Assessing Aux Vases Sandstone Heterogeneity in the Illinois Basin for Potential EOR Projects Using Clay Mineralogy, Permeability and Porosity

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Abstract

The Upper Mississippian Aux Vases Sandstone is a significant oil reservoir in the Illinois Basin (ILB), and may be the target of future enhanced oil recovery (EOR) projects. The producing facies is characterized by fine-grained, tidally reworked, elongated sandstone bars. Despite prolific oil production and detailed study of individual oil fields, the spatial distribution of mineralogical heterogeneity within the Aux Vases is poorly understood. Recognizing the spatial variations in clay mineralogy of Aux Vases reservoir rock across the ILB will aid in future discoveries and could improve the overall oil recovery from the formation through proper implementation of EOR techniques.

Past studies characterized the Aux Vases on individual oil field or outcrop belt scales, but those findings have not been integrated into a basin wide model for mineralogical variation within the Aux Vases. Additionally, because of the focus on individual oil fields, mineralogical data gaps exist across the ILB in areas where the Aux Vases exhibits abnormally low chlorite content, anomalous kaolinite and decreased permeability and porosity; all factors that impact oil recovery potential. Limited data in the northern ILB necessitates a need for a more regional study to understand the mineralogical changes in the Aux Vases.

New samples have been collected to improve mineralogical data resolution and understand the nature of the spatial distribution of clay minerals within the Aux Vases across the ILB. Semi-quantitative X-Ray diffraction (XRD) methods were used on 29 core samples for clay mineral analysis. Measurements of permeability and porosity of core plugs helped determine how the clay mineralogy is related to those parameters. A synthesis of mineralogical, permeability and porosity data in the north-south trending, tidally influenced sandstone bar facies of the Aux Vases Formation is expected to show spatial variations in diagenetic alteration and deposition with implications for the application of EOR. The mineralogical data should provide new insights and detailed information for understanding how the Aux Vases formed and diagenetically evolved in the ILB (figure 1).

Geologic Setting

- Aux Vases Formation was deposited as part of the Kaskaskia sequence, a major sedimentary package in the ILB
- Formed during and after two major orogenic events (The Acadian and Alleghanian) that drove subsidence of the ILB (Devera et al., 2010).
- Aux Vases contains 60-80% quartz, <10% feldspars and <10% clay minerals by total volume.
- Clay mineral assemblage of illite, mixed-layered illite-smectite, (Mg, Fe) chlorites and no kaolinite (Leetaru 1996).

Three Primary Facies (figure 2)

- Western: Thick incised channel fill sandstones, up to 160ft thick.
- Central: Tidally-influenced sandstone bars up to 40ft thick (petroleum reservoir).
- Eastern: Carbonates with interbedded shales (Huff & Seyler, 2010).

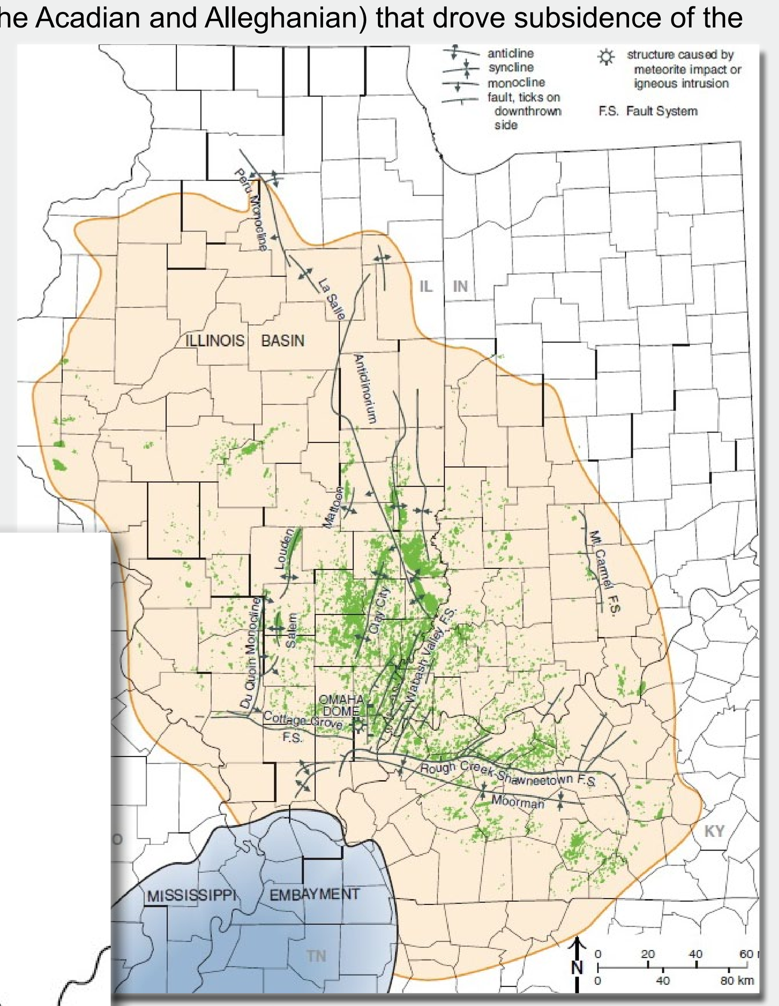


Figure 1. Map of the entire Illinois Basin with structural features, and oil fields (Huff & Seyler, 2010).

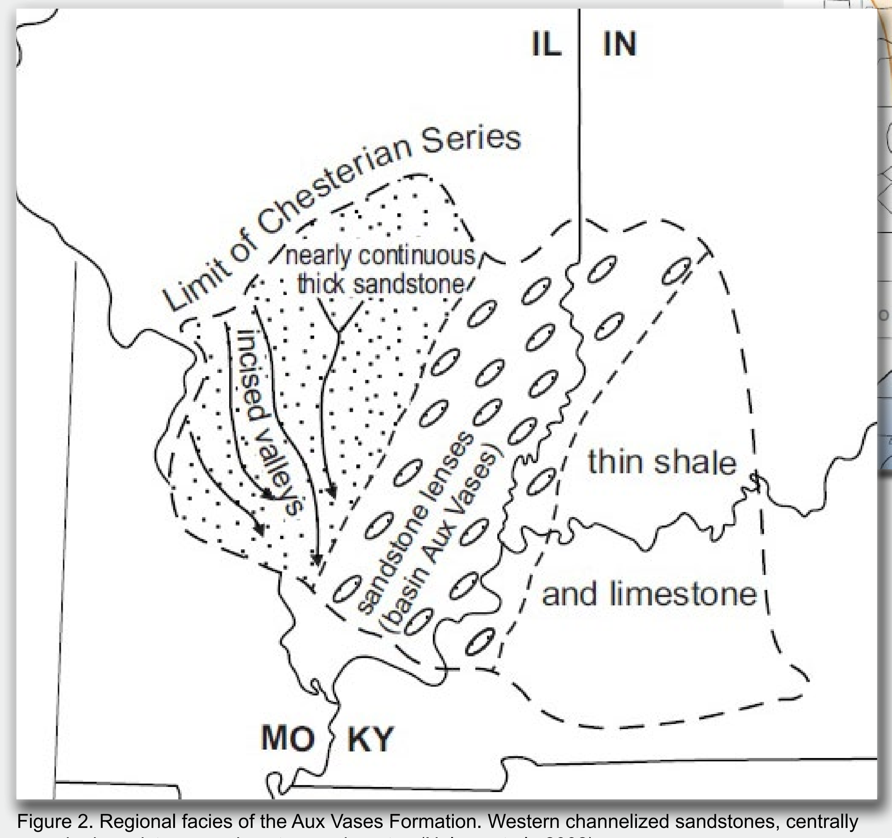


Figure 2. Regional facies of the Aux Vases Formation. Western channelized sandstones, centrally reworked sandstones and eastern carbonates (Nelson et al., 2002).

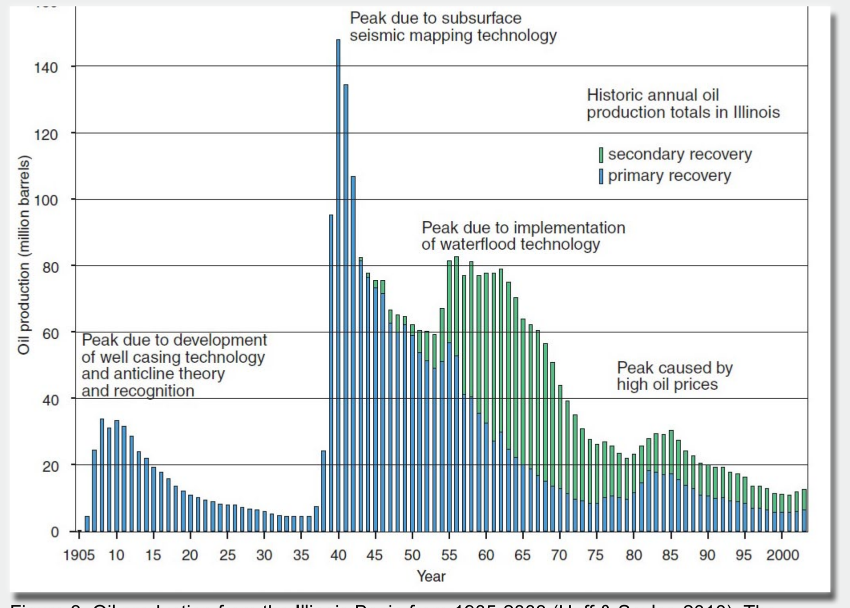


Figure 3. Oil production from the Illinois Basin from 1905-2003 (Huff & Seyler, 2010). The Kaskaskia sequence accounts for around 80% of all hydrocarbons produced from the ILB.

Study Purpose

- Limited clay mineral, porosity, and permeability data suggests regional changes to the north.
- Need for the development of a basin scale mineralogical model via the synthesis of old and new data.
- Specific interest in resolving distribution of low total chlorite, low permeability/porosity and anomalous kaolinite observed in the north.

Importance

- Clay minerals coat framework grains and inhibit mineral overgrowths by preserving primary porosity, which is vital for reservoir quality.
- Interaction between clay minerals and treatment fluids has numerous positive and negative effects on reservoir quality.
- Clay minerals serve as diagenetic and maturity indices (Oltz, 1994).
- It is essential to understand the clay mineral distribution across the basin to better characterize reservoirs for potential EOR projects in addition to prospecting for new discoveries.

Methods

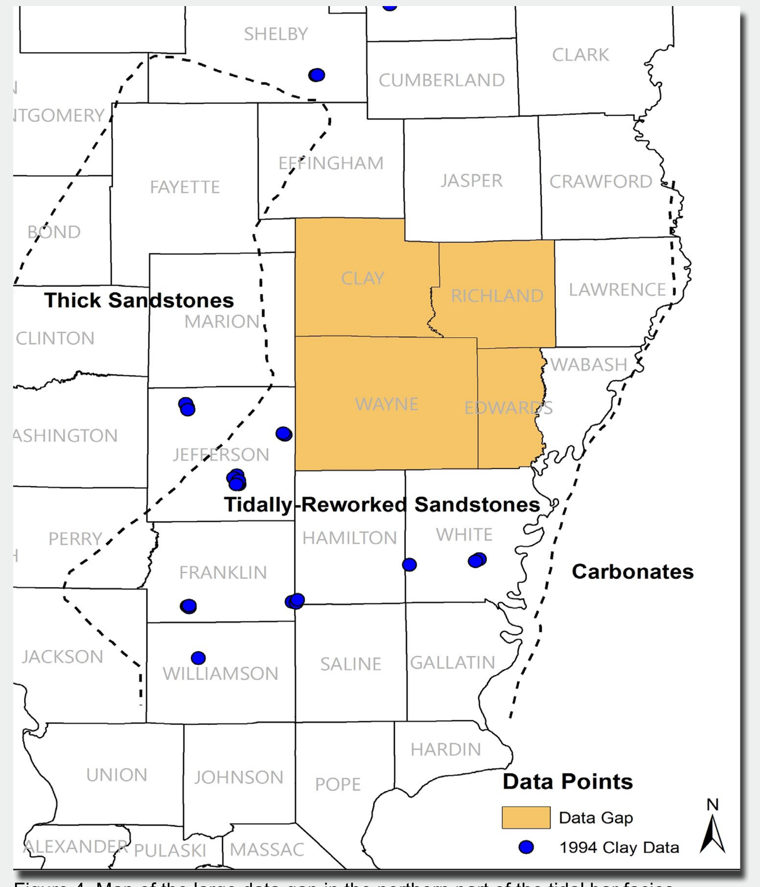


Figure 4. Map of the large data gap in the northern part of the tidal bar facies.

Three main components:
1) Identification of sample locations using GIS, samples were then collected and prepared for analysis.
2) Mineralogical analysis using XRD techniques.
3) Permeability and porosity analysis using porosimeter and permeameter.

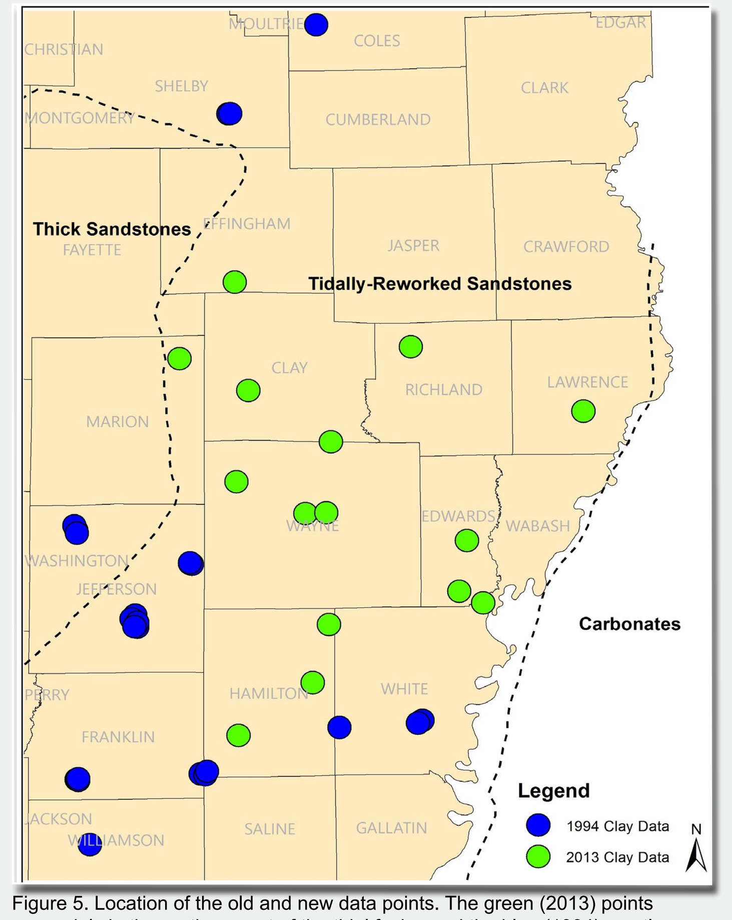


Figure 5. Location of the old and new data points. The green (2013) points are mainly in the northern part of the tidal facies and the blue (1994) mostly southern.

XRD Techniques

Micronized Bulk Pack (MBP)

- Micronized samples were end-loaded as a randomly oriented powder (2° to 60° 2θ).

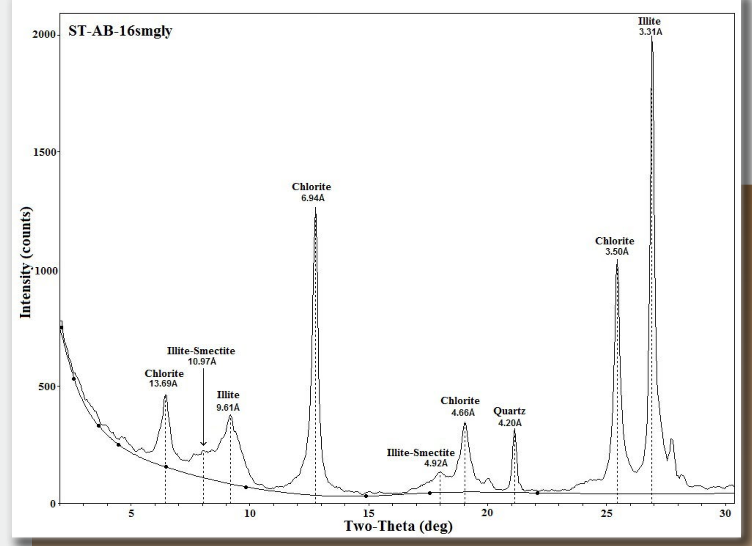
<16um size fraction

- Oil and carbonates were removed, then particles were isolated to <16um size fraction by gravity settling and smeared onto glass slides (2° to 34° 2θ).
- Semi-quantitative data reduction software Jade 9+® was used to analyze all resulting traces. (Glass & Killey, 1986 ; Hughes et al., 1994; Hughes & Warren, 1989).

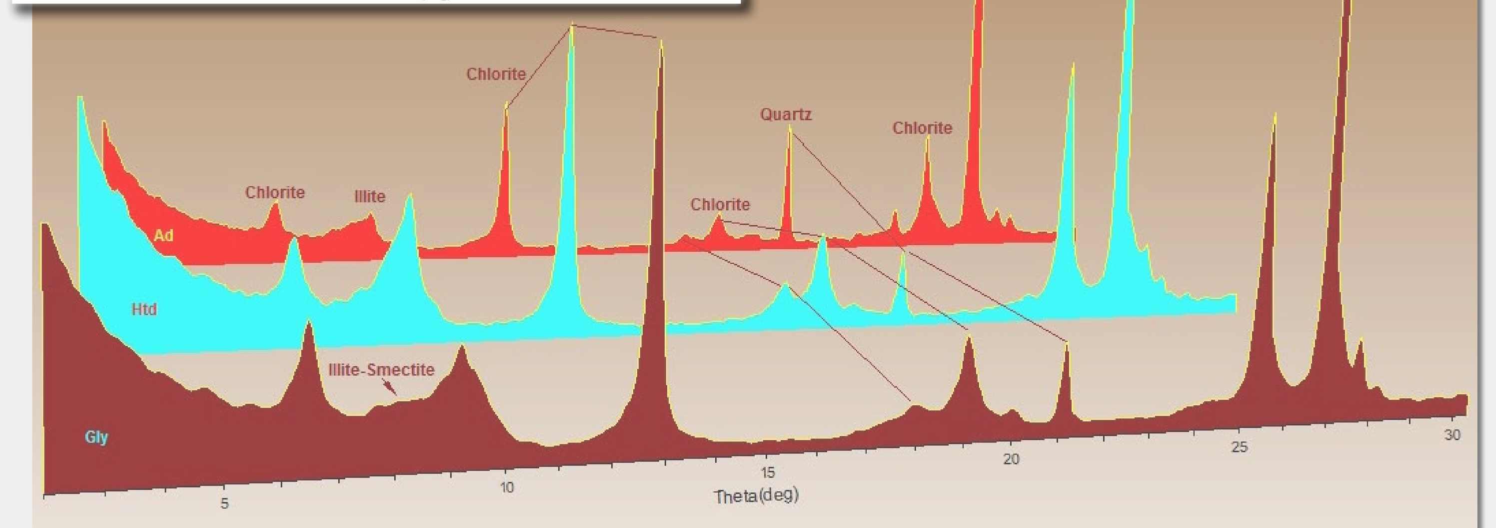
Permeability & Porosity

- Horizontal permeability was calculated from one inch diameter plugs using ΔP and flow rate readings, the permeability was calculated using Darcy's equation.
- Porosity data was measured using a helium porosimeter to determine the effective porosity calculated according to Boyles Law (API, 1998).

Typical Aux Vases <16um XRD



XRD pattern with strong chlorite intensities and broad mixed-layered illite-smectite (I-S) peaks. Fe content within the chlorite, ordering of I-S and the proportion of illite:smectite within the I-S was estimated from the XRD (Moore & Reynolds, 1997).



Results

A total of 29 new core samples were collected for MBP and <16um analysis. The samples were very fine to fine grained, grey-green, mostly subarkosic sandstones with occasional thin flaser bedding. A few samples were dolomitic. The new combined mineralogical dataset contains 193 samples across 41 wells.

MBP Results

Ave. MBP DATA	Quartz	P-Feldspar	K-Feldspar	Calcite	Total Clay
Southern Tidal Facies	75%	3%	1%	17%	4%
Northern Tidal Facies	77%	5%	3%	13%	2%

Table 1. MBP results show similar amounts of quartz and calcite. The 38.262343 degree latitude line was used to divide the tidal facies into northern and southern regions. The total feldspar content was on average doubled in the northern samples, whereas samples from the south had on average twice the amount of total clay minerals. Dolomitic samples are not averaged.

<16um Results

CLAY DATA	Ave. CF Illite	Ave. CF Illite-Smectite	Ave. CF Chlorite
1994 Study	43%	28%	29%
2013 Study	41%	15%	42%

Table 2. <16um clay fraction results showing differences in the illite, illite-smectite and chlorite compositions. Four samples had kaolinite present and are displayed in figure 6.

Porosity and Permeability Results

1994 Study	Porosity	Permeability (Horz.)	2013 Study	Porosity	Permeability (Horz.)
Ave:	20%	135md	Ave:	12%	2md
Max:	27%	788md	Max:	24%	12md
Min:	7%	.1md	Min:	4%	.1md

Porosity and horizontal permeability results show decreases in the 2013 Study. The 2013 study had 11 permeability points and 22 porosity points, much fewer than the 1994 study, which had 83 permeability and 83 porosity points.

Eleven core plugs were used to calculate horizontal permeability. Those same plugs and an additional 11 cube samples were used for porosity measurements. In total, 11 samples yielded permeability results and 22 samples yielded porosity measurements. All samples suitable for plugging or cubing were taken from the same sampling locations and depths as the samples for bulk and clay mineralogy analysis. When combined with data from previous studies, porosity data points number 105 and horizontal permeability number 94. The average values of horizontal permeability and porosity across all samples are 120md (millidarcy) and 19%, respectively.

Kaolinite Distribution

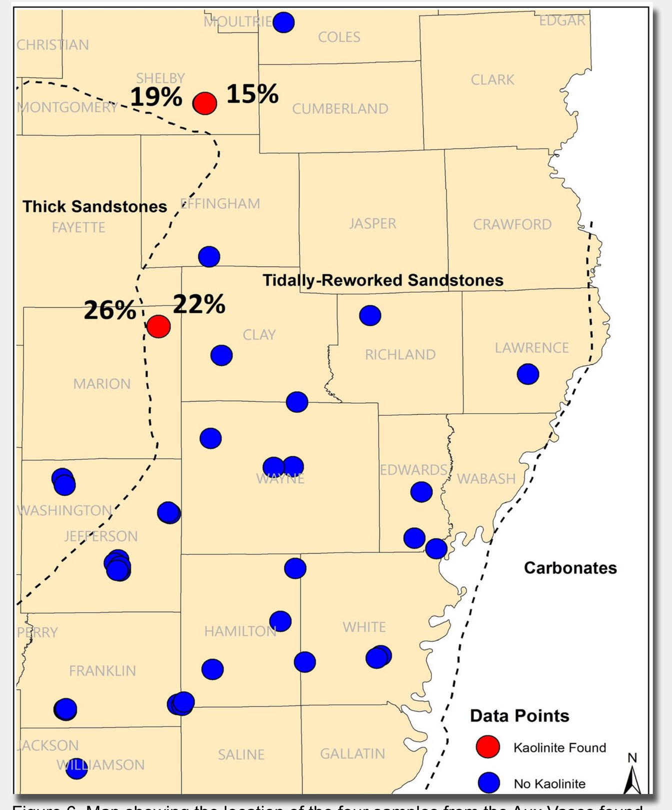


Figure 6. Map showing the location of the four samples from the Aux Vases found to contain Kaolinite. The sample locations are highlighted in red. The kaolinite clay fraction is labeled next to each data point (two wells). The northern point is from 1994 study at Stewardson Field where kaolinite was first observed in the Aux Vases. This 2013 study observed the southern red locality. Note their location in proximity to the facies boundary.

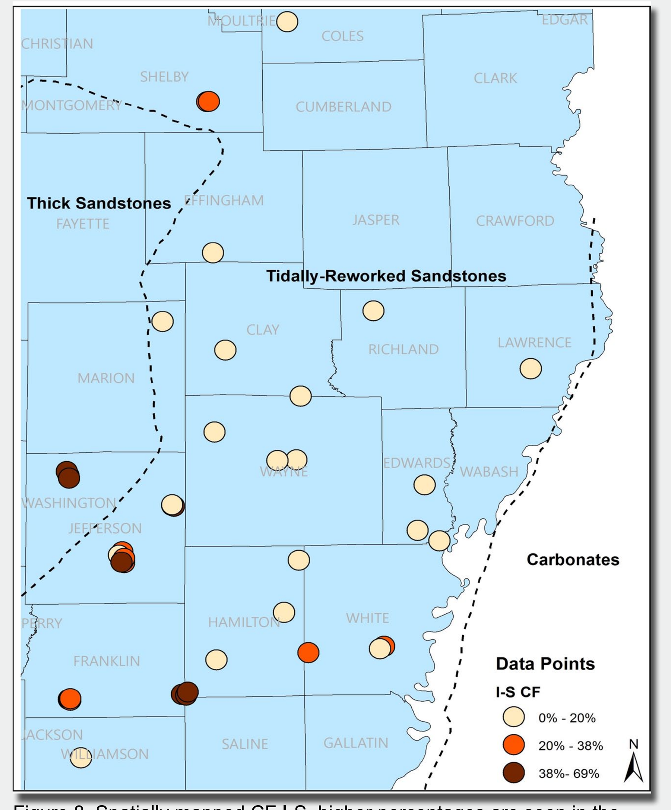


Figure 8. Spatially mapped CF I-S, higher percentages are seen in the southern part of the tidal facies where higher total clay minerals are seen.

Discussion & Conclusions

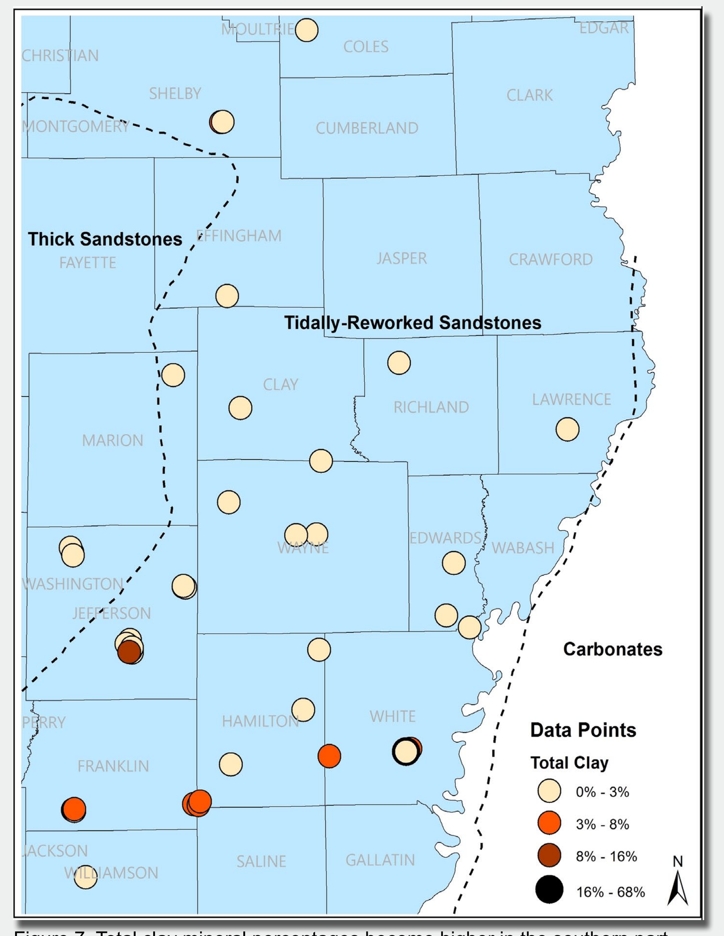


Figure 7. Total clay mineral percentages become higher in the southern part of the tidal facies. Total clay mineral amounts are important for inhibiting secondary mineral overgrowths and preserving primary porosity.

1) Clay fraction I-S and total clay mineral amounts increase southward along the NE-SW tidal facies axis (figure 7 & 8).

- Past SEM/EDX and chemical data indicate dissolution of detrital feldspars provided the primary geochemical source to form diagenetic clay minerals.
- The northern tidal facies contains on average twice the amount of feldspar and half the total clay mineral content (table 1).
- Attributed to less dissolution of feldspars from shallow burial depths in the north and depostional environment change from subtidal bars to supratidal sheet sands.
- The sheet sands limited the ability of fluids to become saturated and form diagenetic clay minerals.

Discussion & Conclusions Cont.

2) Clay fraction chlorite increases northward along the NE-SW facies axis (figure 9).

- Aux Vases Sandstone is known for low Fe (high Mg) chlorites.
- Old and new data indicate five oil fields with high Fe chlorites.
- This suggests changes in local geochemical and diagenetic conditions.
- Aux Vases chlorites are believed to be more effective than other clay minerals at inhibiting mineral overgrowths. For this reason, the total clay mineral amounts and clay fraction chlorite relationship with porosity and permeability is critical to understand.

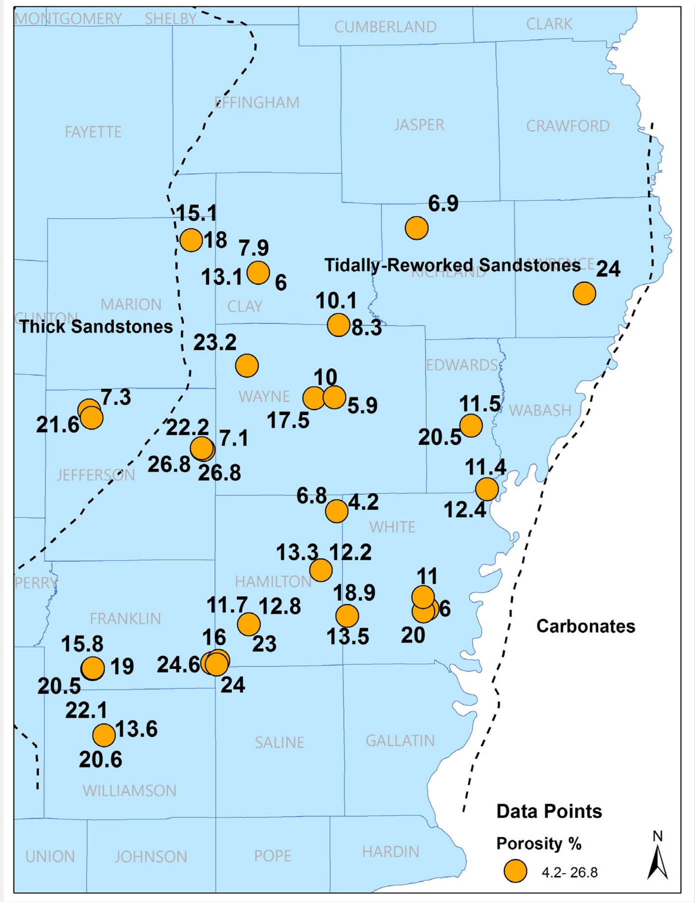


Figure 10. Map showing porosity values of the Aux Vases across the facies. Porosity generally increases southward. Some northern points still have relatively high values. Not all labels can be shown, but the displayed values are representative of their locality.

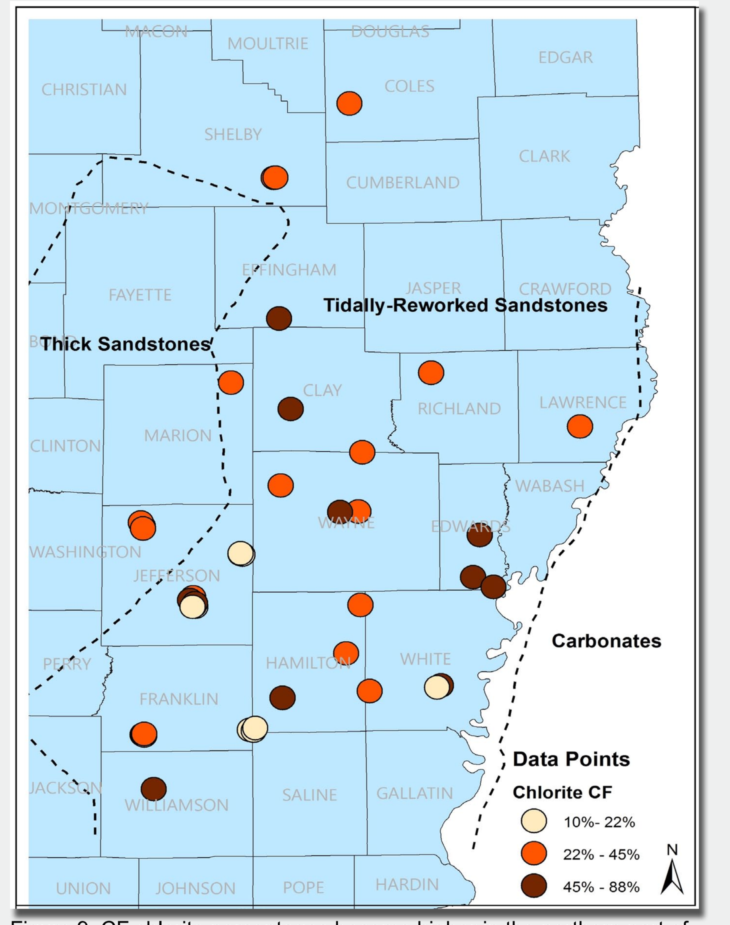


Figure 9. CF chlorite percentages become higher in the northern part of the tidal facies. These locations are where total clay mineral amounts are lower (see also figure 7).

3) Porosity and permeability are increasing southward along the same axis (figure 10).

4) The Illinois Basin's southward dipping cratonic ramp and depositional environment change from subtidal bars to supratidal sheet sands toward the north provided the controls (shallow burial depths and preferential fluid flow, respectively) which limited diagenetic alteration of feldspars and the formation of diagenetic clay minerals in the northern tidal facies.

5) The implication of the kaolinite found in both studies is still not understood. It is perhaps a marker for a change of diagenetic conditions, or a transition into another facies, or both.

Future Work

- Investigations of the mixed-layered chlorites in the Aux Vases Sandstone through examination with chemical analysis may provide deeper insights on origins of all the clay minerals present (Oltz, 1994).
- Further analysis on the spatial distribution of the Mg-Fe-chlorites are needed. High Fe-chlorites are known to be the most volatile when in contact with acid reservoir treatments.
- High levels of mixed-layered I-S, particularly in the south, can swell and detach from grains which decreases porosity and permeability when in contact with water flooding or stream treatments.
- Clay minerals can also adsorb polymer solutions and chemicals typically injected into a reservoir to make petroleum more mobile, increasing the total cost of recovery (Leetaru, 1991).
- More data near the channel-fill and tidal facies boundary is neccesary to resolve the kaolinite enigma in the Aux Vases Sandstone.

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