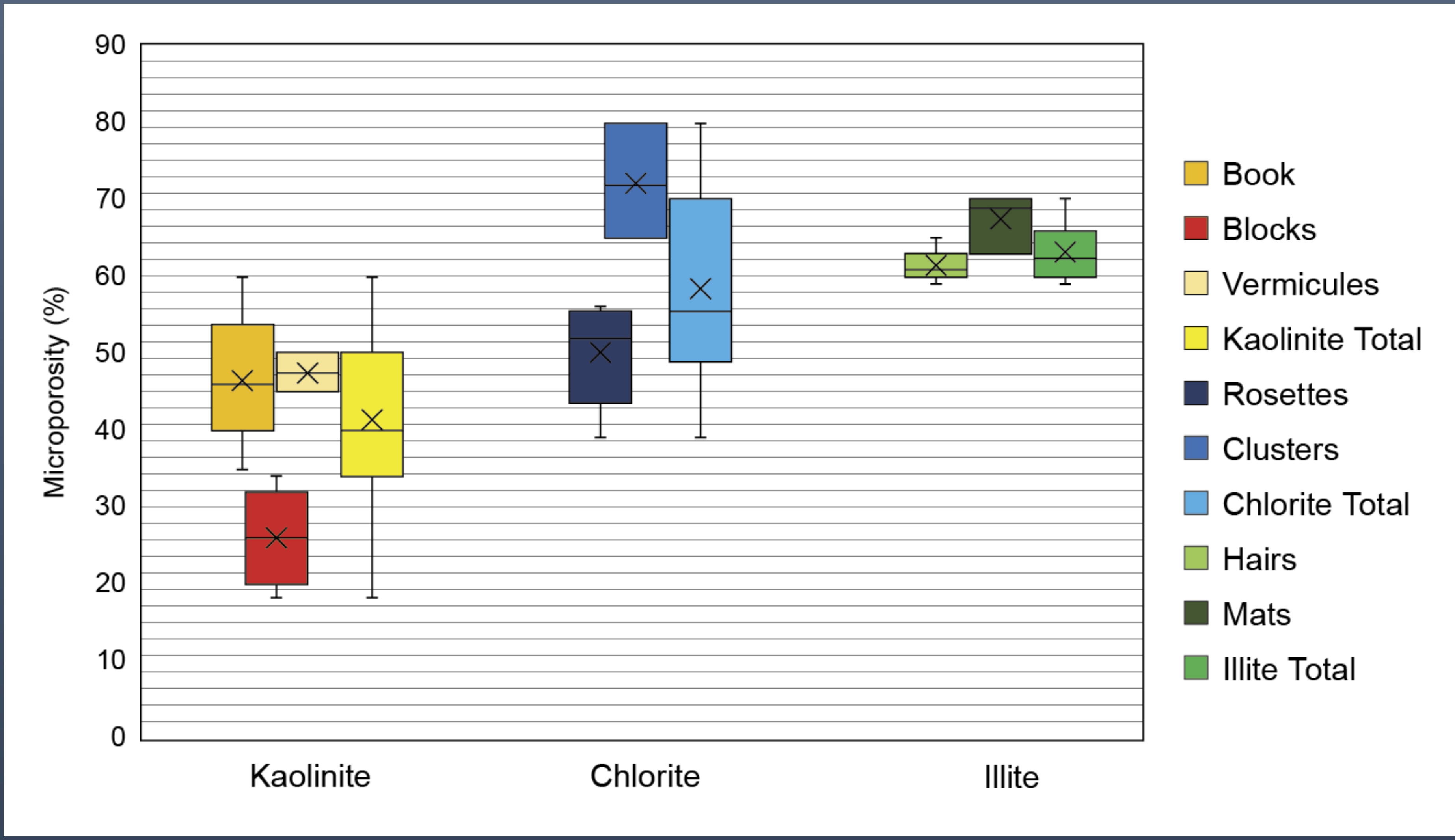
- Least abundant clay mineral
- Pore filling, Imorphology, $\bar{X}\emptyset_m$ **= 65%. Confirmed by XRD, EDS, morphology**





Webs. SE Images

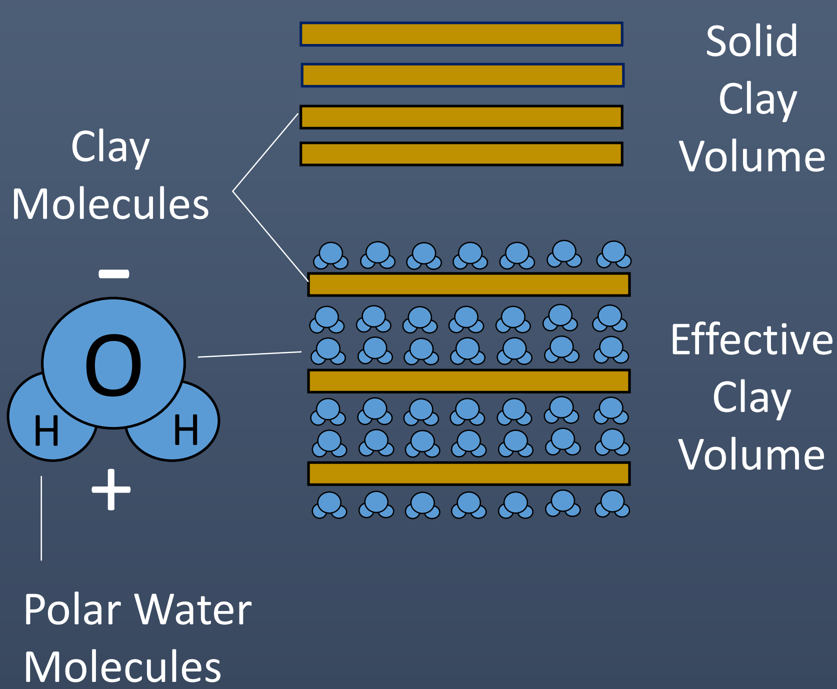
Clay Microporosity Distribution by Morphology



Applications

Effective Clay Mineral Volume

- Dry clay volume estimated by weight % from XRD, but does not include micropores
- Effective clay mineral volume ➔ dry clay + microporosity



Effective clay mineral volume (V_e)

$$\mathbf{V_e} = \frac{\mathbf{V_m}}{(\mathbf{1} - \bar{x}\emptyset_{\mathbf{m}})}$$

$\bar{x}\emptyset_m$ = clay mineral microporosity

V_m = volume of solid clay mineral

Example:

$V_m$kaol = 1.65% bulk mineral fraction

$\bar{x}\,\emptyset_m$kaol = 41%

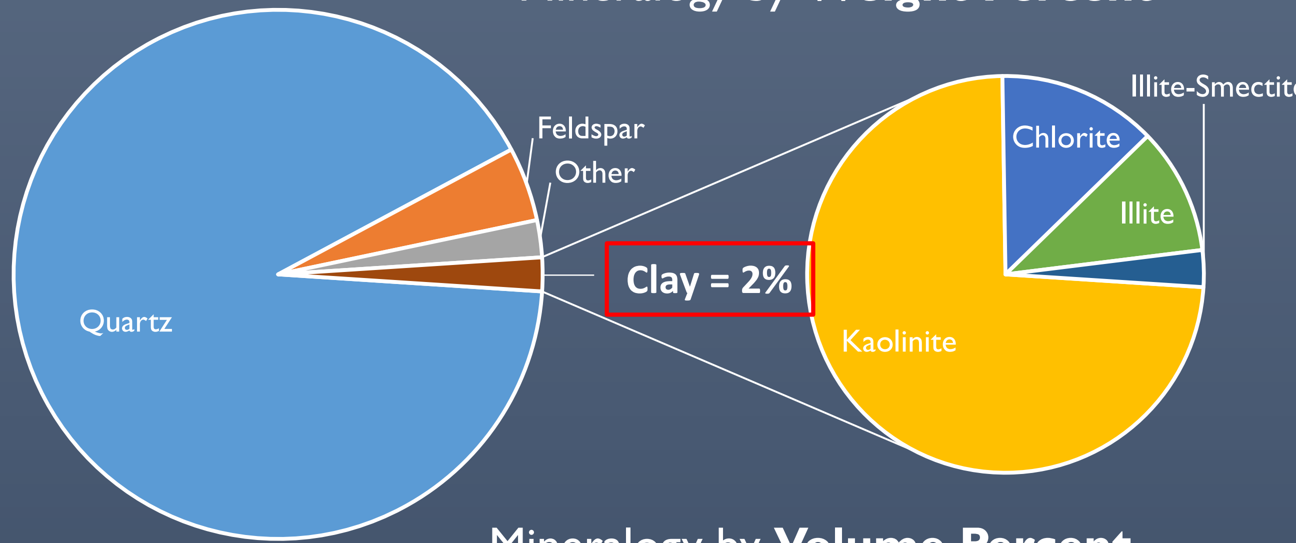
$$V_e\text{kaol} = \frac{1.65}{(1 - 0.41)} = 2.8\%$$

70% Volumetric Increase

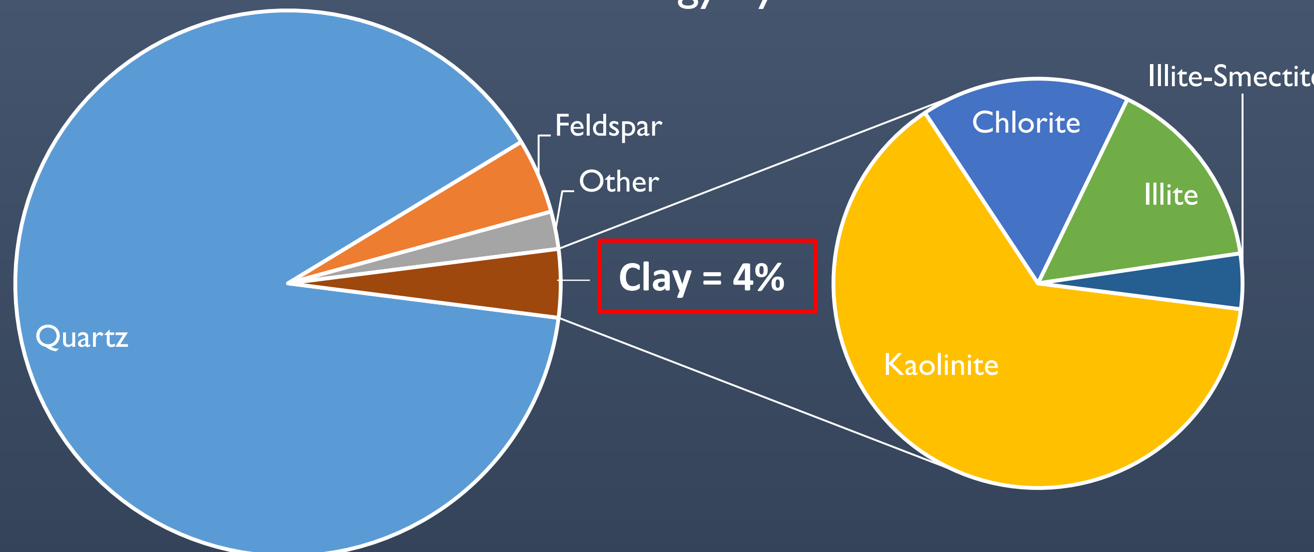
Effective Clay Mineral Volume (Results)

- 56 Samples
- 4% effective clay volume determined
- >2 fold increase from dry clay

Mineralogy by **Weight Percent**



Mineralogy by **Volume Percent**



Water Saturation

- Dual Water Model accounts for excess clay conductivity
- Effective clay mineral volume is a good input parameter

$$S_w = \frac{S_{wt} - S_{wb}}{1 - S_{wb}}$$

$$= V_{shale} * \frac{\bar{x}\, \varnothing_{m(total)}}{\varnothing_{total}}$$

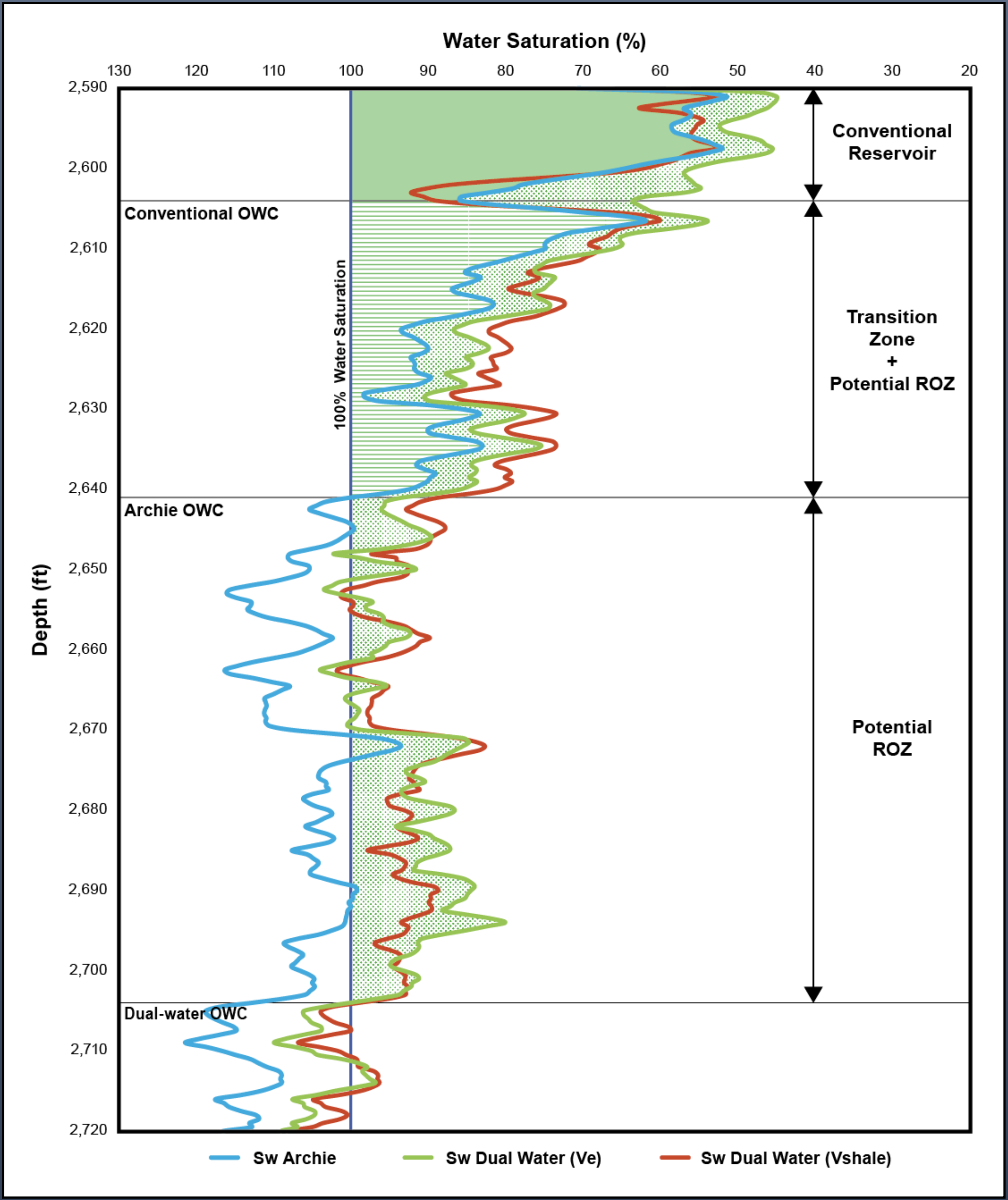
$$= V_e * \frac{\bar{x}\, \varnothing_{m(total)}}{\varnothing_{total}}$$

S_w = effective water saturation
S_{wt} = total water saturation
S_{wb} = clay bound water saturation

*Accounts for clay minerals, avoids assumption that shale = clay minerals

Developed by Clavier, 1984

Dual Water Method (Results)



- Total Residual Oil Zone (ROZ) predictions:
  - Archie's = 37 feet
  - Dual Water = 100 feet
- Dual Water shows:
  - 63ft more potential ROZ
  - Higher oil saturation throughout
- V_{shale} accurate?

Effective Porosity

- Clay microporosity is does not contribute to fluid flow
- Exclude from total porosity for effective porosity (eq.)

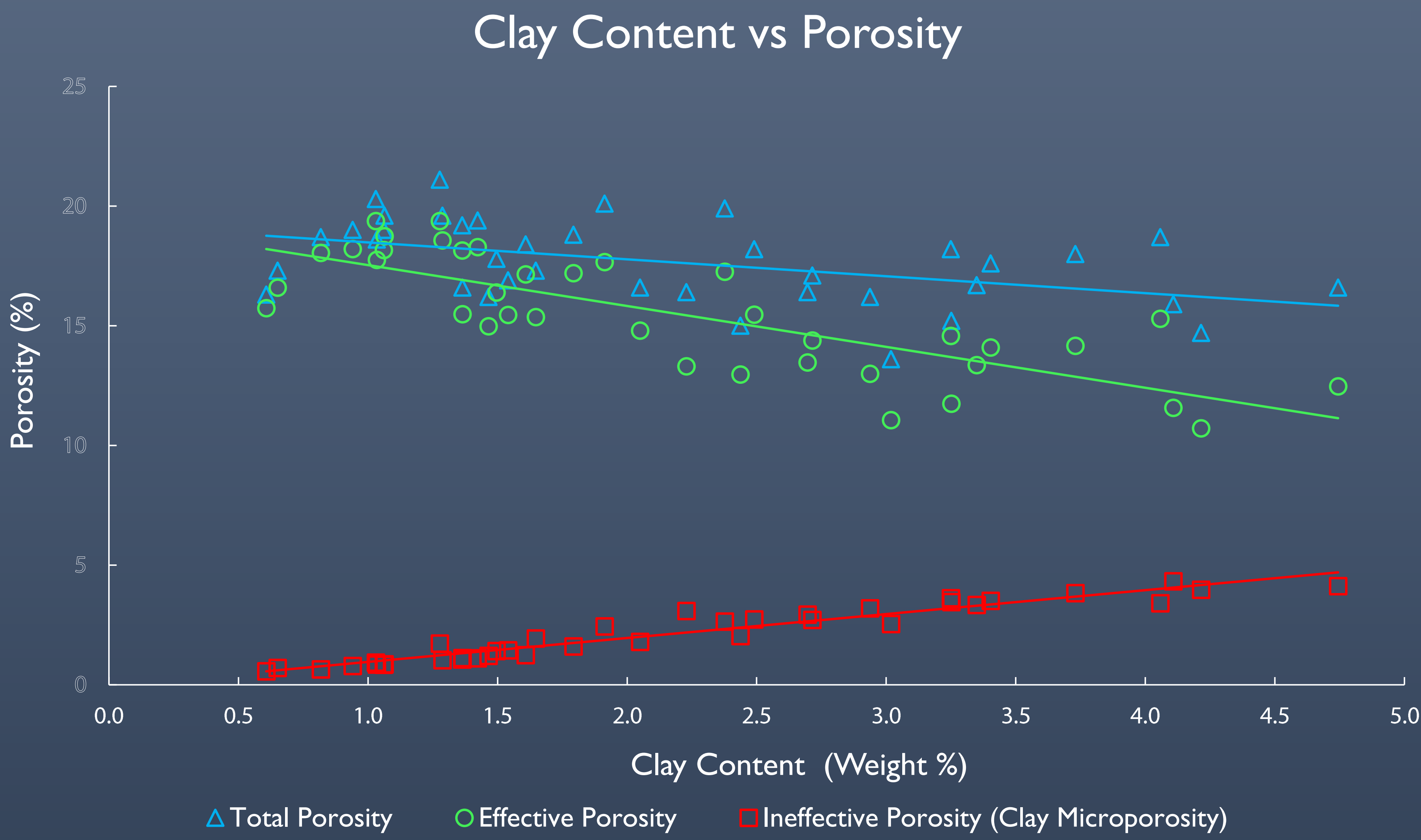
At given depth:

$$\emptyset_e = \emptyset_t - \emptyset_m$$

$\emptyset_e$ = effective porosity
$\emptyset_t$ = total porosity (He-plug)
$\emptyset_m$ = microporosity

- Calculations on 42 samples ➔ 18% $\bar{x}\emptyset_t$ ➔ 16% $\bar{x}\emptyset_e$ in thick Cypress
- ~11% decrease, applicable regionally?

Effective Porosity (RESULTS)



Conclusions

- 4 clay mineral groups and 8 morphologies in the thick Cypress
  - Microporosity specific to morphology. Range of 26 – 72%
- In thick Cypress, accounting for clay microporosity has lead to:
  - > 2 fold increase in clay mineral volume estimates
  - Greater show of a potential ROZ (based on water saturation)
  - Improved estimates of effective porosity
- Future work will require validation of V_{shale} accuracy and the 11% effective porosity decrease

Thank you

Acknowledgements

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