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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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

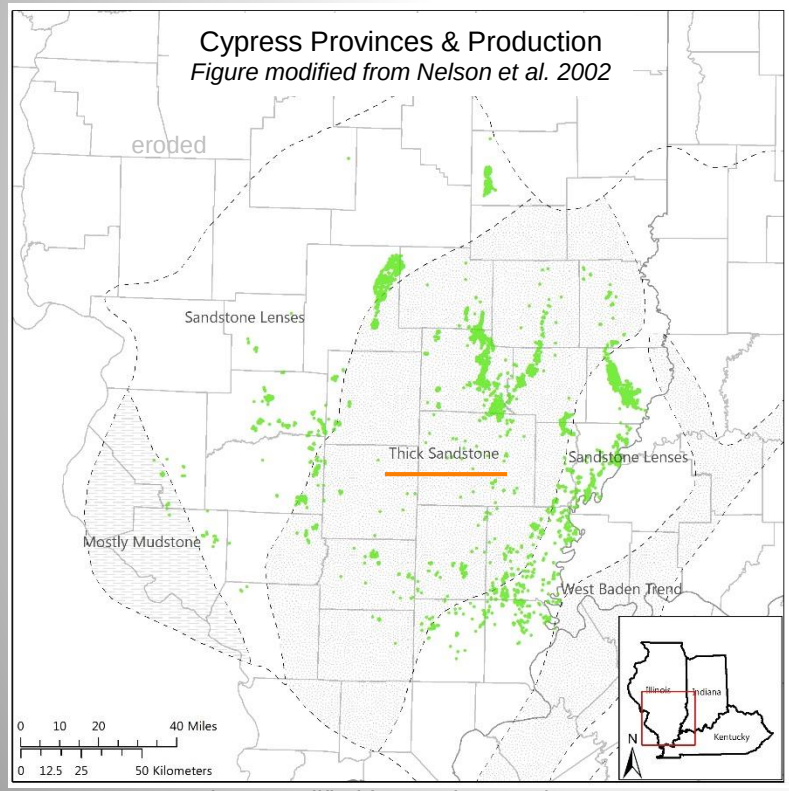


Figure modified from Nelson et al 2002

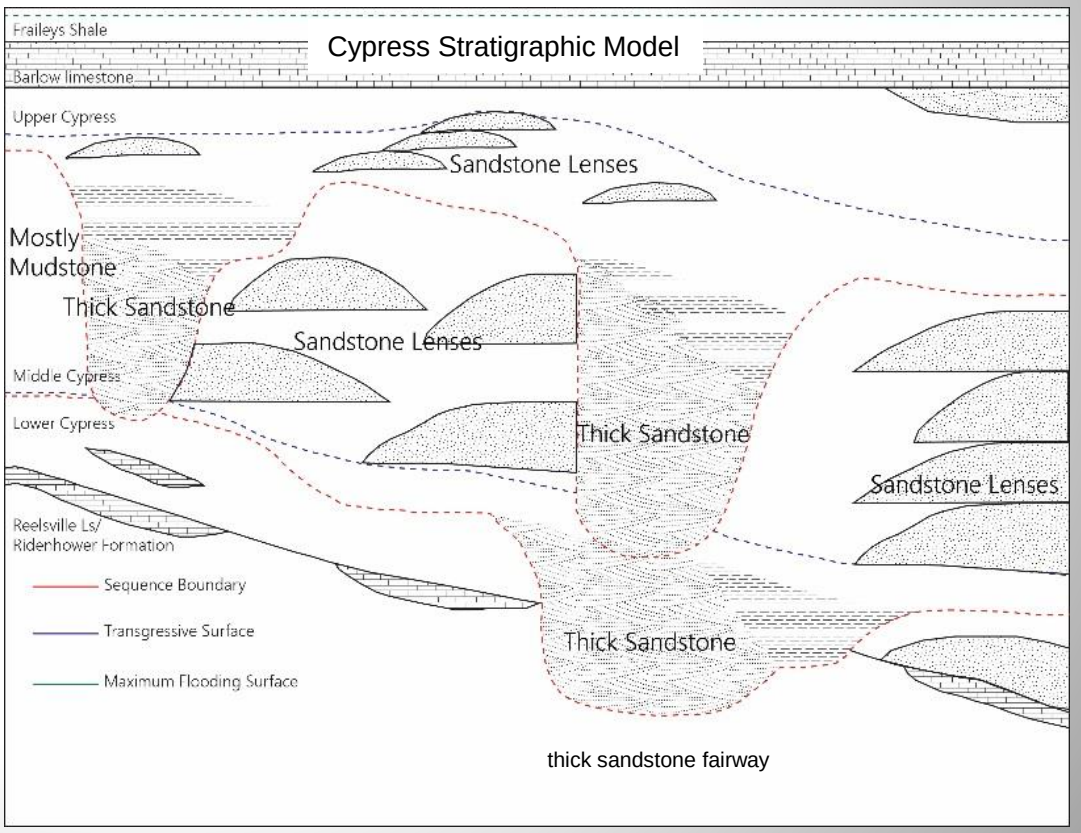
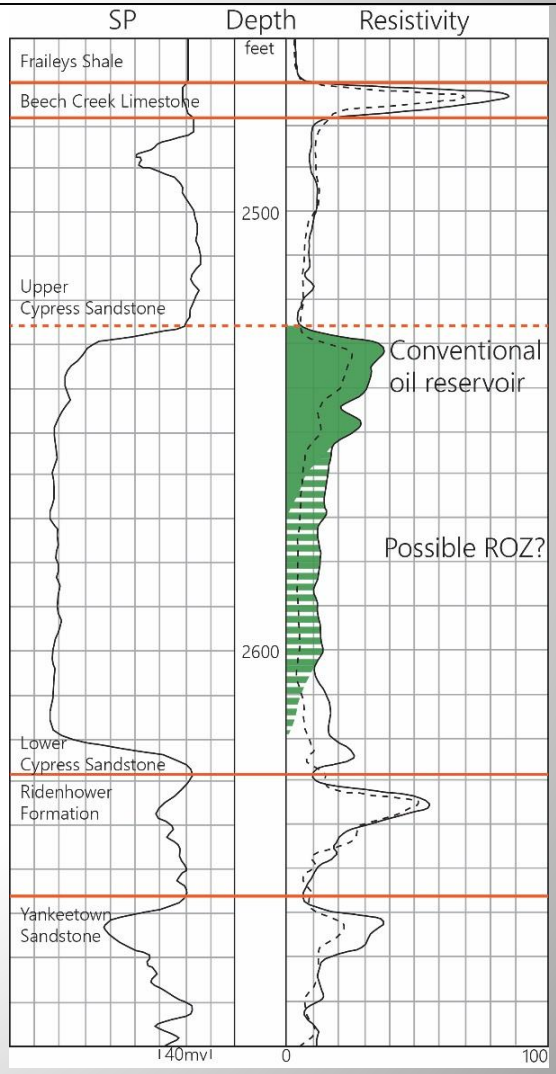


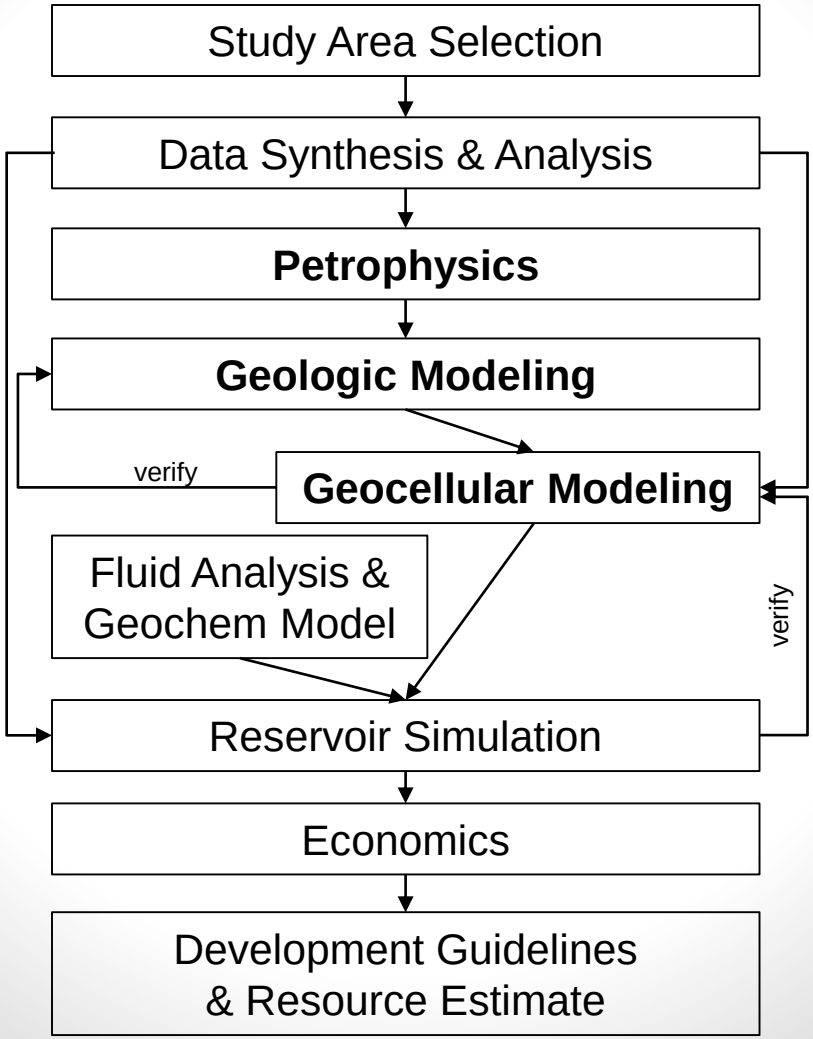
Figure modified from Webb and Grube 2014; no scale implied

Thick Cypress Ss Reservoirs

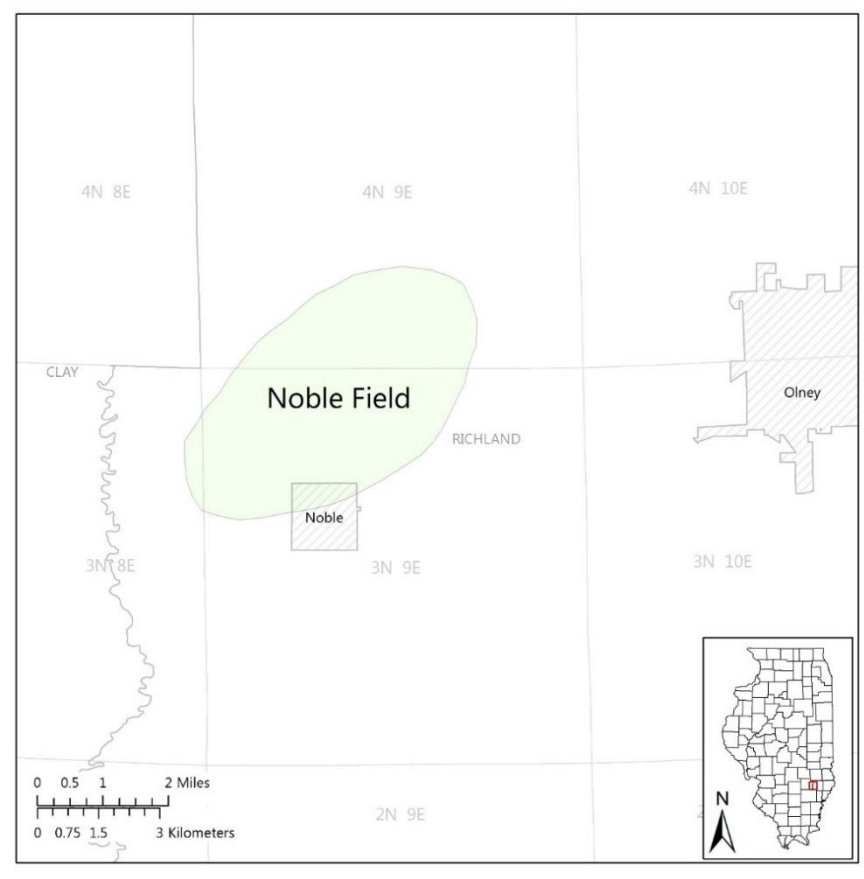
- Thin Oil Reservoirs
  - Residual and mobile oil above brine
  - Fining upward sequence / increasing permeability with depth
  - Difficult to produce economically due to water coning and management
- Nonconventional CO_2-EOR
  - Potential Residual Oil Zone (ROZ)
  - High CO_2 utilization during CO_2-EOR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

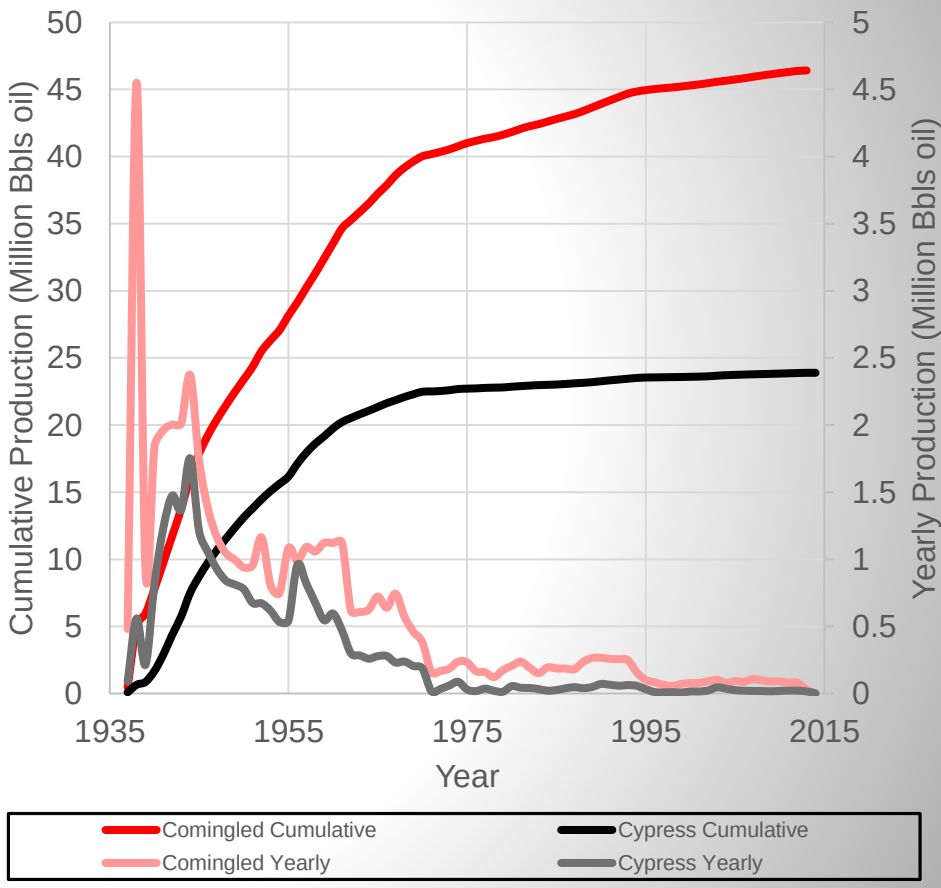


Methodology



Case Study: Noble Field

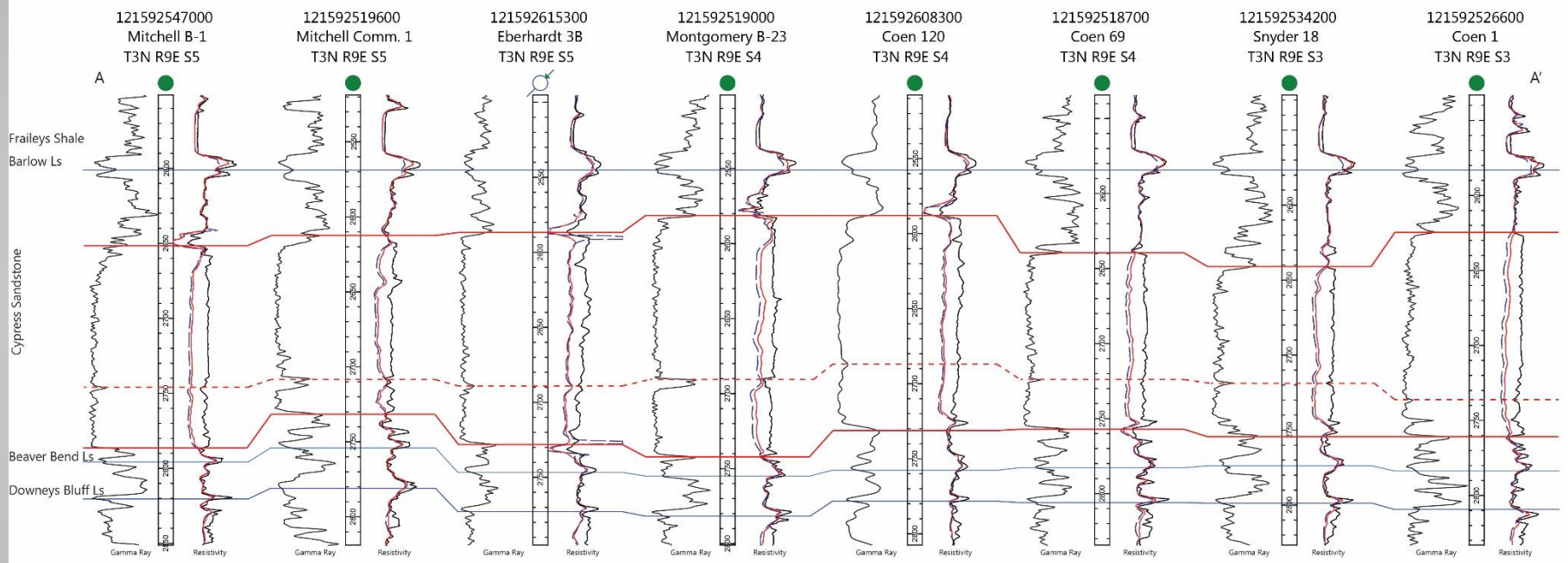




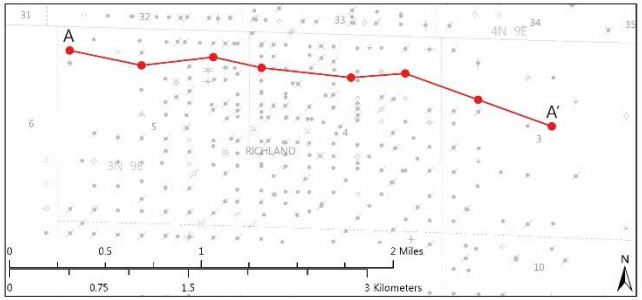
- Oil field with successful production from the thick Cypress Sandstone
- Abundant core and log data available for detailed characterization

Reservoir Characterization

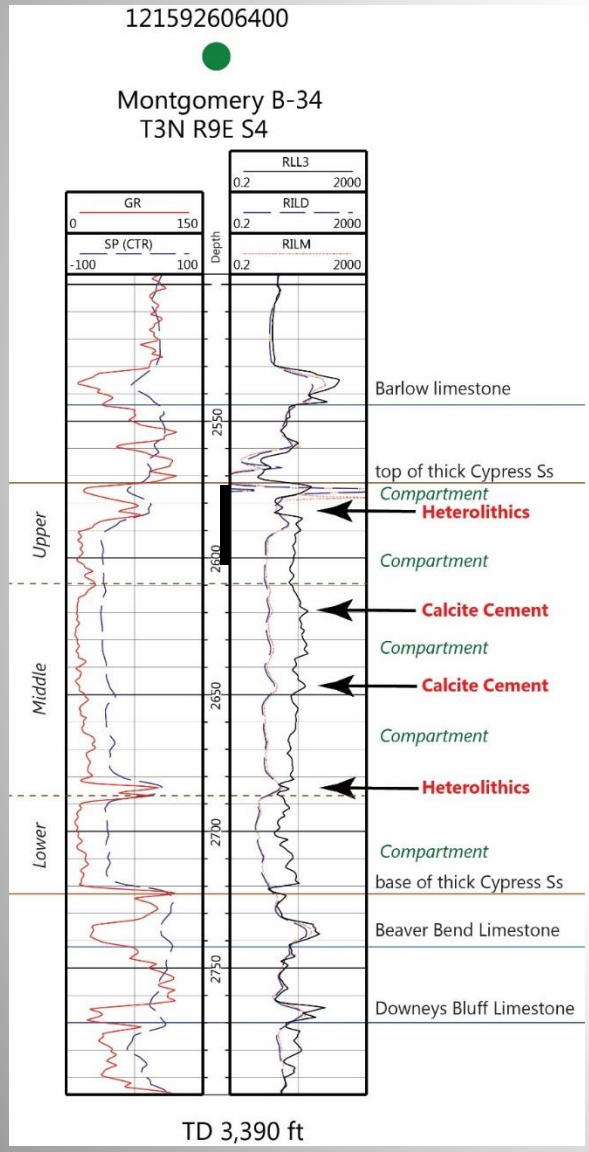
Example Noble Field Cross Section



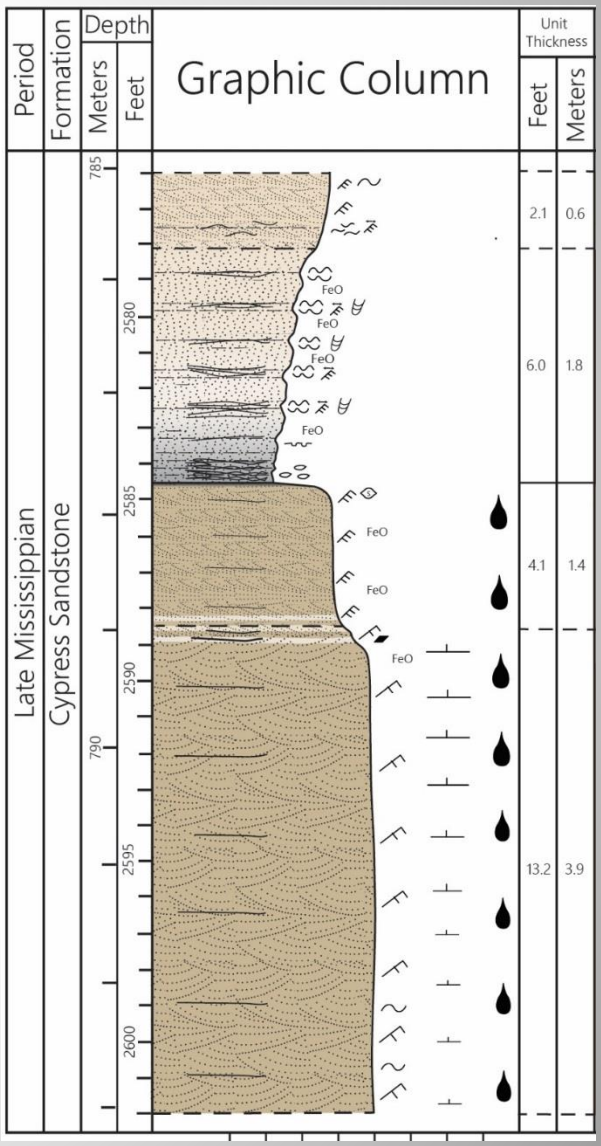
- Correlated nearly 1,000 logs to map geometry of thick Cypress Sandstone
  - Picked upper/lower contacts, baffles (shales, cements), oil/water contact (OWC)



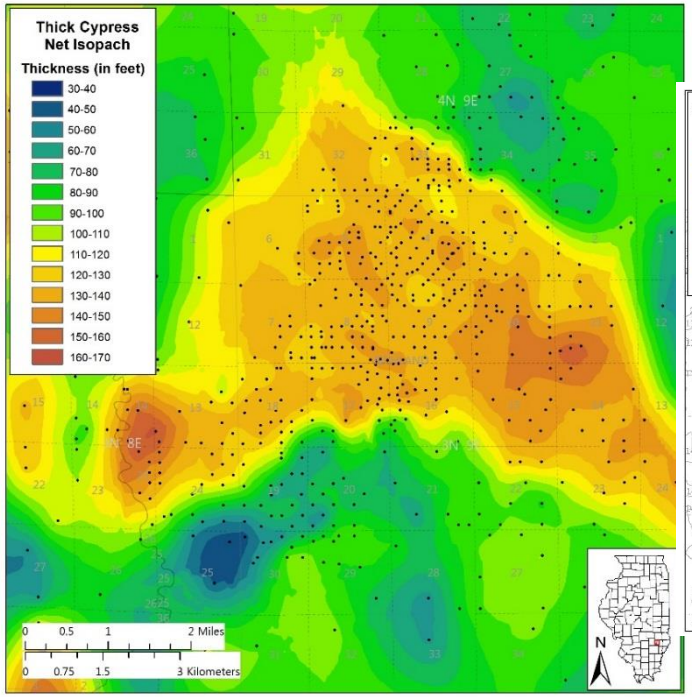
Reservoir Characterization



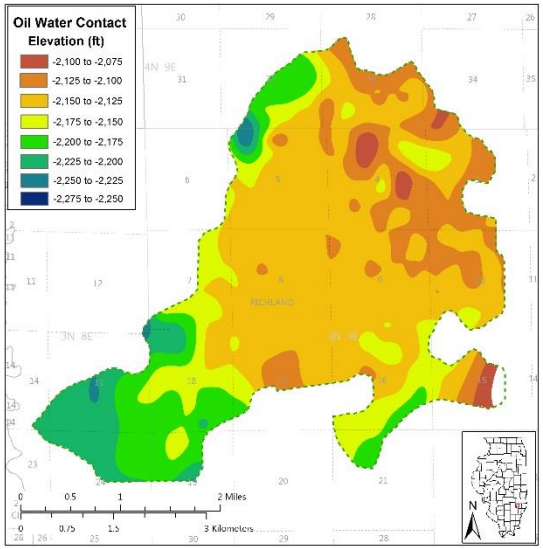
- Compartmentalized despite being relatively homogeneous
  - Thin shale interbeds
  - Heterolithic intervals
  - Calcite cements
    - Concurrent with and below OWC
- Fluvial to estuarine
  - Cross bedded f-m grained sandstone in main body, ripple bedded f grained sandstone at top



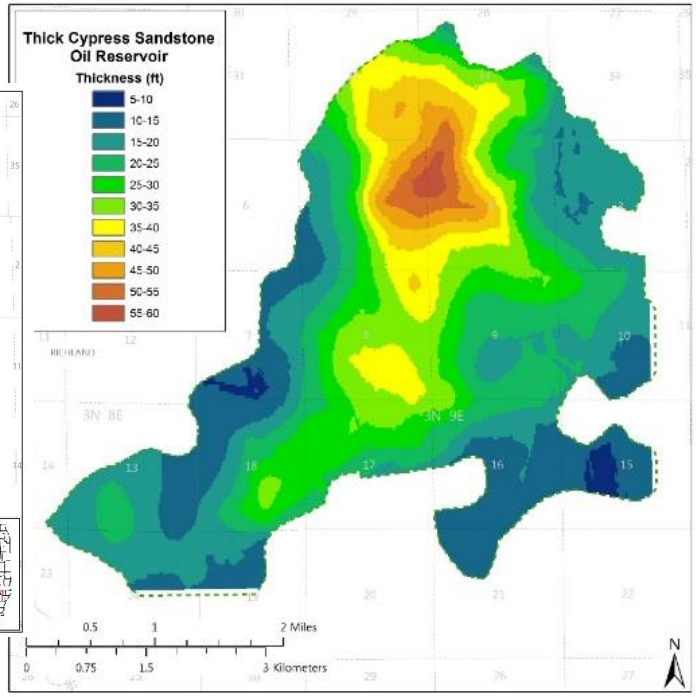
Reservoir Characterization



Cypress net sandstone isopach map



OWC structure map



Oil reservoir isopach map

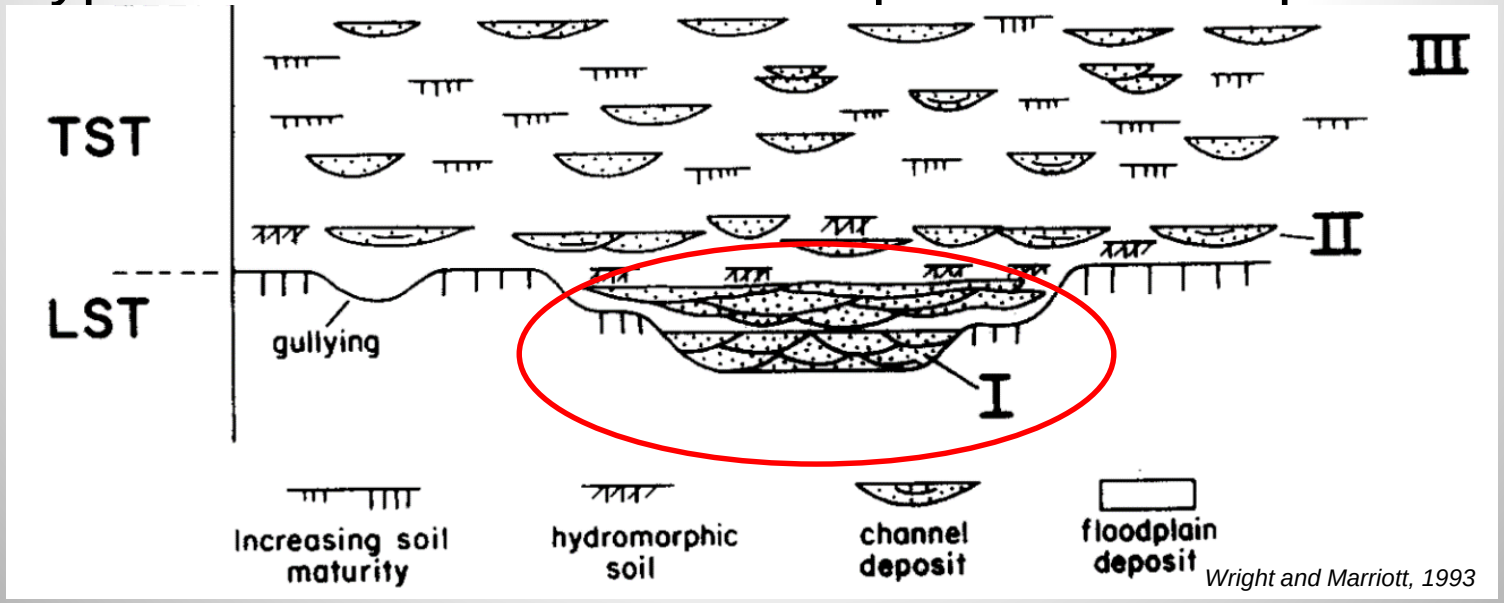
- Inverted “V” geometry
- Up to 170 ft thick

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

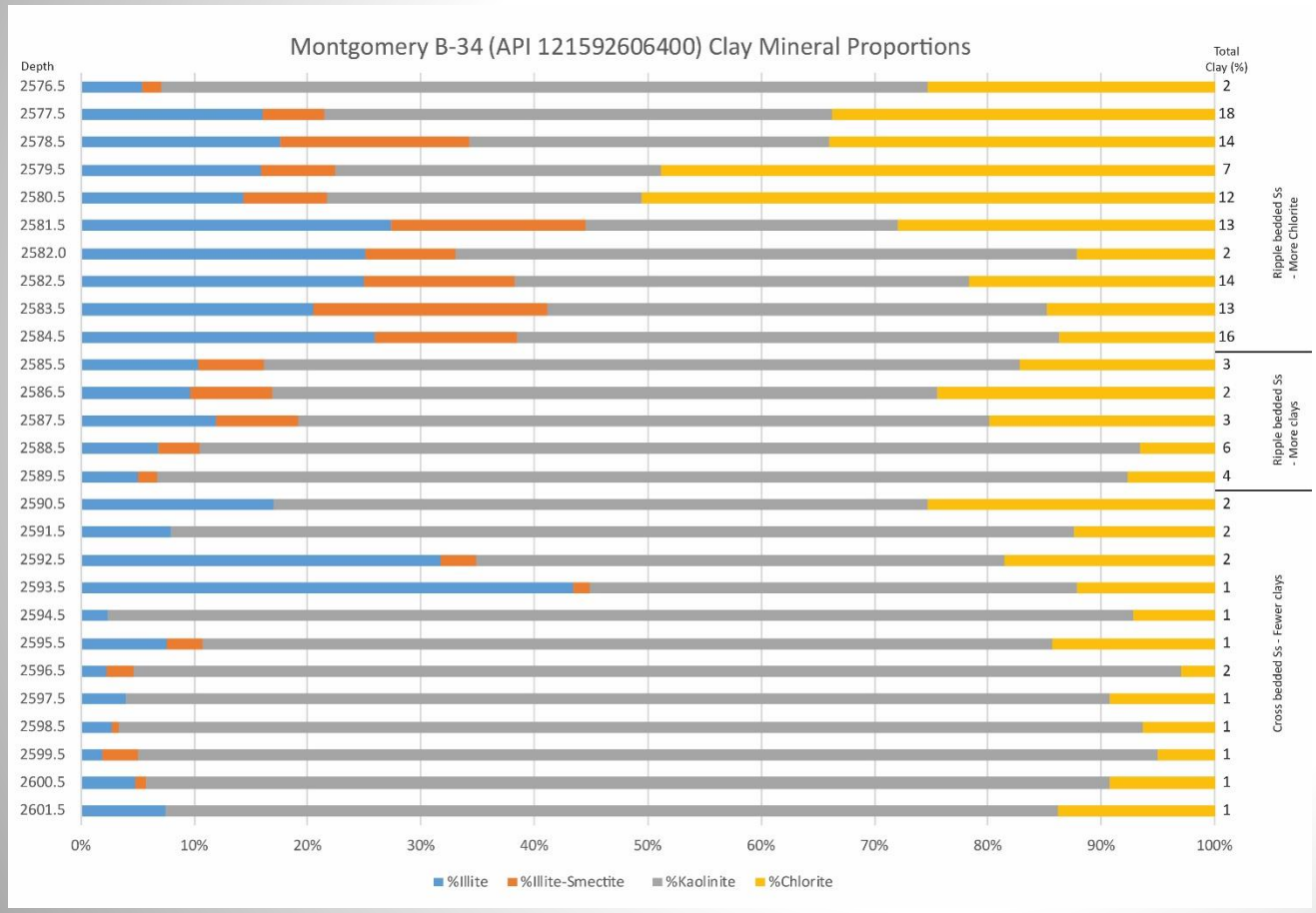
- Reservoir up to 55 ft thick
- OOIP = 95 to 110 MMBO

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

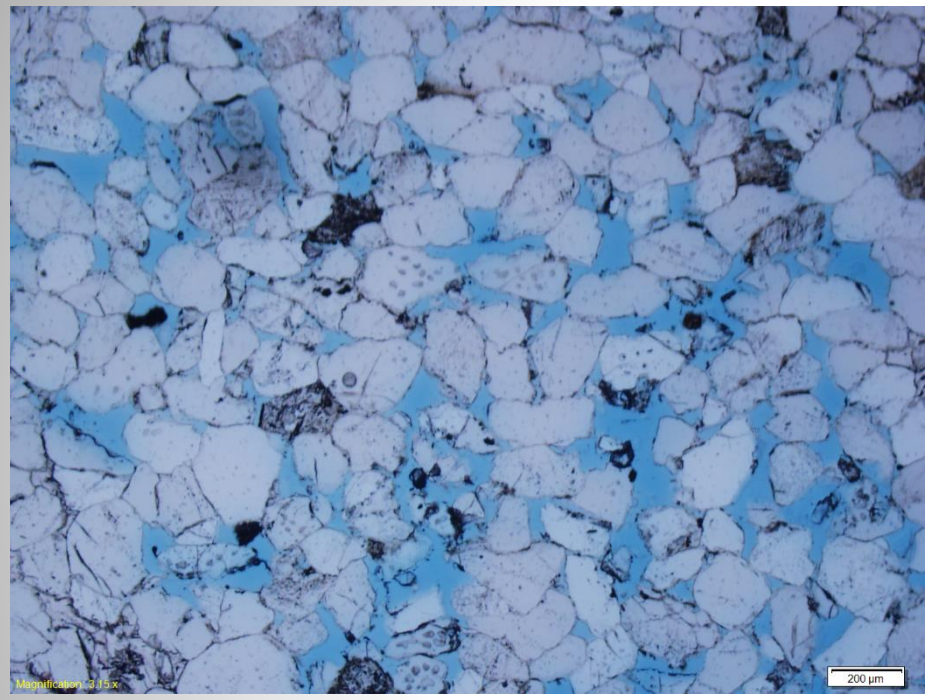


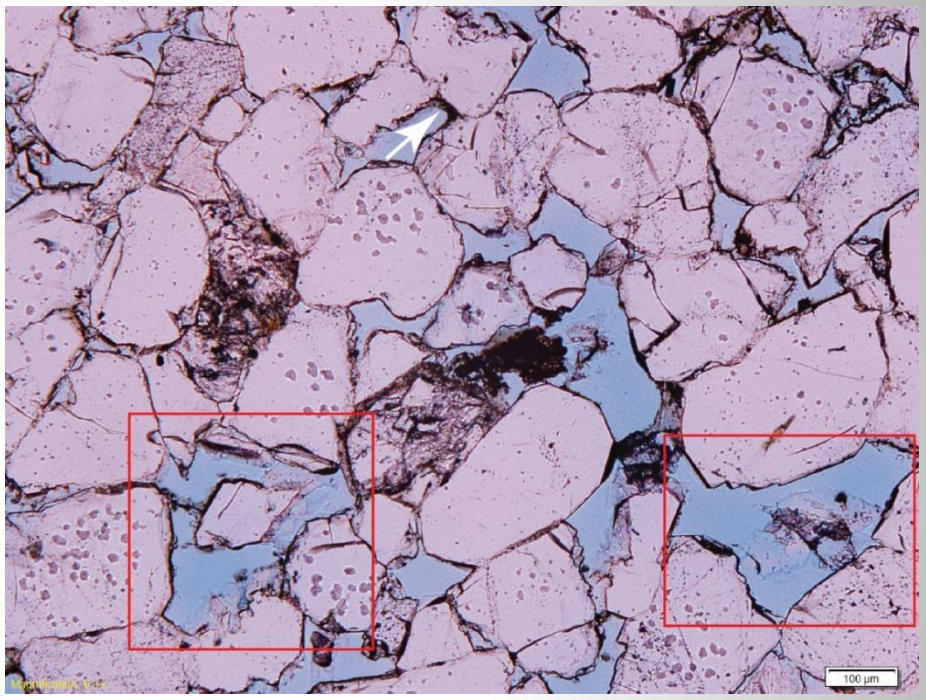
Controls on Porosity/Permeability



- 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

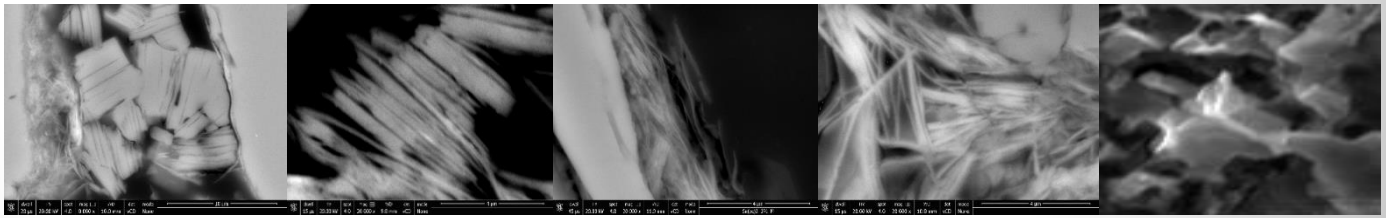
Controls on Porosity/Permeability





- 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

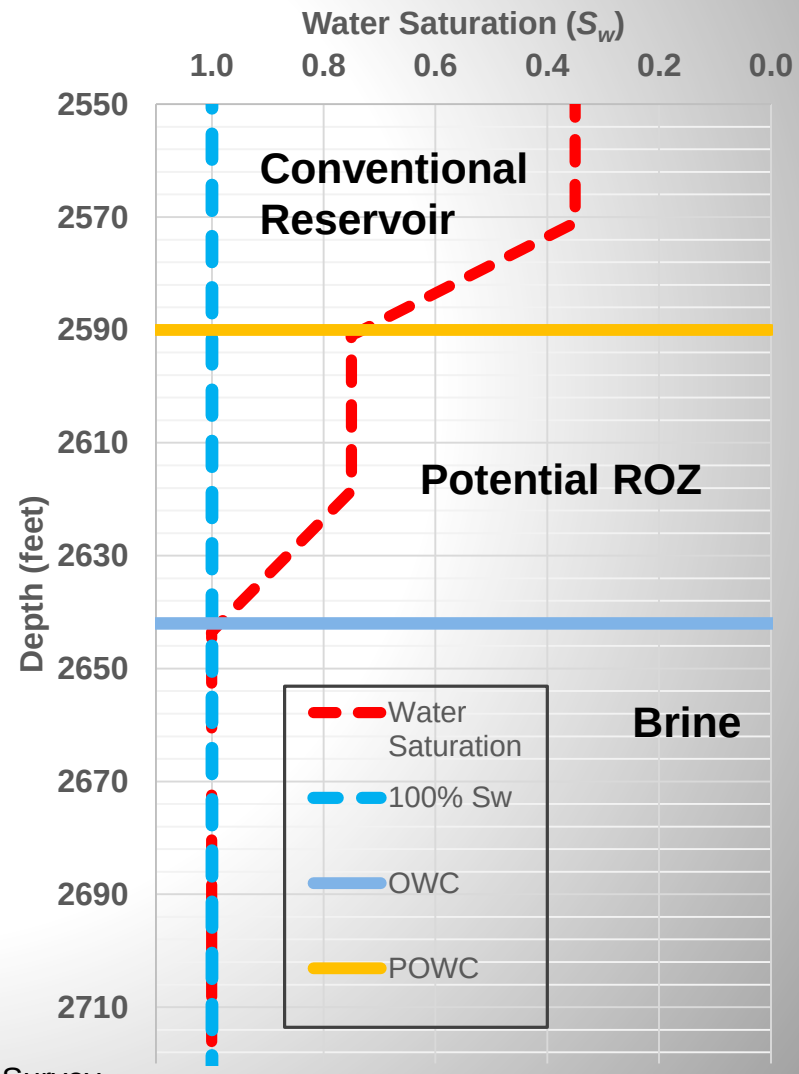
Mineral	Kaolinite	Kaolinite	Chlorite	Illite	Illite-smectite
Morphology	Booklets	Vermicules	Rosettes	Fibrous	Filamentous webs
Occurrence	Pore-filling	Pore-filling	Grain-coating	Pore-filling, bridging	Pore-filling
Microporosity (%)	40	15	50	65	55
SEM Photomicrograph					

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

Petrophysics

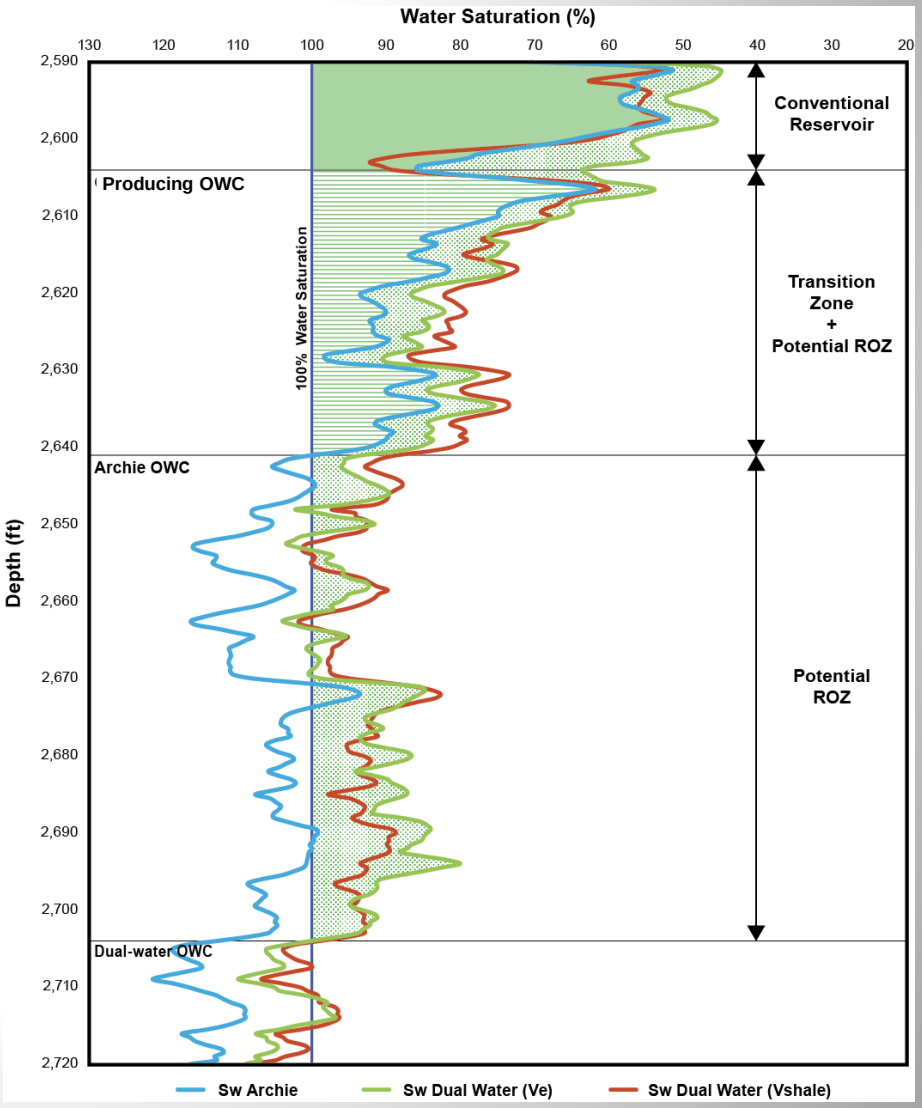
- Calculated water saturation (S_w) profiles from logs in Noble Field using three methods:
  - Archie (Resistivity + Porosity logs)
  - Dual water (Resistivity + Porosity logs + microporosity data)
    - Mitigates influence of dispersed clay that produces anomalously high S_w values

Ideal water saturation profile



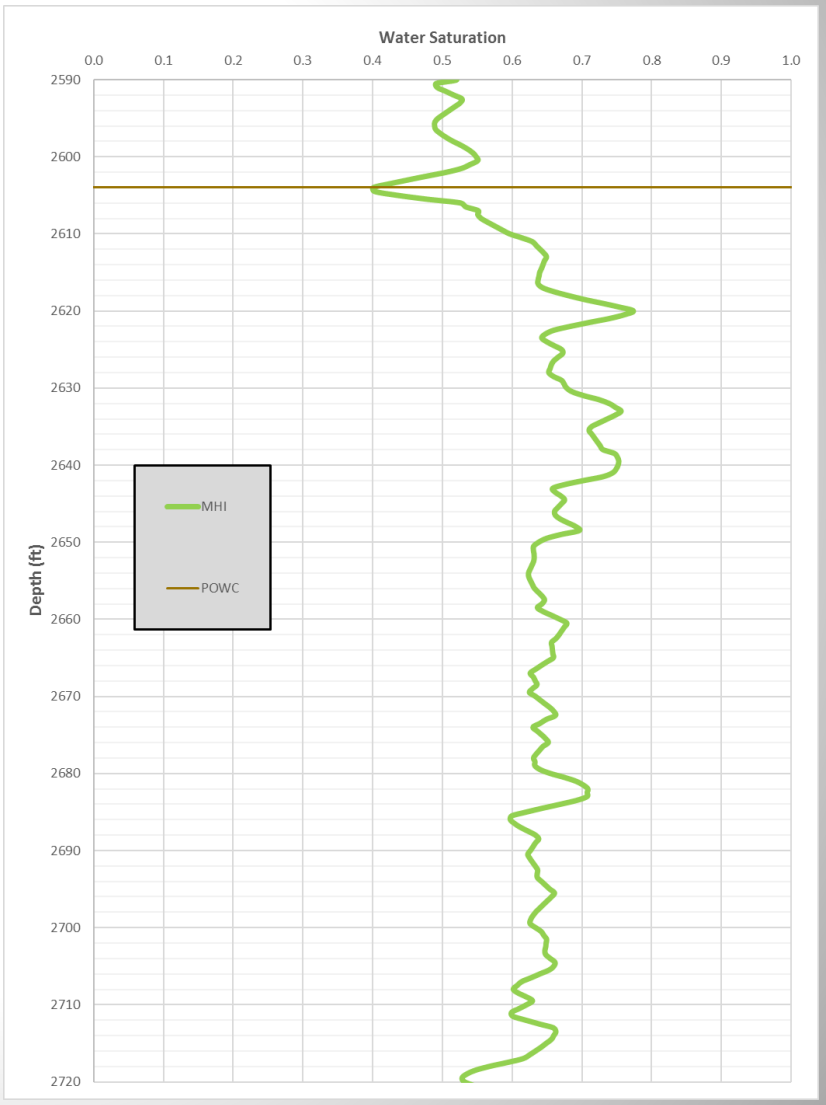
Petrophysics

- 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



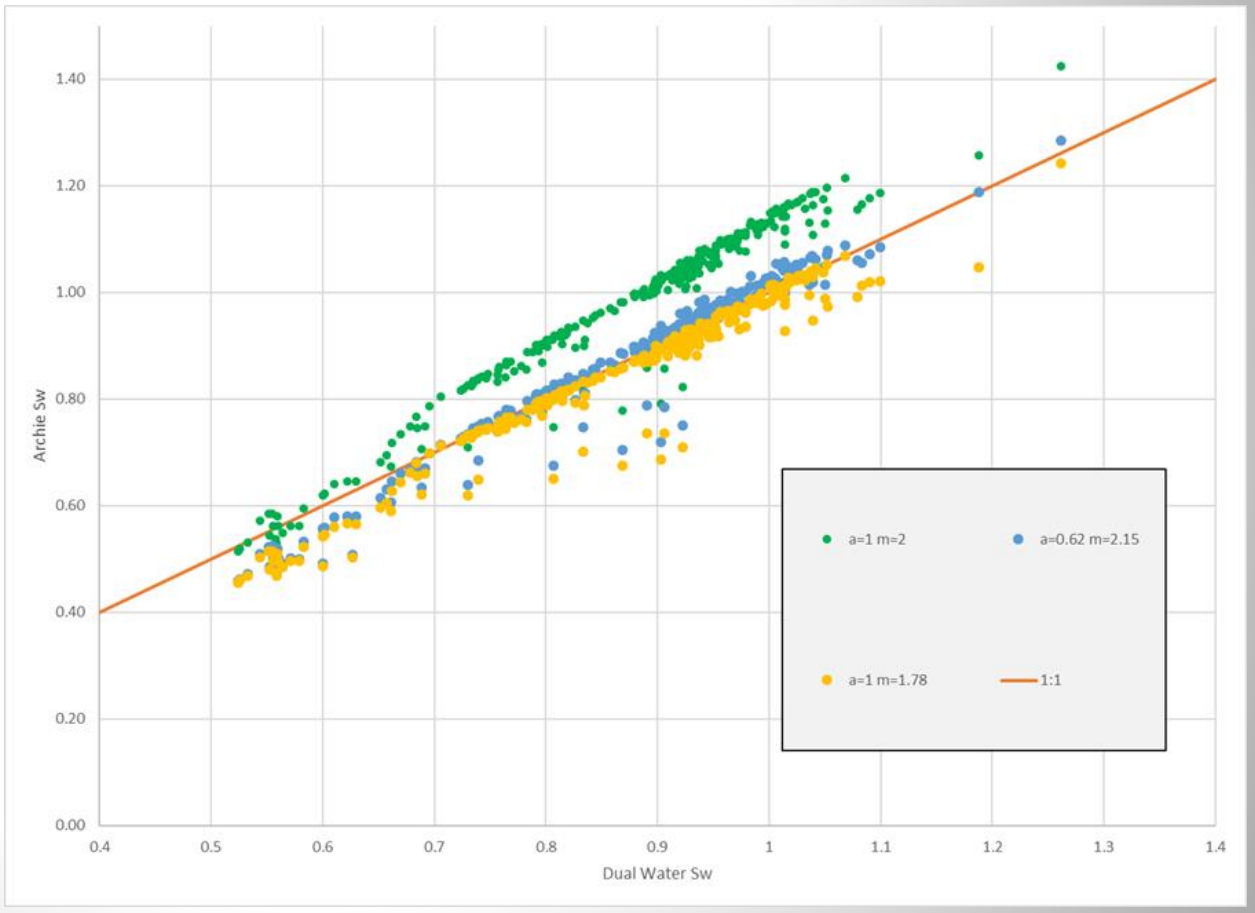
Movable Hydrocarbon Index

- 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”

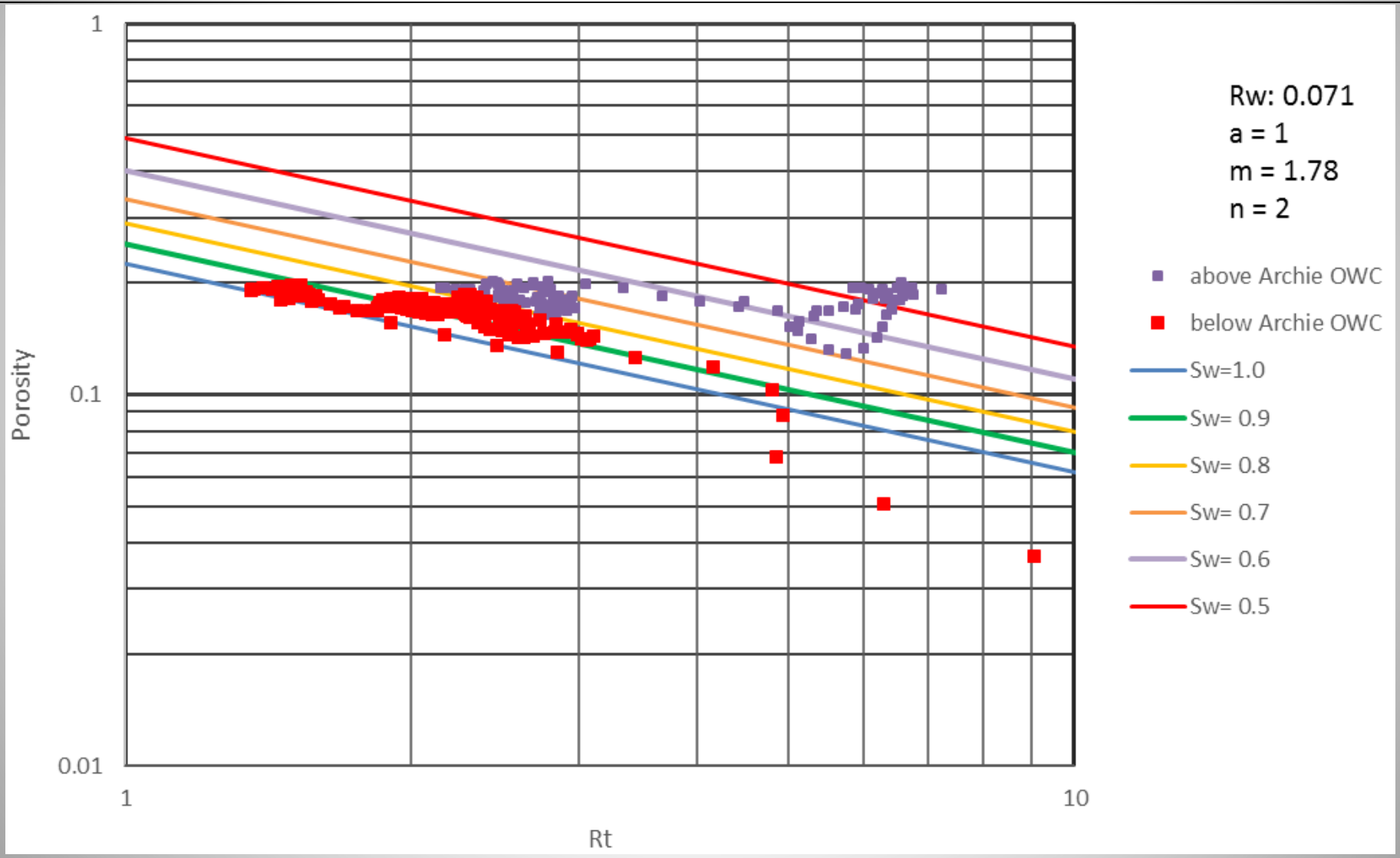


X/Y Scatter Plots

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

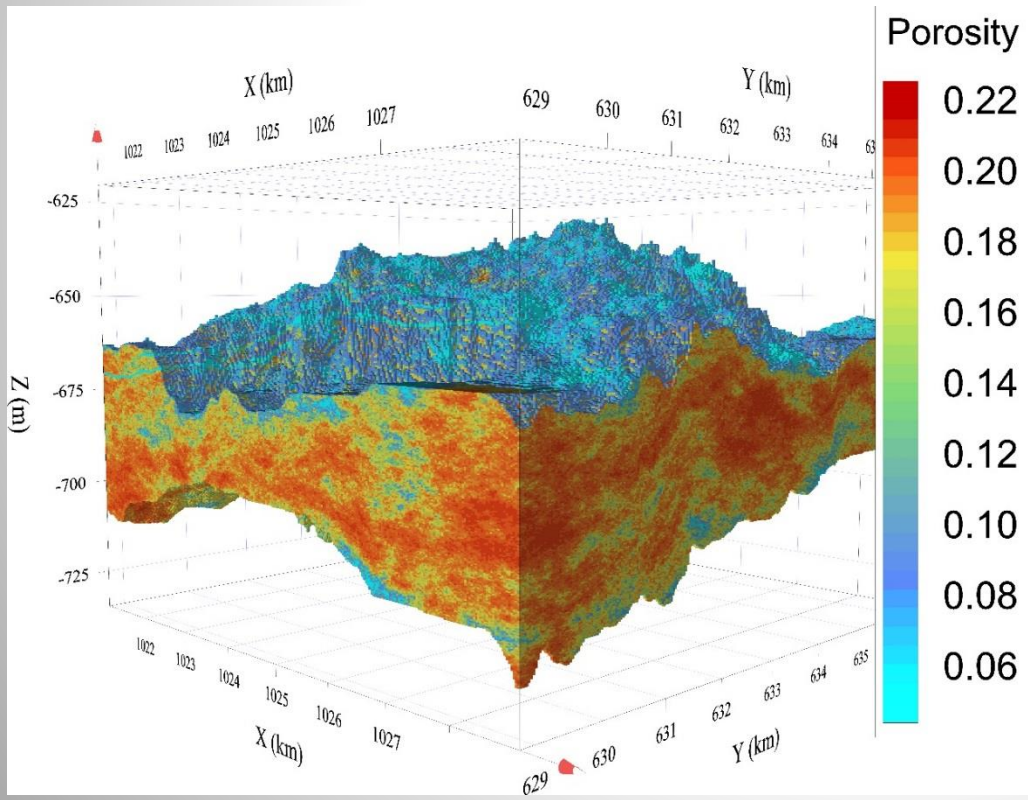


Pickett Plots

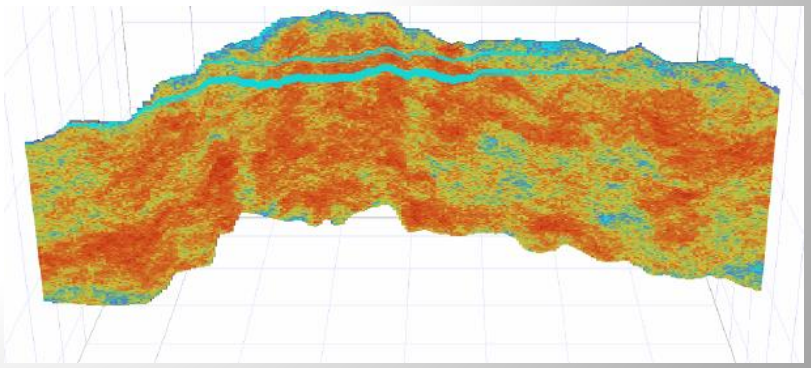


Geocellular Modeling

- 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

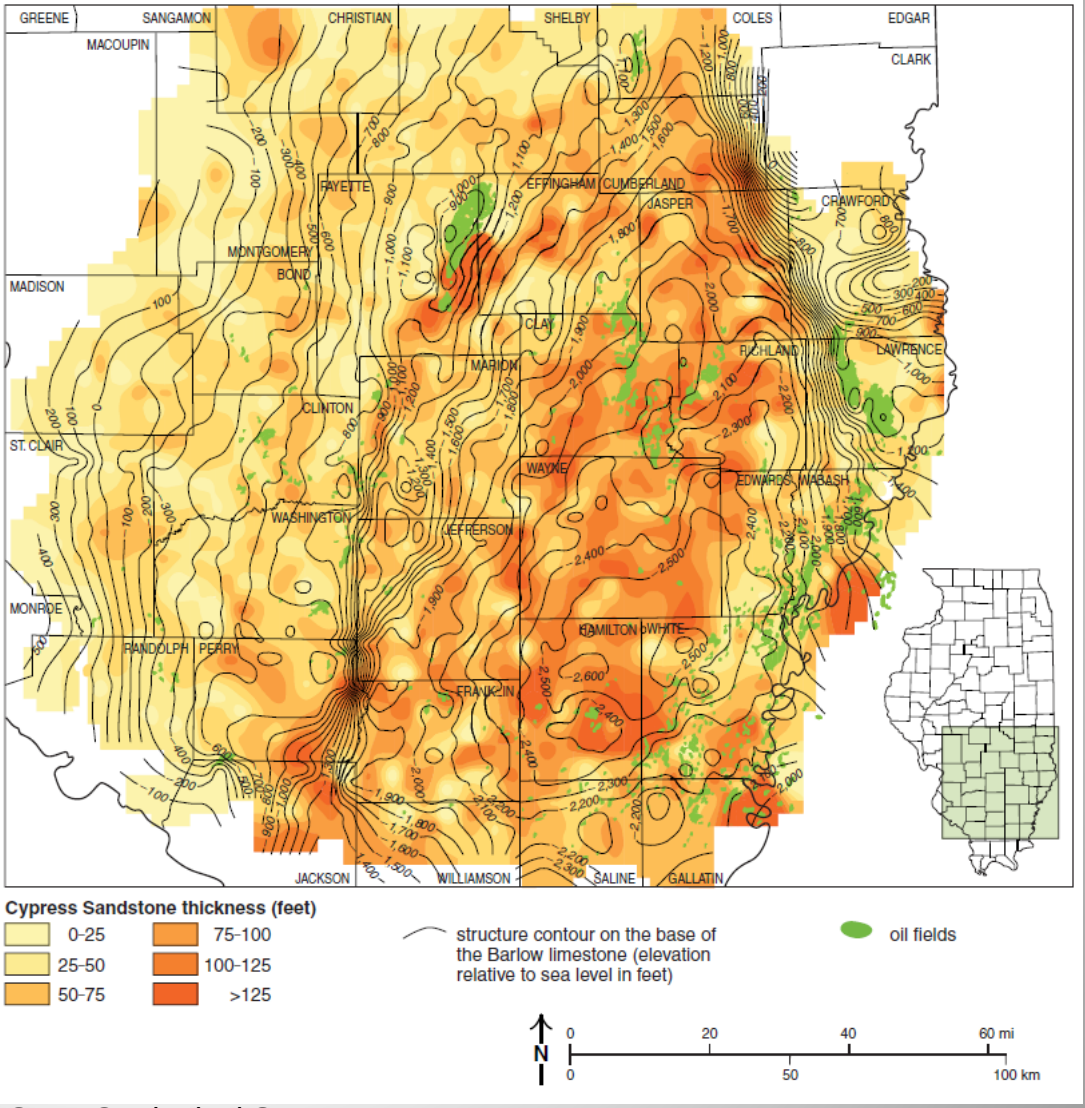


- Low porosity calcite-cemented sandstone zones
- Excluding microporosity from total porosity for accurate resource assessment



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?