Petrography of the Chesterian (Upper Mississippian) thick Cypress Sandstone in the Illinois Basin for CO_2-Enhanced Oil Recovery

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Abstract

The Upper Mississippian Cypress Sandstone in the Illinois Basin (ILB) includes a fairway of thick sandstones, interpreted as incised valley fill (IVF) deposits, which contain relatively thin oil reservoirs developed in the tops of the sandstones. These IVF Cypress Sandstones are composed of a range of sedimentary facies, which can be classified as either reservoir or nonreservoir facies based on their petrological properties. Geologic controls on porosity and permeability, including mineralogy, grainsize and sorting, compaction, and cementation, were assessed through petrographic analysis of IVF Cypress Sandstone core samples to classify sedimentary facies according to their reservoir properties.

The IVF Cypress Sandstones are generally composed of quartz with <10% feldspars and rare (1–2%) calcite occurring primarily as cement. Fine-grained, cross-bedded sandstones and ripple-bedded sandstones constitute the reservoir facies. Porosity is generally primary intergranular porosity with some secondary porosity resulting from dissolution of feldspar grains. Clay minerals and quartz overgrowths can occlude porosity and permeability in the cross-bedded sandstones, which have the highest average porosity and permeabilities at 18% and 755 mD, respectively. Ripple-bedded sandstone is much lower quality at 16.6% and 31.9 mD. Very fine grained flaser-, wavy-, and lenticular-bedded sandstones compose the nonreservoir facies and show a much higher degree of compaction than reservoir facies, with quartz overgrowths and clay minerals filling available pore space. This leaves only secondary porosity from the dissolution of feldspar grains and carbonate cements. The relatively low permeabilities of the nonreservoir facies, generally <10 mD, indicate that they may form baffles to fluid movement within the reservoir.

This petrographic study is part of an assessment of nonconventional carbon dioxide enhanced oil recovery (CO_2-EOR) of the IVF Cypress Sandstones in the ILB, which is expected to store additional CO_2 compared to conventional CO_2-EOR. Results of petrographic analysis of the IVF Cypress Sandstone reservoir will be presented and will demonstrate that petrographic analysis, when combined with sedimentary facies analysis, is a powerful tool for characterizing IVF Cypress Sandstone reservoirs.

Introduction/Methods

Geologic Background

- The Cypress Sandstone is located within the Chesterian Series, which is characterized by alternating siliciclastic and carbonate units.[1]
- The Cypress Sanstone is one of the thickest Mississippian sandstones in the Illinois Basin.
- The lithologies of the the Cypress Sandstone vary from thick sandstone bodies to shale and sandy shale with thin interbedded sandstone beds.[2]
- The thick Cypress Sandstone fairway was deposited as part of an incised valley fill system that eroded older Cypress tidal bars and lies in the central part of the basin[3] (Figure 1).
- The Cypress Sandstone is the leading oil producing formation in the Illinois Basin, it has produced over 1 billion barrels, roughly one-third of all the oil from Illinois.[2]

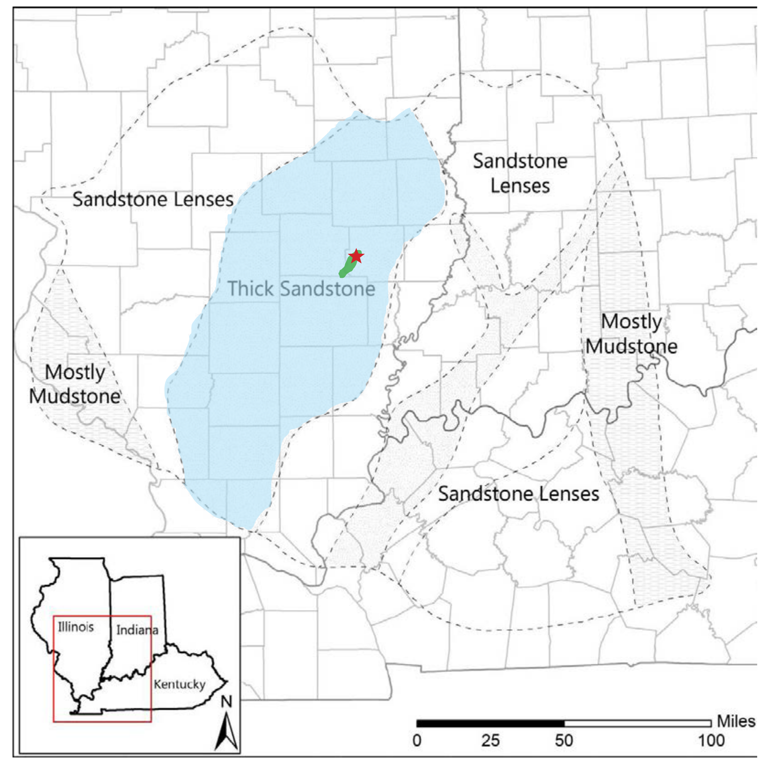


Figure 1: The blue area represents the relative location of the thick Cypress Sandstone fairway (Modified from Nelson et al., 2002)[5]. The green area is Noble Field and the red star shows the location of the Montgomery B-34 well.

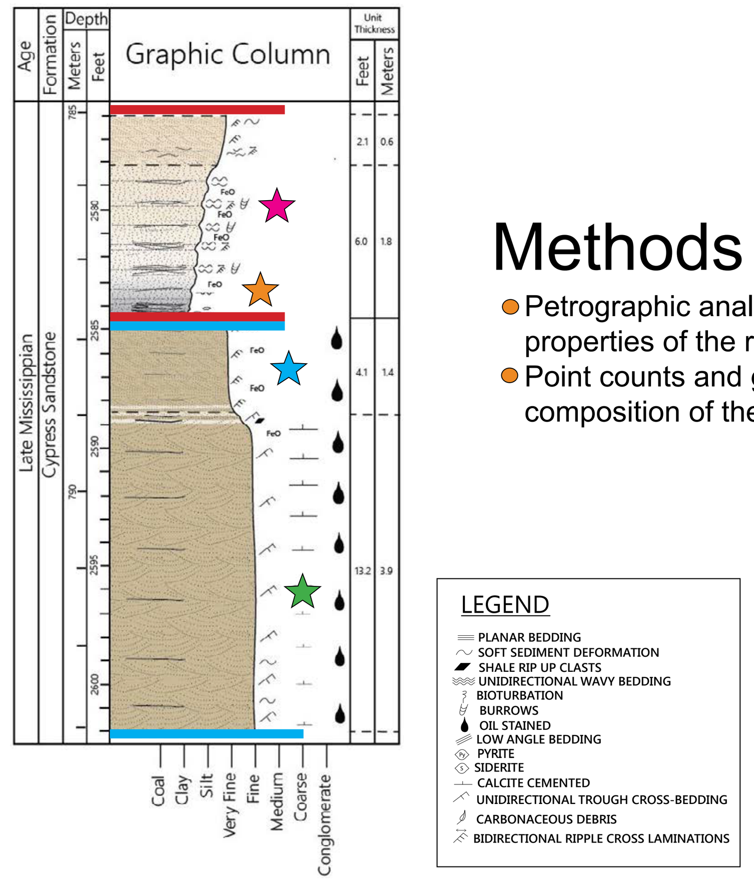


Figure 2: This is an interpreted stratigraphic column of the Montgomery core. The section bounded by the red lines includes the lenticular– and wavy–bedded sandstone. The section bounded by the blue lines includes the ripple– and cross–bedded sandstone.

Methods

- Petrographic analysis is being conducted to better understand how different properties of the rock relate to reservoir properties.
- Point counts and grain–size analysis are being conducted to determine the composition of the rock unit.

Figure 3: This picture shows the Montgomery B-34 core. It begins in the top left corner and continues down to the bottom right corner. The section bounded by the red lines includes the lenticular– and wavy–bedded sandstone. The section bounded by the blue lines includes the ripple– and cross–bedded sandstone.

Results

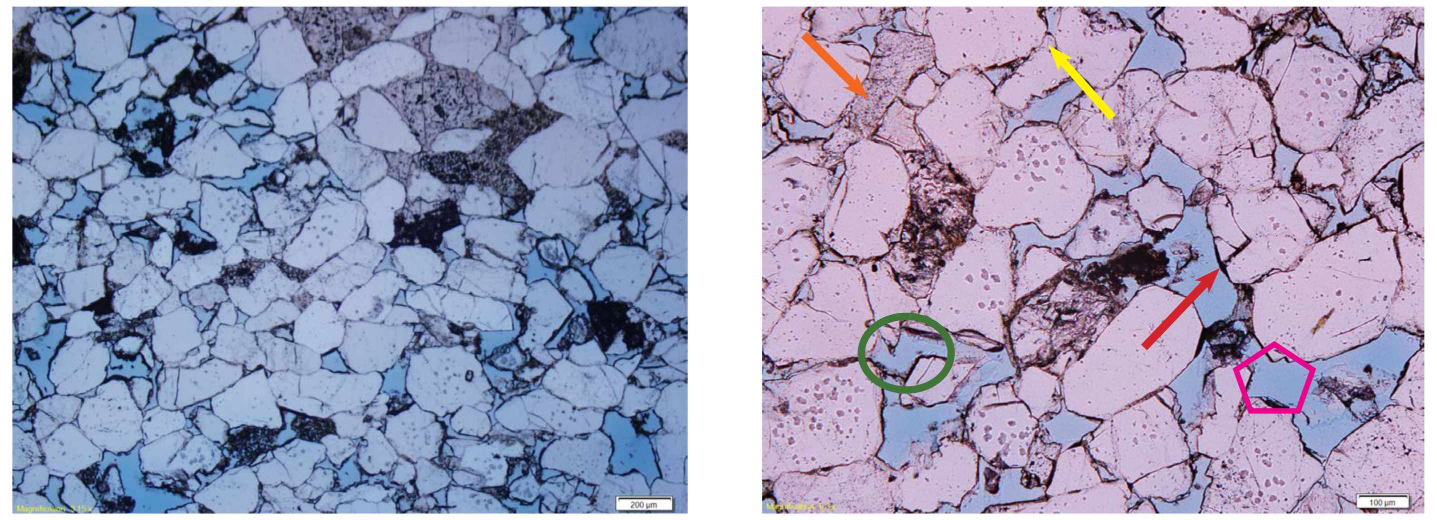
Montgomery B-34 Core

- Whitish-gray in color
- Sandstone
- Angular to very rounded grains
- May contain oil staining, calcite cement, iron oxide staining, pyrite

Reservoir and non-reservoir facies were determined through core and thin section analyses. Those sections that displayed oil saturation and oil staining were deemed reservoir facies and those that did not show oil staining were deemed to be non-reservoirs.

Reservoir Facies

Cross-Bedded Facies



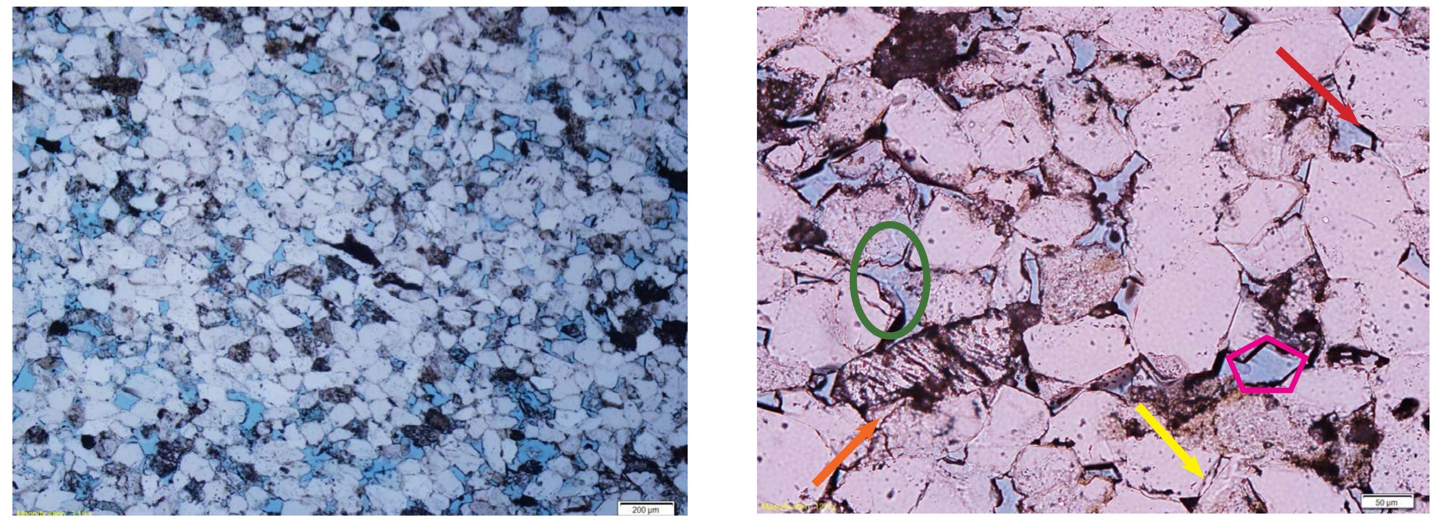
Figures 4&5: Theses photomicrographs show the composition at 2596.5 ft. Each picture is showing the same depth at a different scale. The blue coloring of isolated porosity can be easily seen in these pictures.

- Very fine to medium grained
- Mostly angular grains
- Semi-isolated intergranular primary porosity
- Intragranular secondary porosity caused by dissolution of feldspar and carbonate grains
- Unidirectional sedimentation
- Moderate to high energy environment

Table 1: This table represents the point count data and core plug values at 2596.5 ft.

Quartz	Feldspar	Clay	Carbonate	Lithic	Opaques	Primary Poro. from thin section	Secondary Poro. from thin section	Porosity from core	Perm. from core
78.64%	1.04%	5.2%	1.76%	0.0%	1.28%	10.88%	1.2%	18.4%	1821 mD

Ripple-Bedded Facies

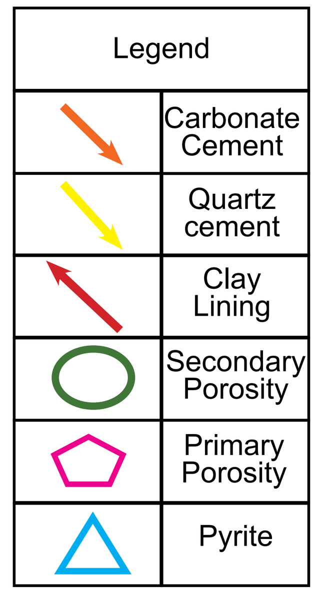


Figures 6&7: These photomicrographs show the composition at 2586.5 ft. Each picture is showing the same depth at a different scale. The blue coloring of isolated porosity can be easily seen in these pictures.

- Very fine to fine grained
- Well sorted
- Mostly angular to sub-angular grains
- Isolated intergranular primary porosity
- Intragranular secondary porosity caused by dissolution of feldspar and carbonate grains
- Bedload sedimentation
- Low energy traction currents

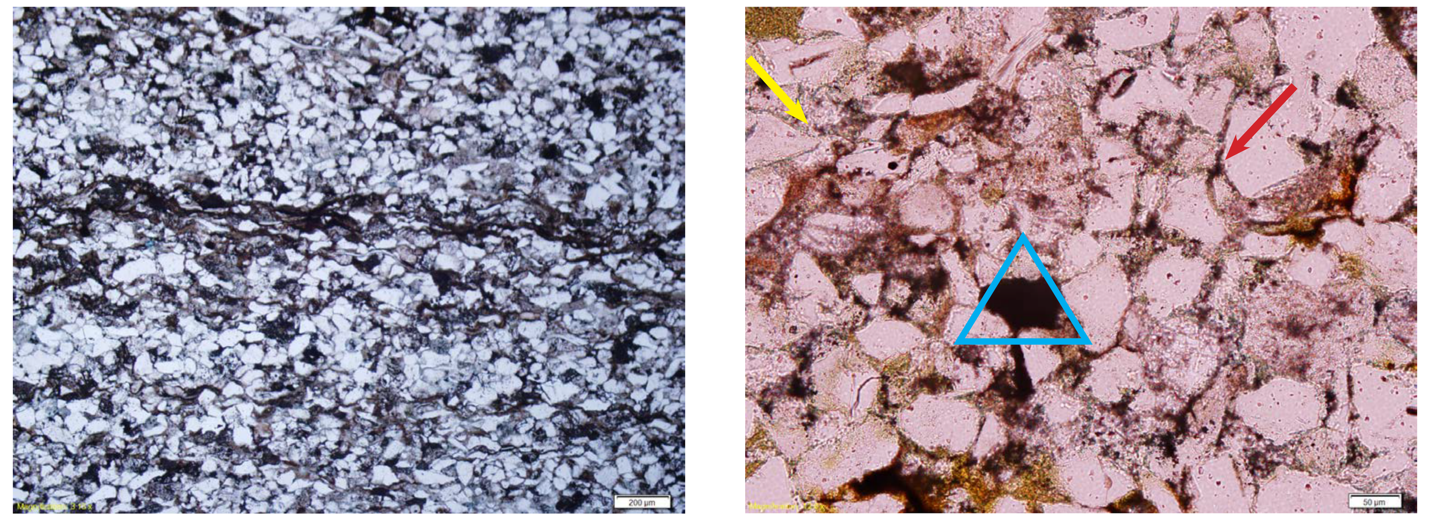
Table 2: This table represents the point count data and core plug values at 2586.5 ft.

Quartz	Feldspar	Clay	Carbonate	Lithic	Opaques	Primary Poro. from thin section	Secondary Poro. from thin section	Porosity from core	Perm. from core
72.48%	3.18%	5.10%	0.23%	0.0%	1.43%	15.15%	2.39%	18.2%	58 mD



Non-reservoir Facies

Wavy-Bedded Facies



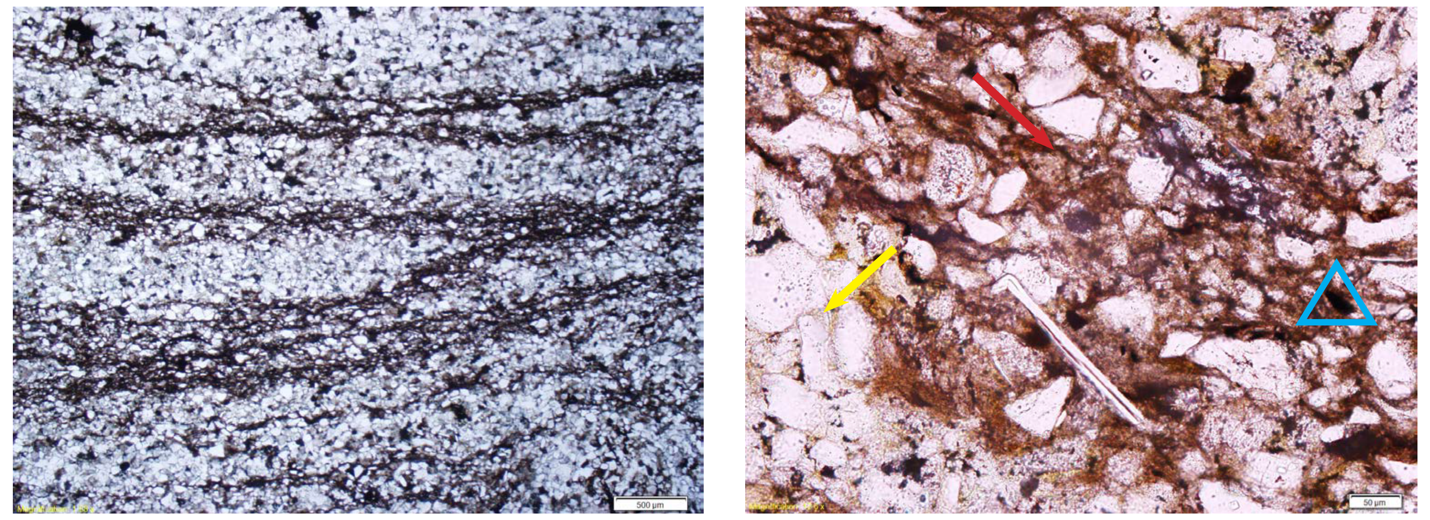
Figures 8&9: These photomicrographs show the composition at 2580.5 ft. Each picture is showing the same depth at a different scale. Clay interbeds can be seen cutting across the slide.

- Silt to very fine grained
- Well sorted
- Few clay laminations
- Mostly angular grains
- Very little visible pore space
- Very consolidated
- Low energy environment
- Sediment fallout

Table 3: This table represents the point count data and core plug values at 2580.5 ft.

Quartz	Feldspar	Clay	Carbonate	Lithic	Opaques	Primary Poro. from thin section	Secondary Poro. from thin section	Porosity from core	Perm. from core
77.02%	8.06%	9.34%	2.26%	0.0%	2.26%	0.80%	0.48%	10%	1.1 mD

Lenticular-Bedded Facies



Figures 10&11: These photomicrographs show the composition at 2583.5 ft. Each picture is showing the same depth at a different scale. Clay interbeds can be seen cutting across the slide; they are more numerous than the wavy–bedded facies.

- 1-4 cm silty lenses in a mud or silty mud matrix
- Numerous clay laminations
- Very little visible pore space
- Very consolidated
- Moderately sorted
- Angular to rounded grains
- Low energy environment
- Sediment fallout

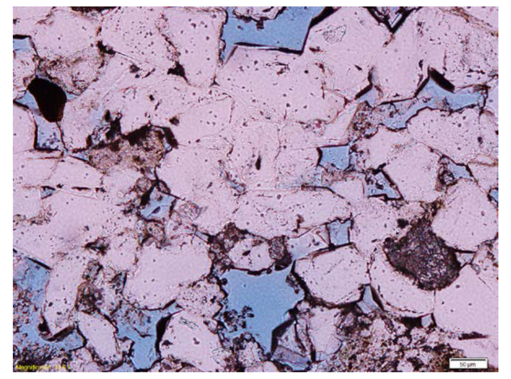
Table 4: This table represents the point count data and core plug values at 2583.5 ft.

Quartz	Feldspar	Clay	Carbonate	Lithic	Opaques	Primary Poro. from thin section	Secondary Poro. from thin section	Porosity from core	Perm. from core
65.70%	4.076%	28.46%	0.64%	0.0%	0.96%	0.0%	0.16%	7.7%	0.4 mD

Discussion

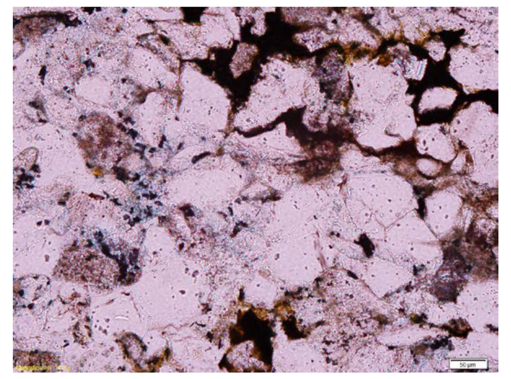
- As can be seen in Tables 1-4, the point count measured porosity and the core measured porosity vary significantly. This is considered "normal" due to the differences of two-dimensional vs. three-dimensional analysis, microporosity, the scale at which the thin section is being analyzed, and the point count data only considering macroporosity.
- Permeability difference can be attributed to the facies: the core pugs were horizontal plugs so the ripple-beds will contain discontinuities. whereas the cross-bedded facies will be more continuous.
- Much of the counted primary porosity could possibly be secondary porosity of a completely dissolved out grain, appearing to be primary porosity.
- Human error is to be expected when conducting point count analysis.

Reservoir Facies



- Because of the larger grain size and sedimentary structures of the reservoir facies, it can be concluded that this was a higher energy depositional environment.
- The reservoir facies are very clean– they contain less clays– due to this higher energy environment.
- Late dissolution of feldspars within this facies allowed SiO_2 to reprecipitate into the quartz cement seen in the photomicrographs.
- Had dissolution occurred earlier, secondary pore space would have likely been filled in and any dissolved minerals carried out of the system.
- Much of the secondary porosity in the reservoir facies is preserved.
- The reservoir facies are likely to be a better option for CO_2-EOR and CO_2 storage because of their high porosity and permeability values.
- The controls on porosity are primarily diagenetic features.

Non-reservoir Facies



- The finer grain size and higher clay content of the non-reservoir facies reflect a lower energy depositional environment.
- The wavy- and lenticular-bedded facies are more consolidated because of their high clay content facilitating the compaction of the grains.
- The occurence of pyrite in the non-reservoir facies, identified in hand sample, is a characteristic early diagenetic mineral in marine environments.
- Pyrite is rare throughout the entire core, suggesting more of a mixed freshwater/marine environment such as a delta or estuary.[2]
- A reducing environment promotes the precipitation of pyrite.
- The non-reservoir facies are likely to be a poor choice for CO_2-EOR and CO_2 storage because of their lack of permeability.
- The controls on porosity are primarily depositional features.

Future Goals

Future work for this project includes the following:

- Increase the number of cores that are petrographically analyzed
- Devlop a regional understanding of diagenetic trends
  - Analyze the differences in regional cores
- Use a cathodoluminescence microscope to look for different carbonate cement generations
- Determine the paragenetic sequence of each facies to better understand the geologic history and sequence of events.

References

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[5] Nelson, W.J., et al., 2002, Sequence Stratigraphy of the Lower Chesterian (Mississipian) Strata of the Illinois Basin; Illinois State Geological Survey, Bullletin V. 107.

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