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)

(Leroy et al., 2007)
(Sand Grain)
(Pore Water)
(Fixed Layer)
(Diffuse Layer)
(Bulk Solution)
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)

• 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

Back-Scattered Electron (BSE) Image

Information on mineral morphology, topography

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 $m$
- $\rho_a =$ density of mineral $m$
- $\varphi_t =$ total porosity
- $\sum(m_i/\rho_i) =$ sum of weight % of each mineral over its respective density

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

Effective clay volume ($V_e$)

- $\varphi_m =$ 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:

\[ V_{\text{immob water}} = V_e - V_m \]

\( V_e \) = Effective Clay Volume
\( V_m \) = Volume of Solid Clay Mineral

Correct water saturation values to exclude immobile water
Reservoir Quality Implication: Effective Porosity

- Effective porosity ($\varphi_e$) 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 ($\varphi_m$) must be excluded from total porosity ($\varphi_t$)

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

$\varphi_t$ = total porosity (evaluated from wireline logs)

$\varphi_m$ = 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
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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:

\[ \text{mean and } \sigma \varphi_m \text{ (vermicular kaolinite)} \]

\[ = 18\% \pm 4.2\% \]