An Integrated Approach to Identifying Residual Oil Zones in the Cypress Sandstone in the Illinois Basin for Nonconventional CO_2-EOR and Storage*

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Search and Discovery Article #80581 (2017)**
Posted February 27, 2017

*Adapted from oral presentation given at AAPG Eastern Section Meeting, Lexington, Kentucky, September 25-27, 2016

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Abstract

The central portion of the Illinois Basin has a fairway of incised valley fill Cypress Sandstone deposits that exceeds 150 feet in thickness. Where local structural features are present, the Cypress may contain a relatively thin oil reservoir above a significant aquifer. Because of the thickness of the aquifer, nonconventional carbon dioxide (CO_2) enhanced oil recovery (EOR) is expected to require more CO_2 compared to a conventional CO_2 EOR for each barrel of incremental oil produced due to CO_2 migrating into the underlying aquifer. For this study, the entire incised valley part of the Cypress is being investigated for the presence of residual oil zones (ROZs), regardless of the presence of an overlying oil reservoir.

In a case study of Noble Field, western Richland County, Illinois, identification of ROZs in the Cypress Sandstone has required an integrated, multidisciplinary approach of detailed geologic characterization, petrography, and petrophysics. Geologic characterization suggested that the Cypress Sandstone occurs as multistory fluvial sandstones that become estuarine upward and were deposited in an accommodation limited setting. A tilted producing oil water contact (OWC), an indicator of an ROZ, was identified and mapped. A zone of dense diagenetic calcite cement occurs along the OWC, with a second similar zone 20 feet below, is an indication of a relict OWC.

Water saturation determined with Archie's Equation was found to be anomalously high for several wells, suggesting the presence excessive conductivity, e.g. from water-saturated clay micropores. Clay mineral morphologies were identified, volume

of clay was determined, and the percent-volume of clay micropores were quantified to correct water saturation estimates. The depths of the oil saturated, brine saturated, and ROZ within several wells was used to identify areas of the field that had the greatest potential to have an ROZ.

Integrating water-oil saturation into a detailed, representative geocellular model of the reservoir architecture will reduce CO_2-EOR and storage uncertainty in the results of reservoir simulations. A summary of how each discipline was used to better understand the ROZ and preliminary findings of this integrated study will be presented.

Reference Cited

Webb, Nathan D., and John P. Grube, 2014, The Mississippian Cypress Sandstone: Geologic characteristics of a potential EOR target in the Illinois Basin: Geological Society of America Abstracts with Programs, v. 46/4, p. 43.

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Presentation Outline

- Background
- Methodology
- Findings
- Summary
- Acknowledgements

Cypress Sandstone

- Cypress Sandstone presents nCO_2-EOR and storage opportunity
  - NE-SW trending fairway of thick incised valley fill sandstone deposits though the central Illinois Basin

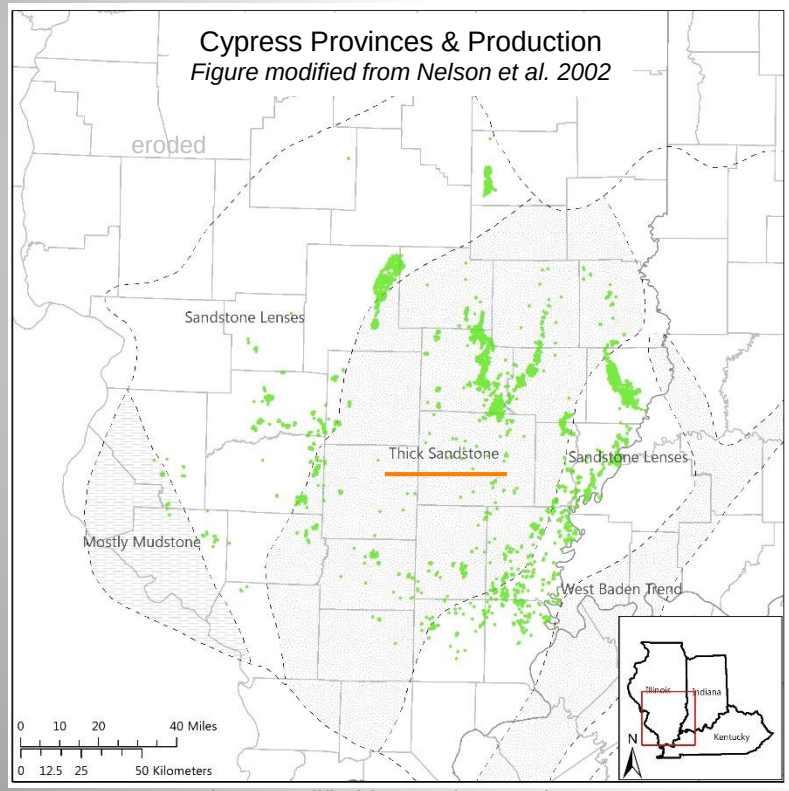


Figure modified from Nelson et al 2002

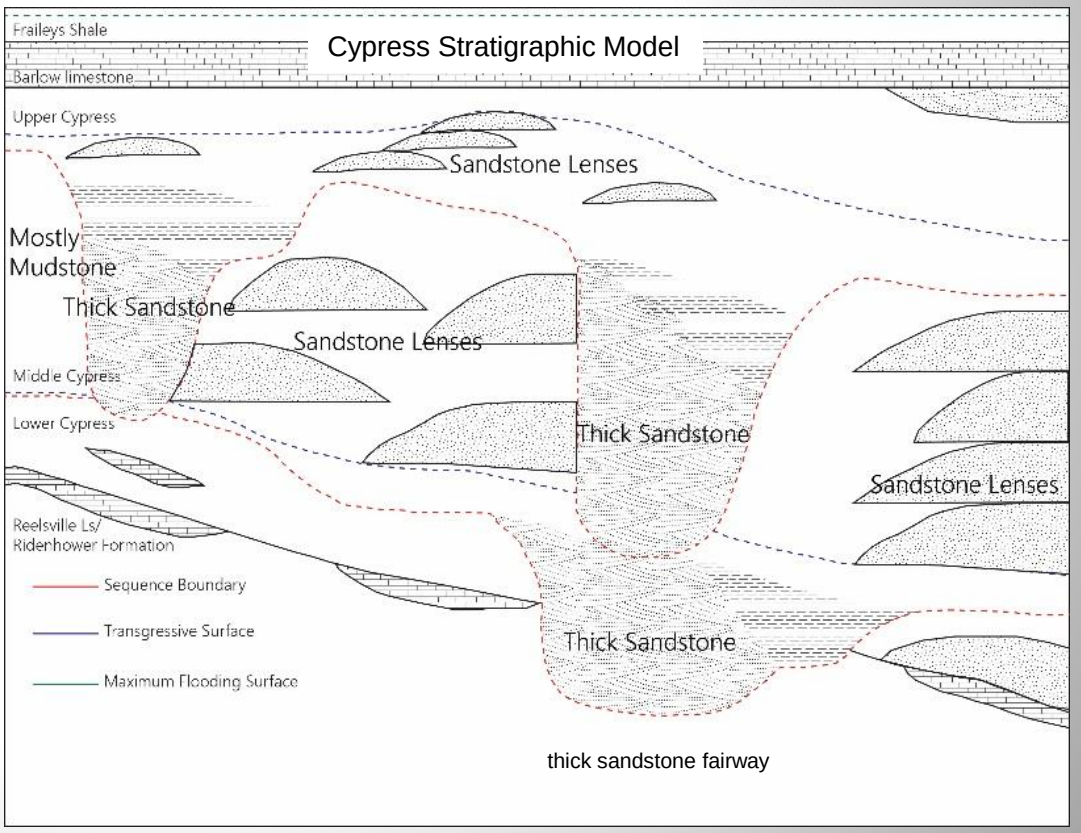
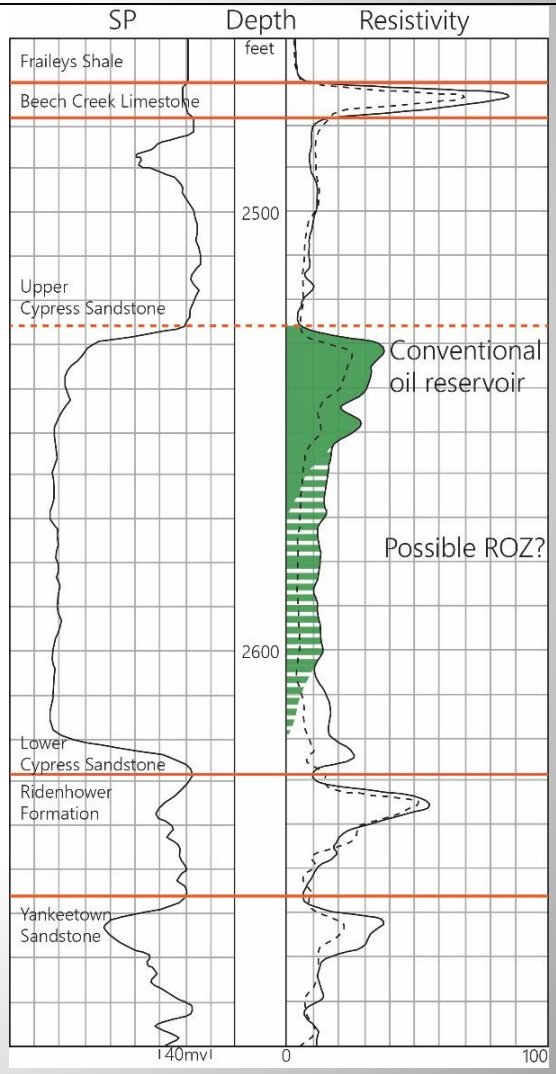


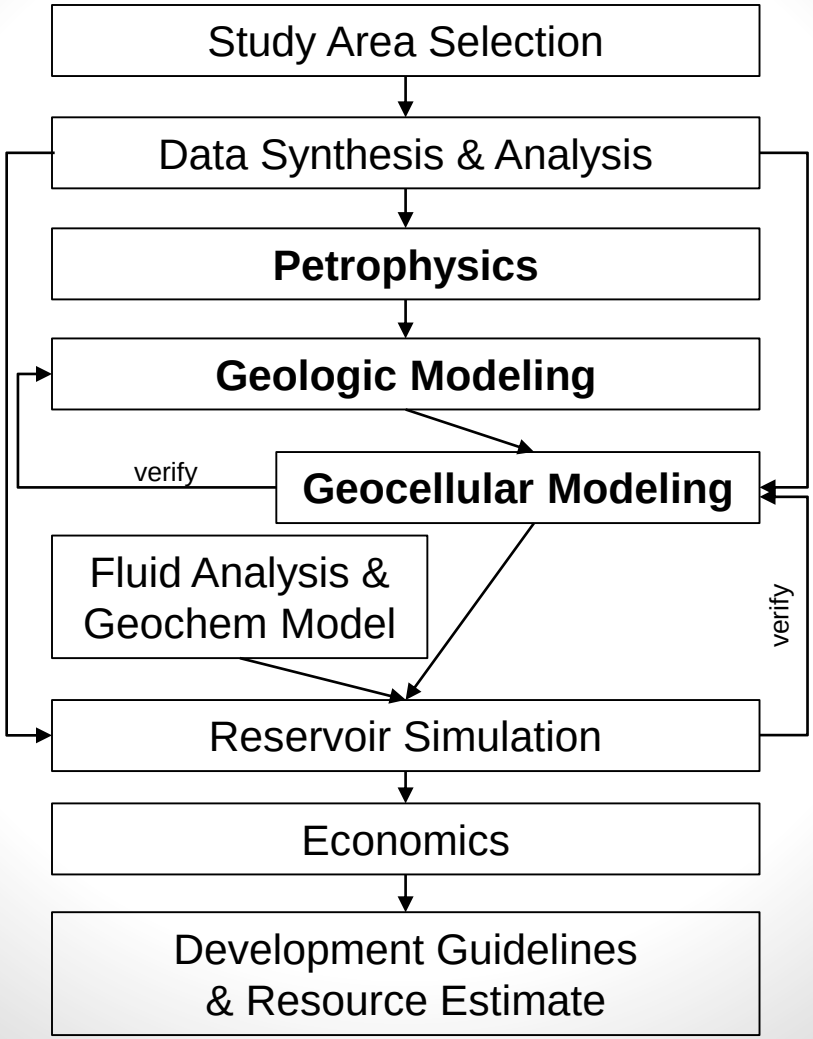
Figure modified from Webb and Grube 2014; no scale implied

Thick Cypress Ss Reservoirs

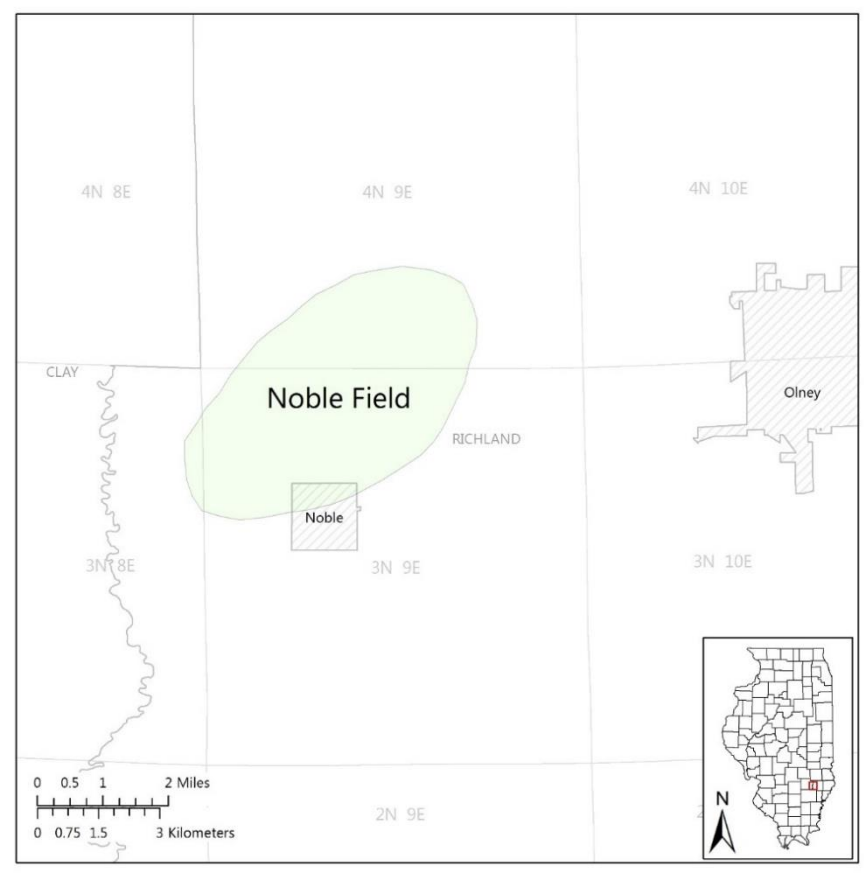
- Thin Oil Reservoirs
  - Residual and mobile oil above brine
  - Fining upward sequence / increasing permeability with depth
  - Difficult to produce economically due to water coning and management
- Nonconventional CO_2-EOR
  - Potential Residual Oil Zone (ROZ)
  - High CO_2 utilization during CO_2-EOR
  - 0.2 to 2.3 Gt saline CO_2 storage potential (DOE/MGSC, 2012)

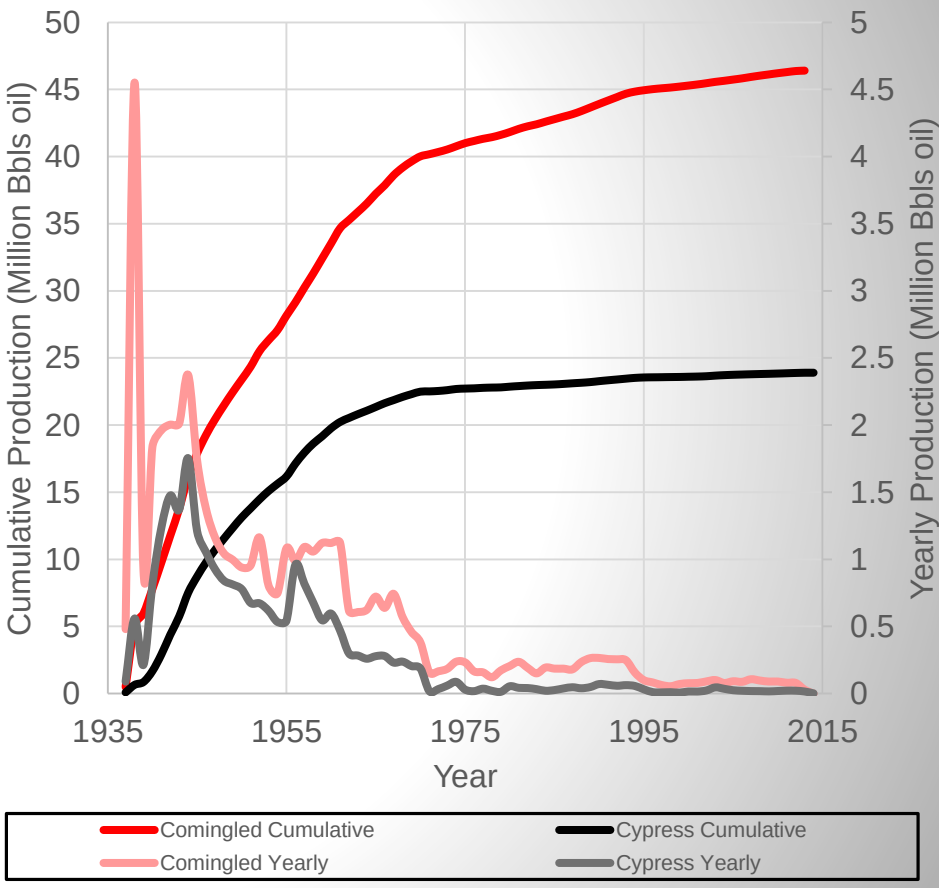


Methodology



Case Study: Noble Field

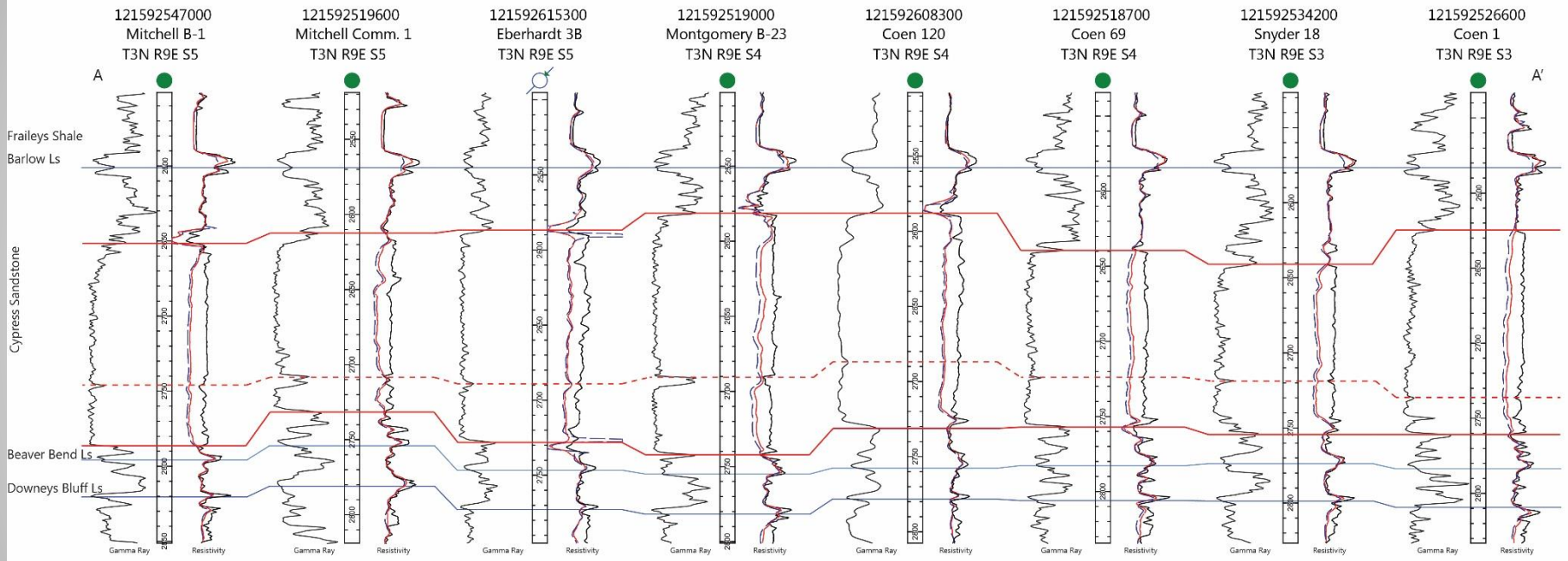




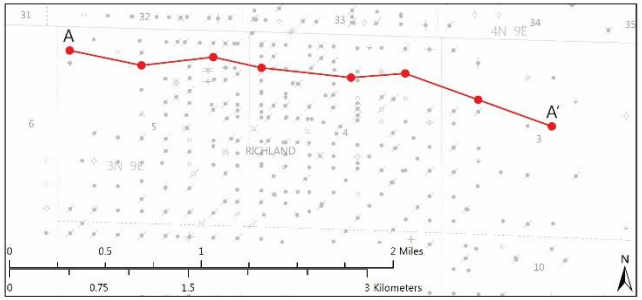
- Oil field with successful production from the thick Cypress Sandstone
- Abundant core and log data available for detailed characterization

Reservoir Characterization

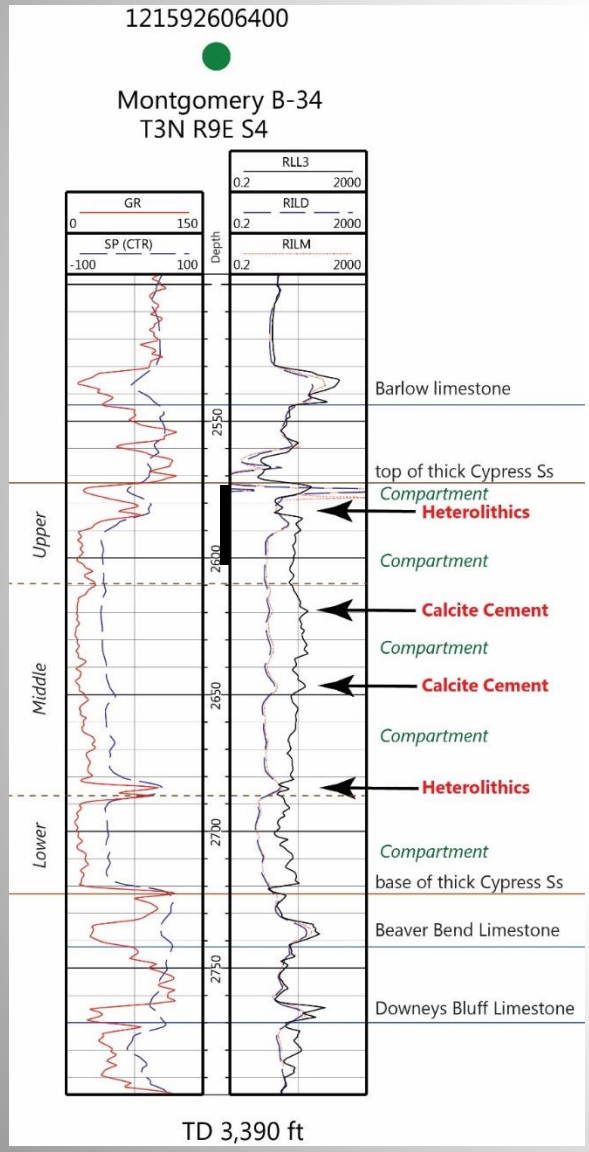
Example Noble Field Cross Section



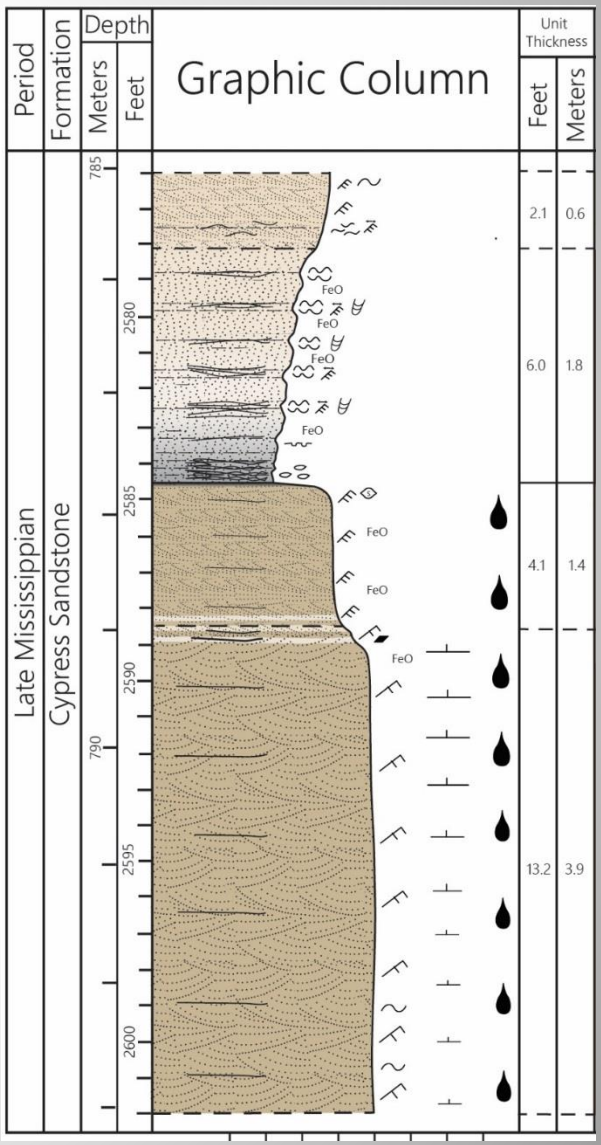
- Correlated nearly 1,000 logs to map geometry of thick Cypress Sandstone
  - Picked upper/lower contacts, baffles (shales, cements), oil/water contact (OWC)



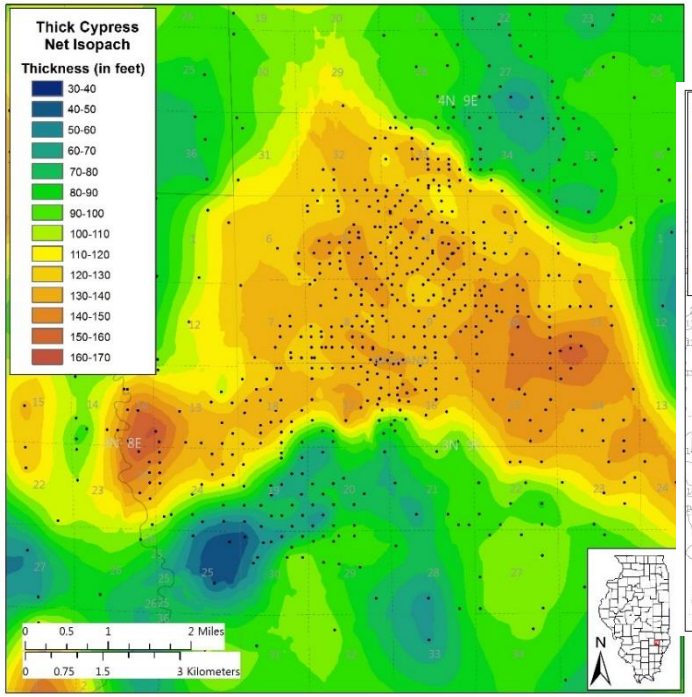
Reservoir Characterization



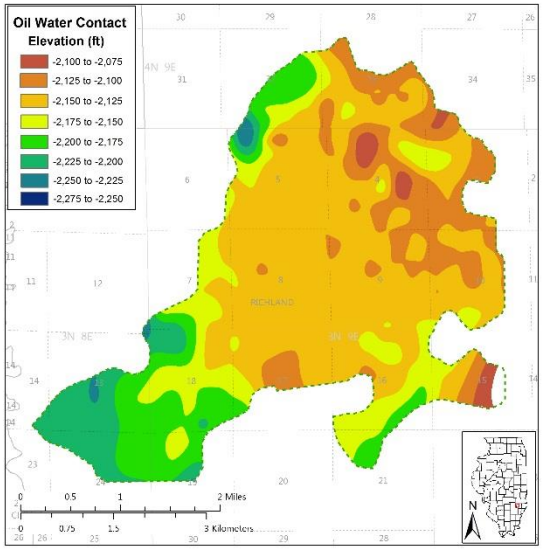
- Compartmentalized despite being relatively homogeneous
  - Thin shale interbeds
  - Heterolithic intervals
  - Calcite cements
    - Concurrent with and below OWC
- Fluvial to estuarine
  - Cross bedded f-m grained sandstone in main body, ripple bedded f grained sandstone at top



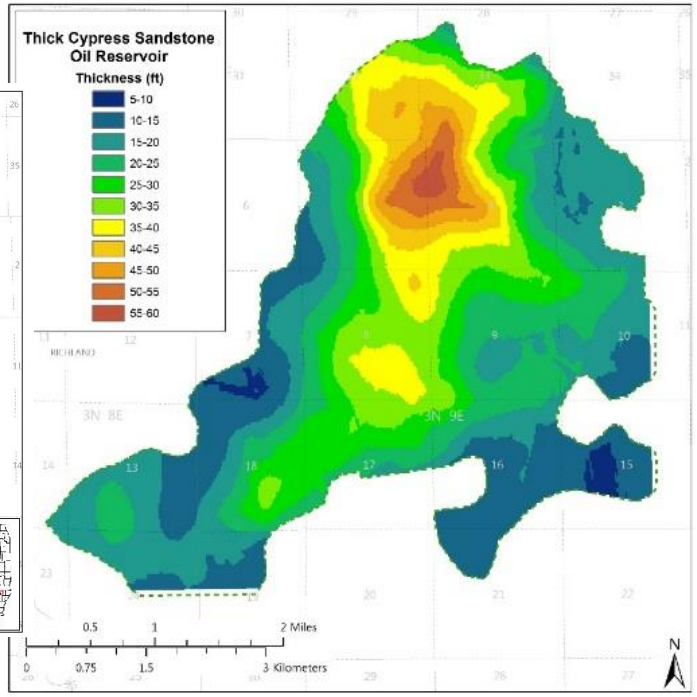
Reservoir Characterization



Cypress net sandstone isopach map



OWC structure map



Oil reservoir isopach map

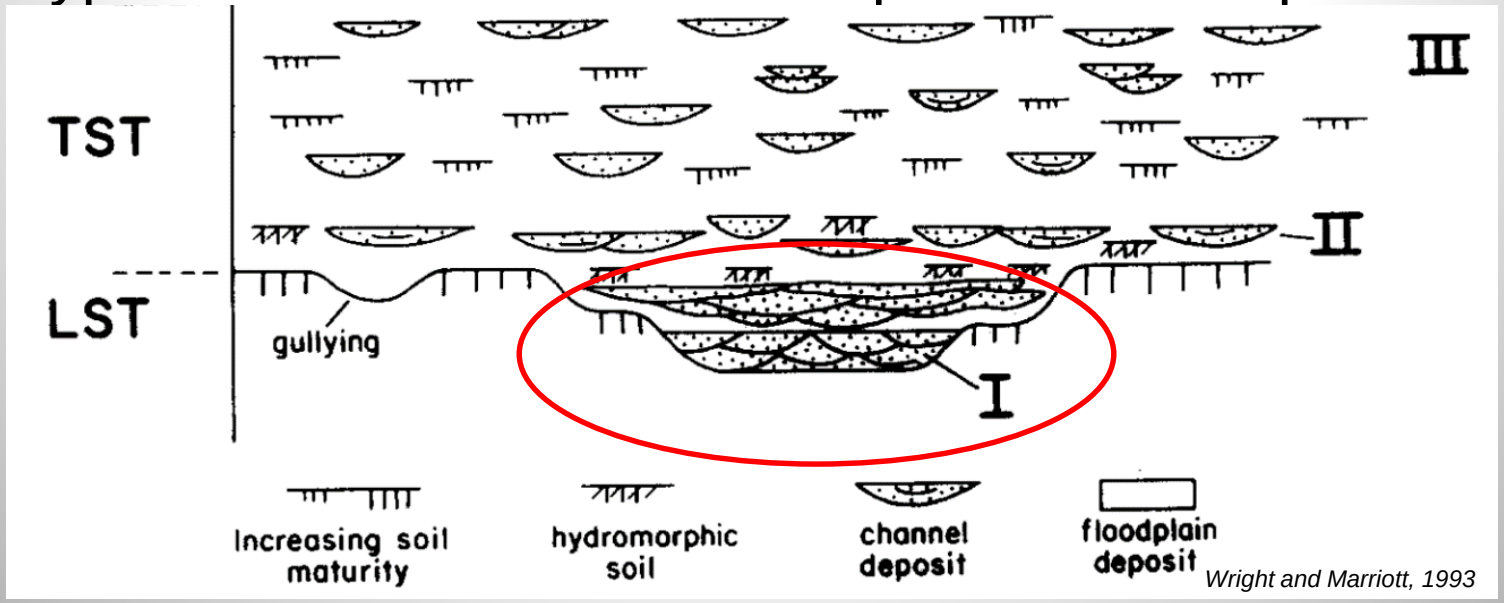
- Inverted “V” geometry
- Up to 170 ft thick

- ROZ indicators
  - Tilted OWC
  - Paleo-OWC related calcite cement?

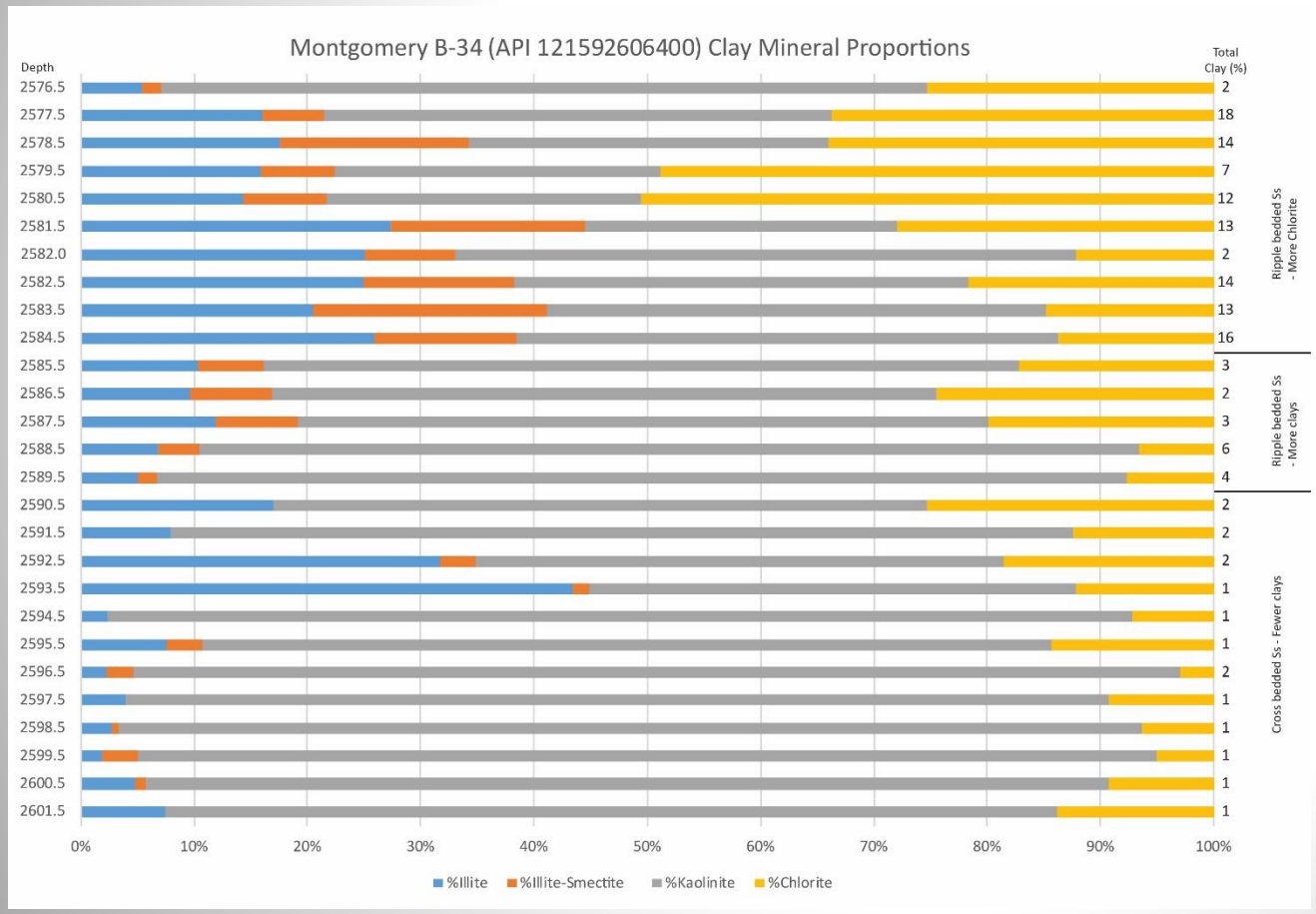
- Reservoir up to 55 ft thick
- OOIP = 95 to 110 MMBO

Depositional Environments

- Interpreted the Cypress Sandstone at Noble Field as part of an incised valley fill system
  - Multistory sandstone built through parasequence-scale successive fluvial to estuarine depositional episodes
- Next Step: Coring and outcrop studies of entire thick Cypress Sandstone should help confirm interpretations

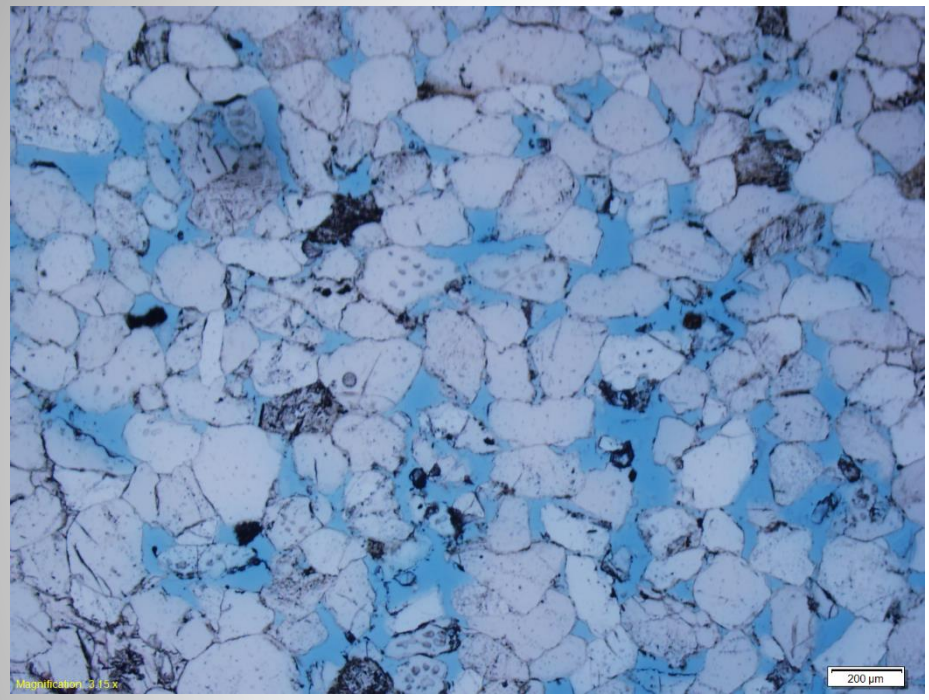


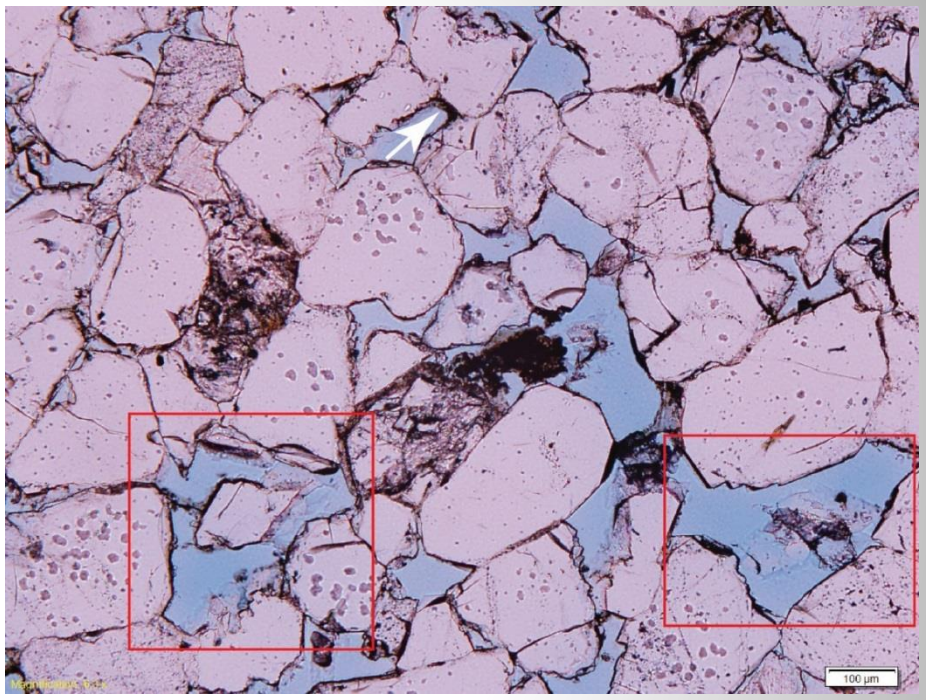
Controls on Porosity/Permeability



- Analyzed XRD results for bulk and clay mineralogy
  - Related results to facies and porosity / permeability
  - Understanding depositional and diagenetic history and controls on reservoir quality

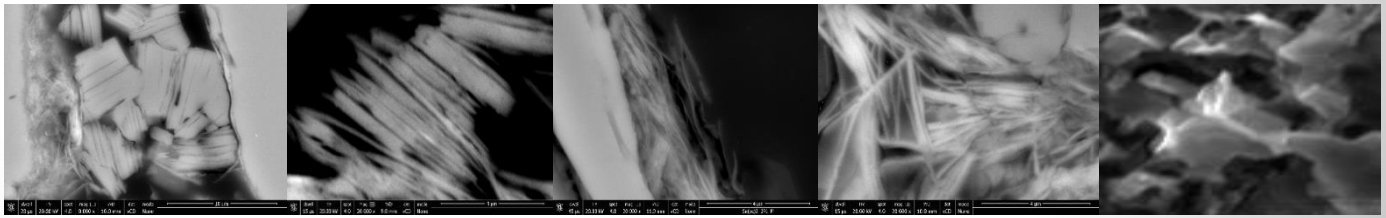
Controls on Porosity/Permeability





- Typical porosity and permeability of 18% and 480 mD
- Hybrid pore system of primary intergranular and secondary porosity from dissolution of grains and cements
- Long, well-connected pores contribute to the exceedingly high permeabilities

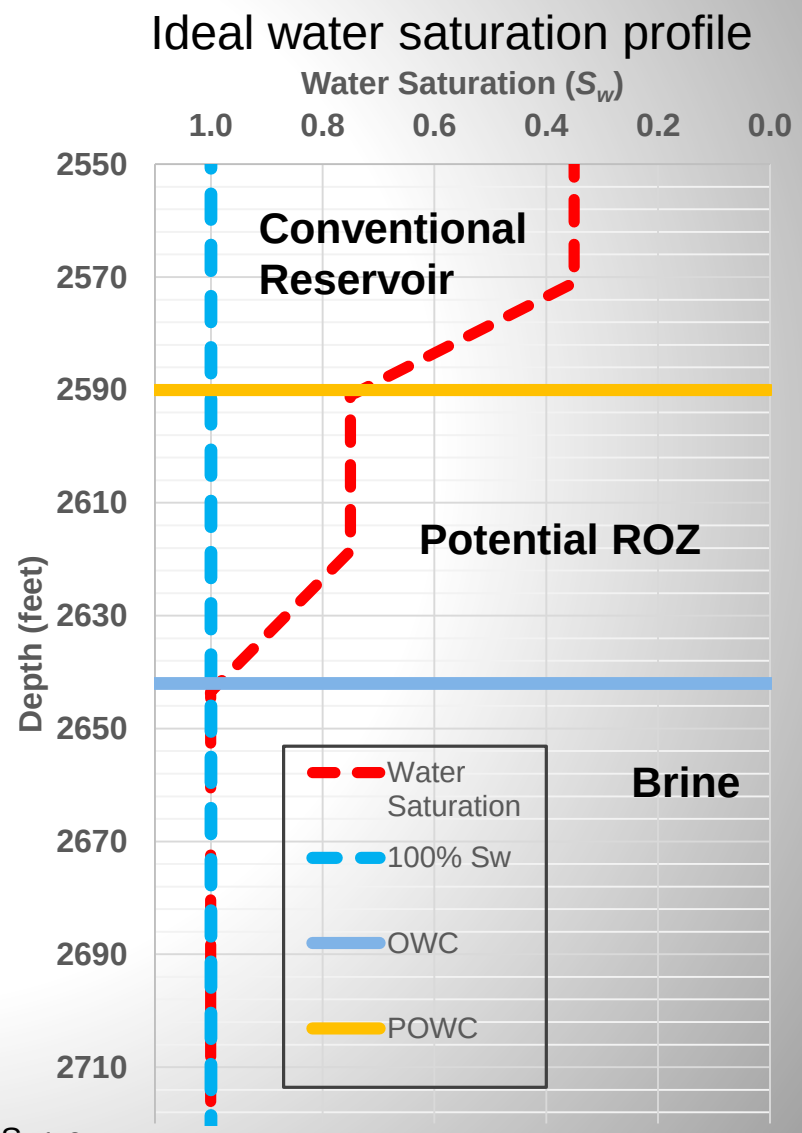
Microporosity Analysis

Mineral	Kaolinite	Kaolinite	Chlorite	Illite	Illite-smectite
Morphology	Booklets	Vermicules	Rosettes	Fibrous	Filamentous webs
Occurrence	Pore-filling	Pore-filling	Grain-coating	Pore-filling, bridging	Pore-filling
Microporosity (%)	40	15	50	65	55
SEM Photomicrograph					

- Determined clay mineral microporosity via scanning electron microscopy and image analysis
  - Refined petrophysical calculations
  - Calculated effective porosity for geocellular models

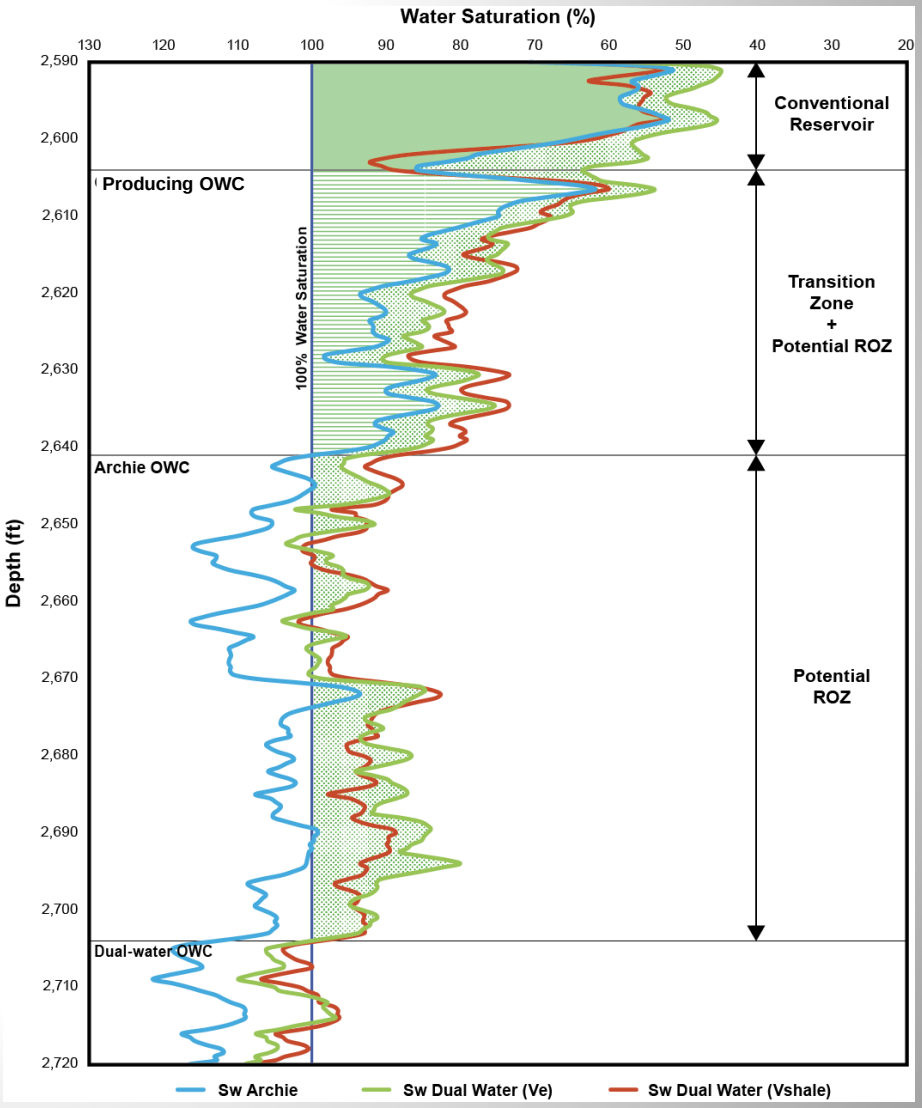
Petrophysics

- Calculated water saturation (S_w) profiles from logs in Noble Field using three methods:
  - Archie (Resistivity + Porosity logs)
  - Dual water (Resistivity + Porosity logs + microporosity data)
    - Mitigates influence of dispersed clay that produces anomalously high S_w values



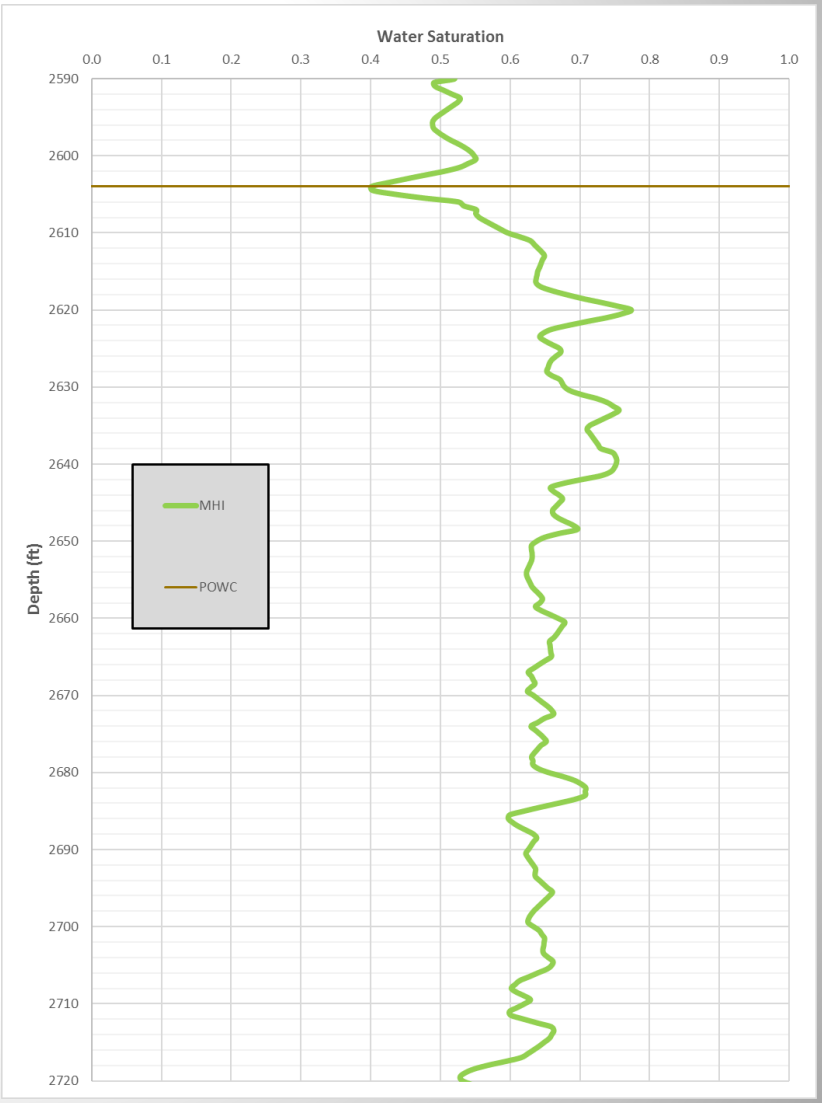
Petrophysics

- Analyzed results produced by different methods
  - Determined clay microporosity was affecting Archie results
- Interpreted logs to define producing oil-water contact (POWC) and ultimate OWC
  - Mapped thickness of conventional reservoir and potential ROZ
  - Conducted visible cut tests to confirm oil saturation



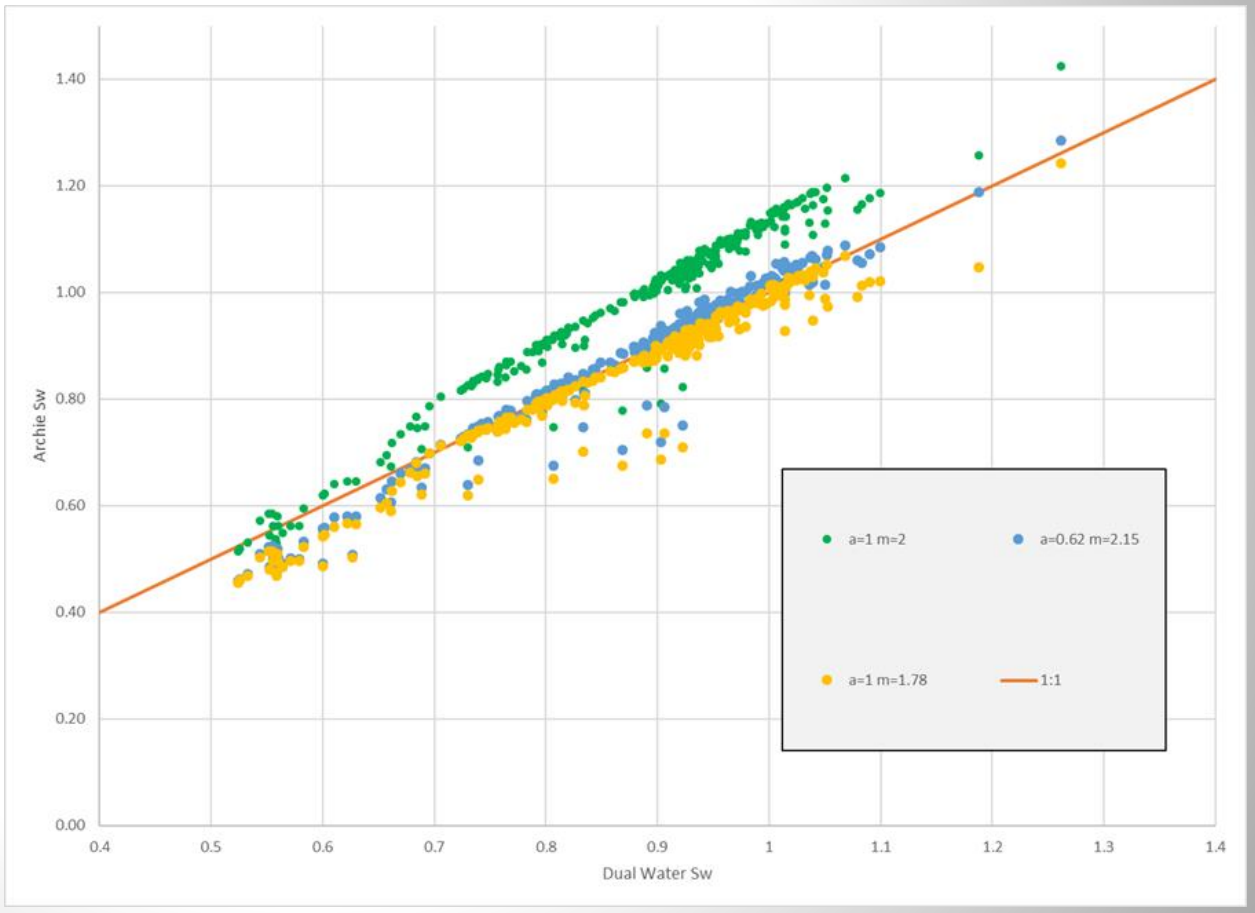
Movable Hydrocarbon Index

- Used MHI to compare shallow and deep resistivity to determine if oil has been flushed
- Picked POWC based on MHI
  - MHI provides more reliable indication of what oil saturation is “producible”

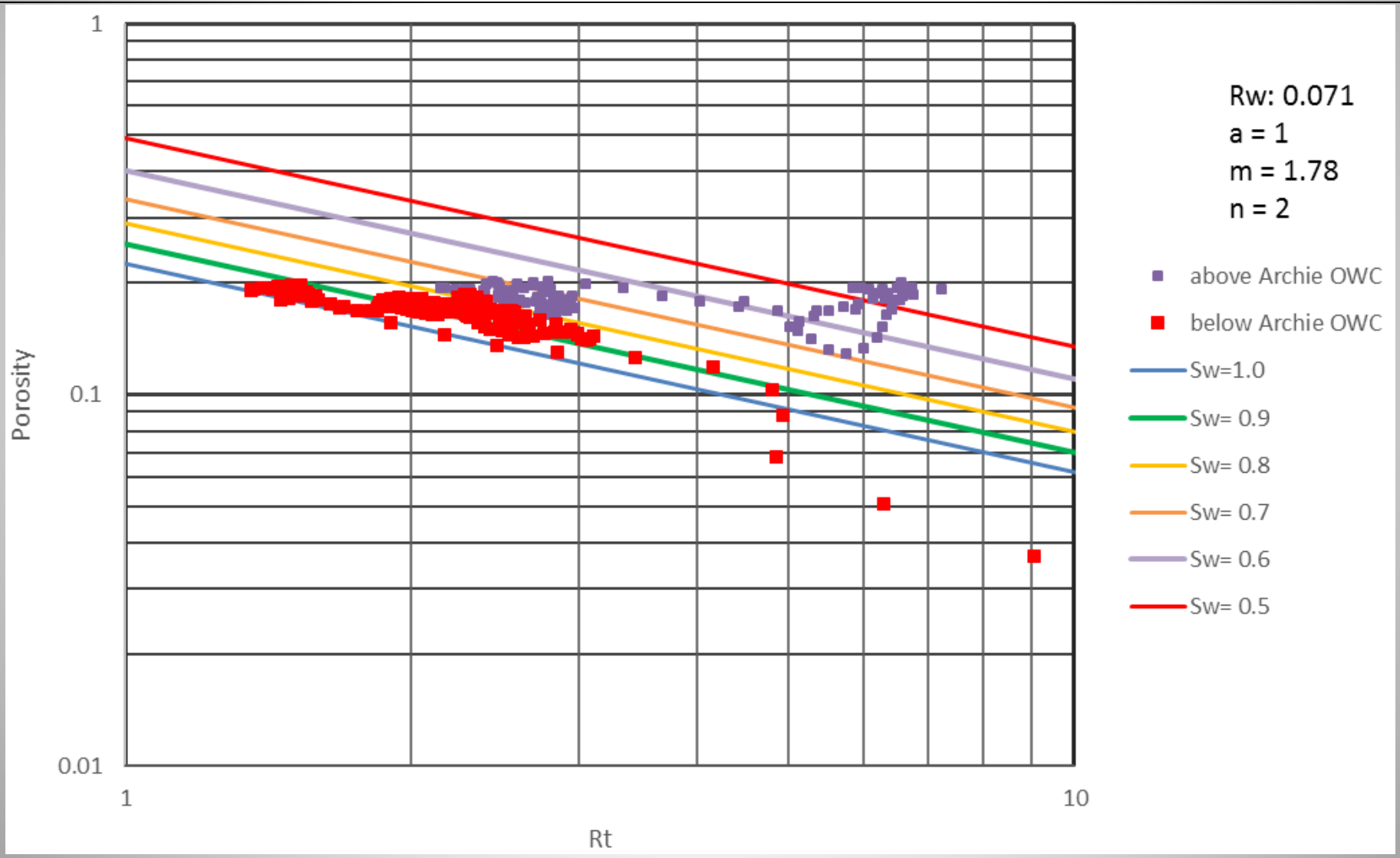


X/Y Scatter Plots

- Tested different Archie parameters to minimize discrepancy between Dual water and Archie method
  - A=1 and m=1.78 produced the best fit

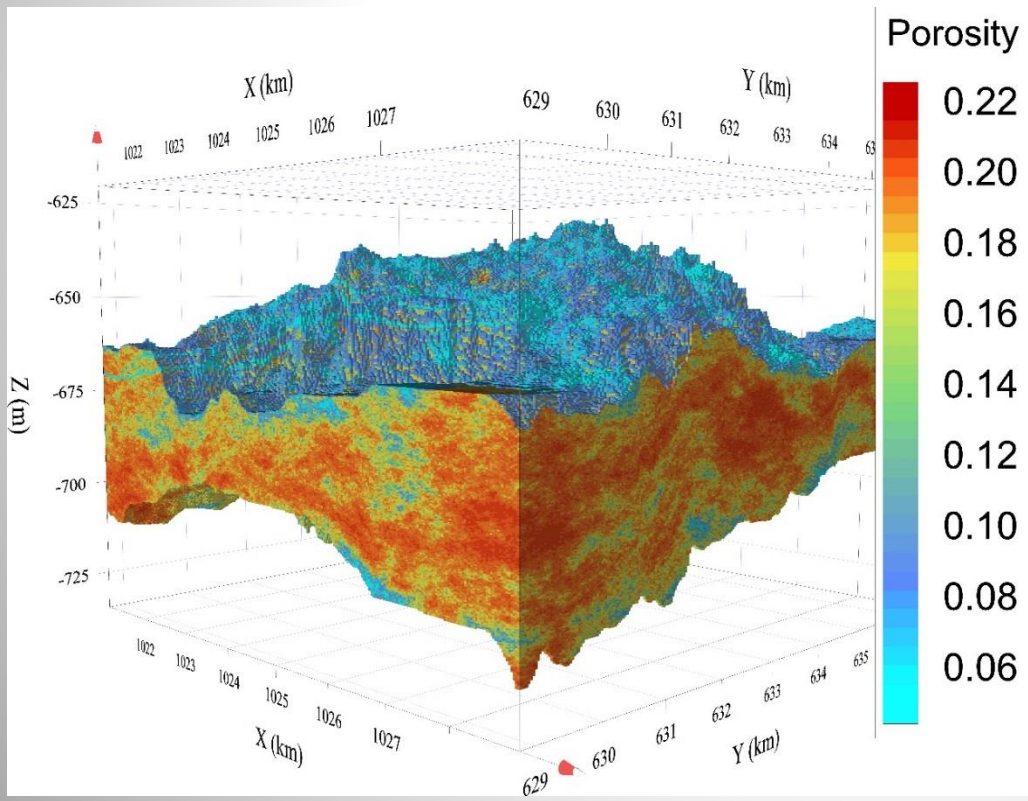


Pickett Plots

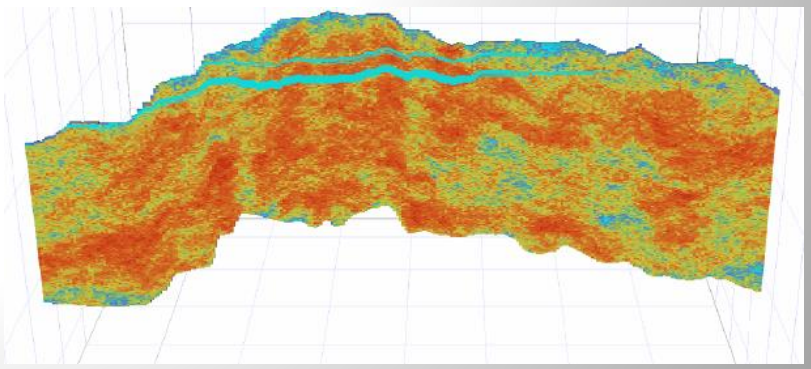


Geocellular Modeling

- Built geocellular models to accurately reflect the geology of the Cypress Sandstone
  - Encapsulated depositional and diagenetic facies
  - Shaly, estuarine facies at the top of the model; thin shale interbeds

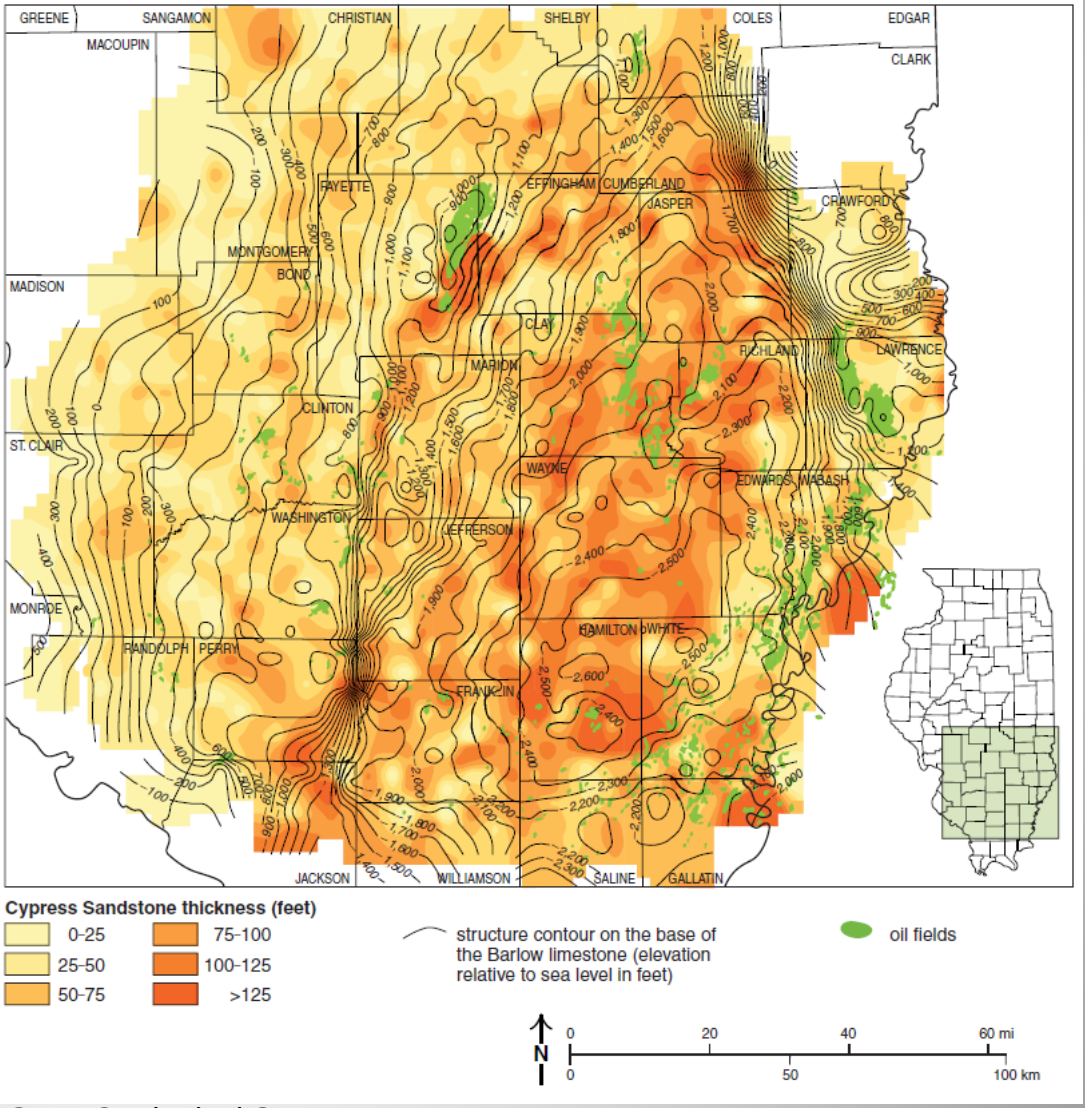


- Low porosity calcite-cemented sandstone zones
- Excluding microporosity from total porosity for accurate resource assessment



Regional Resource Estimate

- Correlating logs to refine regional isopach map
- Developing new regional facies map to define CO_2 storage resource in the thick Cypress Sandstone
- Integrating geology, petrophysics, and reservoir simulation to identify areas with nonconventional CO_2-EOR potential



Summary

- Cypress Sandstone is composed of multistory fluvial/estuarine sandstone bodies
  - Homogeneous but still compartmentalized
- Multiple indications of an ROZ within the Cypress
  - Tilted OWC
  - Paleo-OWC related calcite cement?
  - Petrophysical calculations show saturation below POWC
- Petrophysical analysis
  - Significant microporosity affects conductivity of the formation and thus estimates of fluid saturation
- Modeling reflects geology of the Cypress Sandstone

Acknowledgments

- Research herein was supported by the US Department of Energy contract number DE-FE0024431
- Through a university grant program, IHS Petra, Geovariences Isatis, and Landmark Software was used for the geologic, geocellular, and reservoir modeling, respectively.

- For project information, including reports and presentations, please visit:

http://www.isgs.illinois.edu/research/ERD/NCO2EOR

Where will the CO_2 Come From?